DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME XXXIV

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE GLACIAL GRAVELS OF MAINE AND THEIR ASSOCIATED DEPOSITS

BY

GEORGE H. STONE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

University of Chicago,
Chicago, June 13, 1894.

Sir: I have the pleasure of transmitting a report by Prof. George H. Stone on The Glacial Gravels of Maine and their Associated Deposits.

The value of this elaborate report upon one of the most remarkable of the phenomena connected with the Ice age needs no comment in this connection.

Very respectfully, yours,

T. C. Chamberlin,
Geologist in Charge.

To the Director,
United States Geological Survey.

THE GLACIAL GRAVELS OF MAINE AND THEIR ASSOCIATED DEPOSITS.

By George H. Stone.

CHAPTER I.

INTRODUCTION.

This investigation was begun in the summer of 1876, and has been prosecuted during vacations. The report was substantially completed in June, 1889. The work was much embarrassed by the lack of sufficiently accurate maps, those available warranting only a reconnaissance and an approximate location of the kames, osars, etc., in relation to the roads, streams, and other features shown. The true relation of the glacial gravels to the relief forms of the land can be shown only on topographical maps, and the full delineation of the magnificent kame and osar systems of Maine is therefore left to the topographer and geologist of the future. In certain parts of the State, especially in the wooded regions, the work is not complete, but it can be confidently claimed that all the longer systems and the more common types of formation are here described.

The investigation made slow progress, not only because there were several thousand miles to be carefully explored, but especially because the nature of the subject renders such an investigation exceedingly difficult. The scout of the Western frontier who undertakes to guide a body of troops in pursuit of hostile Indians—to follow the trail, and, from the traces left behind, to give a history of the enemy's performances from day to day—has a difficult task before him; but in thus reconstructing history he has the advantage of knowing, from direct observation, the habits of the Indians. In his study of glacial deposits the glacialist labors under the disadvantage of not knowing, by observation, the exact nature of the geological work going on beneath and within an ice-sheet. It is comparatively

easy to theorize regarding the probable behavior of such a body of ice, and, if properly held in check, imagination is of the greatest use in such an investigation, but the chances for error are very great. The method here adopted has been to collect as large a body of facts as possible, and then carefully to test various hypotheses by the facts, rejecting or holding in abeyance all theories not supported by positive field evidence. Glacialists are exploring a comparatively untrodden field, and it behooves them to proceed cautiously and to avoid dogmatism and denunciation.

This report is intended to apply only to Maine, and is not a history of the progress of glacial science. For present purposes, therefore, it is not necessary to refer in detail to the many reports and articles which have been written on the subject of the water-assorted glacial drift of North America.

Chronological list of works treating of the glaciology of Maine.

BAILEY, J. W. Account of an excursion to Mount Katahdin, in Maine. Am. Jour. Sci., 1st series, vol. 32, 1837, pp. 20–34. Drift phenomena, pp. 26, 33–34.

JACKSON, Charles T. First report on the geology of the State of Maine. Augusta, 1837. 8°. 127 pp.

Second report on the geology of the State of Maine. Augusta, 1838. 8°. 168 pp.

Third annual report on the geology of the State of Maine. Augusta, 1839. 8°. Pp. 1–276, i–lxiv.

[Also two reports on the geology of the Wild Lands (1839), largely duplicative of the above works.]

[Bowlders and diluvial scratches in Maine. Discussion.] Am. Jour. Sci., 1st series, vol. 41, 1841, p. 176.

[Glacial drift.] Am. Jour. Sci., 1st series, vol. 45, 1843, pp. 320–324. Reference to drift in Maine.

HITCHCOCK, C. H. General report upon the geology of Maine. In sixth annual report of the secretary of the Maine board of agriculture (Augusta, 1861, 8°), pp. 146–328. Superficial deposits, pp. 257–288. Includes letter from John De Laski concerning effects of glacial action on Vinalhaven.

Geology of the Wild Lands. In sixth annual report of the secretary of the Maine board of agriculture (Augusta, 1861, 8°); Part II, Physical geography, agricultural capabilities, geology, botany, and zoology of the Wild Lands in the northern part of the State, pp. 331–458. Geology, pp. 377–442, including remarks on glacial drift. Geological map opposite p. 377.

Geology of Maine. In seventh annual report of the secretary of the Maine board of agriculture (Augusta, 1862, 8°); Part II, Reports upon the geology of Maine, pp. 223–430. Surface geology, pp. 377–401. Glacial phenomena described, pp. 378–391. This report includes a letter from John De Laski on "Ancient glacial action in the southern part of Maine," pp. 382–388.

HOLMES, Ezekiel. Geology of a portion of Aroostook County, Maine. In seventh annual report of the secretary of the Maine board of agriculture (Augusta, 1862, 8°); Part II, Reports upon the geology of Maine, pp. 223–430. Letter from Dr. Holmes to Prof. C. H. Hitchcock, geologist, pp. 359–376. Reference to drift phenomena.

DE LASKI, John. Ancient glacial action in Maine. In seventh annual report of the secretary of the Maine board of agriculture (Augusta, 1862, 8°); Part II, Reports upon the geology of Maine, pp. 223–430. Letter to Prof. C. H. Hitchcock, geologist, pp. 382–388. Also in Am. Jour. Sci., 2d series, vol. 36, 1863, pp. 274–276.

DE LASKI, John. Glacial action about Penobscot Bay. Am. Jour. Sci., 2d series, vol. 37, 1864, pp. 335–344.

PACKARD, A. S. Results of observations on the drift phenomena of Labrador and the Atlantic coast southward. Am. Jour. Sci., 2d series, vol. 41, 1866, pp. 30–32. Maine, pp. 31, 32.

WHITTLESEY, Charles. On the ice movements of the Glacial era in the valley of the St. Lawrence. Am Ass. Adv. Sci., Proc., vol. 15, 1866, part 2, pp. 43–54.

PACKARD, A. S. Observations on the glacial phenomena of Maine and Labrador. Mem. Boston Soc. Nat. Hist., vol. 1, 1866–1869. 4°. Pp. 210–303, pls. 7–8.

WELLS, Walter. Report of the superintendent of the hydrographic survey of Maine. Augusta, 1869. The water power of Maine.

DANA, J. D. On the position and height of the elevated plateau in which the glacier of New England, in the Glacial era, had its origin. Am. Jour. Sci., 3d series, vol. 2, 1871, pp. 324–330.

DE LASKI, John. Glacial action on Mount Katahdin. Am. Jour. Sci., 3d series, vol. 3, 1872, pp. 27–31.

DANA, J. D. On the Glacial and Champlain eras in New England. Am. Jour. Sci., 3d series, vol. 5, 1873, pp. 198–211, 217–218. Maine, 205, 206, 210.

HITCHCOCK, C. H. The geology of Portland, Maine. Proc. Am. Ass. Adv. Sci., vol. 22, 1873, pp. 163–175.

HITCHCOCK, C. H. (J. H. Huntington and Warren Upham, assistants). Report on the geology of New Hampshire (Concord), vol. 1, 1874; vol. 2, 1877; vol. 3, 1878. This report contains much information as to the drift of the western border of Maine and the region adjacent thereto. The chapters on glacial geology are largely by Upham.

SHERMAN, Paul. Glacial fossils in Maine. Am. Naturalist, vol. 7, 1873, pp. 373–374.

SHALER, N. S. Recent changes of level on the coast of Maine. Mem. Boston Soc. Nat. Hist., vol. 2, part 3, No. 3. Boston, 1874. 4°. Pp. 321–340.

PACKARD, A. S. Glacial marks on the Pacific and Atlantic coasts compared. Am. Naturalist, vol. 11, 1877, pp. 674–680.

HUNTINGTON, J. W. Geology of the region about the headwaters of the Androscoggin River, Maine. [Abstract.] Proc. Am. Ass. Adv. Sci., vol. 26, 1877, pp. 277–286. Glacial drift, pp. 284–285.

STONE, George H. The kames of Maine. [Abstract.] Proc. Boston Soc. Nat. Hist., vol. 20, 1878–1880 (Boston, 1881), pp. 430–469.

WRIGHT, G. F. The kames and moraines of New England. Proc. Boston Soc. Nat. Hist., vol. 20, 1878–1880, pp. 210–220.

STONE, G. H. The kames or eskers of Maine. Proc. Am. Ass. Adv. Sci., vol. 29, 1880, pp. 510–519.

HAMLIN, C. E. Observations upon the physical geography and geology of Mount Katahdin and the adjacent district. Bull. Mus. Comp. Zool. Harvard Coll., vol. 7, 1880–1884, pp. 189–223.

STONE, George H. Apparent glacial deposits in valley drift. Am. Naturalist, vol. 15, 1881, pp. 251–252.

The kame rivers of Maine. [Abstract.] Science, vol. 2, 1883, p. 319.

The kame rivers of Maine. [Abstract.] Proc. Am. Ass. Adv. Sci., vol. 32, 1883, pp. 234–237.

SHALER, N. S. The geology of the island of Mount Desert, Maine. In Eighth Annual Report of the United States Geological Survey, 1886–87, J. W. Powell, Director, Part II (Washington, 1889), pp. 987–1061. Surface and glacial geology, pp. 994–1031, with map of surface geology, p. 1060.

Many briefer articles have been published on the subject of the Maine drift. Notable among these are the early writings of Agassiz on the glacial geology of New England, published in part in the Atlantic Monthly.

CHAPTER II.

FUNDAMENTAL FACTS OF SURFACE GEOLOGY AS ILLUSTRATED IN MAINE.

In order that there may be no doubt as to the sense in which certain words are employed in this report, or as to the standpoint from which it is written, the following explanatory chapter is prefixed to the report proper. This is the more necessary because I have found it desirable to use some words in a more restricted sense than that in which they have been used by many in the past.

The principal facts with which the student of the drift has to deal are the following:

SURFACE FEATURES OF MAINE.

The surface features of the regions penetrated by the several systems of glacial gravel will be described in connection with the gravels. It is therefore not necessary here to give any detailed description of the topographical features of the State. A few remarks will suffice.

The State consists of two main drainage slopes: (1) That drained southward into the Gulf of Maine by the Saco, Presumpscot, Androscoggin, Kennebec, Penobscot, Narraguagus, Machias, and St. Croix rivers, and by numerous smaller streams. The average fall of the streams of this slope is not far from 7 feet per mile. All the larger deposits of glacial gravel appear to be confined to this slope. (2) That drained northward and eastward into the St. John River. This slope contains much swampy and other rather level land, with here and there hills rising above the great plain.

An inspection of the river systems of Maine shows great irregularities

of surface. In the absence of topographical maps these surface features can be described only approximately. A fact of great significance in an investigation of the drift of Maine is the presence of numerous ranges of hills rising 200 to 1,000 feet above the country to the north of them, and—a fact still more significant—they usually were more or less transverse to the direction of glacial flow. Part of these have the general northeast Appalachian direction, others lie nearly east and west. During the time of maximum thickness of the ice the glacier flowed up and over these hills, but during the final melting these ranges stopped the flow of the ice in many cases and confined it to the valleys lying north of them. The behavior of the glacial rivers with respect to these transverse hills is of great assistance in determining the character of the rivers and their laws.

Much information regarding the kames, eskers, and osars of Maine was collected during the geological surveys of Maine made by Dr. Jackson and Professor Hitchcock. I have also received assistance from hundreds in various parts of the State, but it has hardly been practicable to make the proper acknowledgments in detail in cases where the information gained from others was subsequently superseded by my own field work.

NATURE OF THE ROCKS OF MAINE.

A small area of sandstone is found in Perry and adjoining towns in the southeastern part of the State. With this exception the coast region is covered by granite, gneiss, mica, and other coarse-grained schists, with small areas of syenite, diorite, and other crystalline rocks. In the central part of the State, nearly parallel with the coast, is a long belt of slates and other fine-grained schists. Still farther north is a parallel belt of fossiliferous rocks—sandstones, conglomerates, and limestones. Numerous knobs and ridges of granite rise in the midst of the other rocks. The contrast between these various rocks is great, both chemically and mineralogically, and this makes it possible to readily compare the areas of different rocks one with another with respect to the composition both of the till and of the glacial sediments. Most of these rocks are tough and compact in structure and contain free quartz; they are therefore hard to abrade. Except in a few places the nature of the rock is favorable to the production of a great number of stones and bowlders. The great abundance of gravel in the

glacial sediments, as compared with the amounts of sand and clay, is caused by the nature of the rocks.

CONDITION OF ROCK IN PLACE.

In Maine, as in a large part of eastern North America, the solid rock has been so planed and scratched by the great ice-sheet that only here and there is there to be found any residue of the preglacially weathered surface. The state of preservation of the glacial scratches varies greatly. In Brownville, Munson, and all the roofing-slate region, the scratches are wonderfully well preserved. On broad, level tops of hills, where the wet surface precluded any suspicion that the till had been eroded, I have repeatedly found areas of bare rock several rods in diameter upon which minute scratches, such as might be made by the finest needle point, are still sharply defined, and the situation of the rock shows that they must have been exposed to the weather ever since the melting of the ice. But, though the durable Maine roofing slate has preserved almost unchanged the record that was engraved upon it by the drift agencies, it is far otherwise with most of the other rocks. On most of the exposed ledges the glacial scratches have either disappeared or are gradually vanishing because of the weathering of the surface. Over large areas it is already impossible to ascertain the direction of the glacial movement except approximately by the forms of the "roches moutonnées" or, better, by digging away the overlying earth, when the scratches on the subjacent rock will usually be found perfectly preserved. Already some of the ledges are split and weathered to a depth of several inches, and occasionally to a depth of several feet. All this indicates the condition of the rock before the coming of the ice-sheet. During the unnumbered ages of Mesozoic and Tertiary time all the State was above the sea, and subaerial weathering and erosion had done their long work upon the surfaces of upheaval. The hills and valleys were in nearly their present forms, but the surface was weathered and shattered often to the depth of 50 or even 100 feet. Over most of the State the great glacier removed the weathered rock and planed the surface, but here and there the planing did not reach the bottom of depressions of weathering.

The weathering of exposed ledges and bowlders has been greatly aided by forest fires and by the burning of brush in clearing the land.

WEATHERING.

This is the gross result of the action of the elements on exposed rocks and minerals. It is partly a chemical process, partly physical and mechanical. The oxygen, watery vapor, carbon dioxide, nitric acid, ammonia, and many other substances present in the air, either constantly or accidentally, often combine chemically with the rocks or with certain of their constituent minerals. Rain and snow water dissolve many minerals, usually being assisted in this action by oxygen, carbonic acid, and other gaseous substances absorbed from the air, from the soil, or from decaying organic matter. Nor does the process stop with the simple solution of solids and liquids; great chemical changes often result. The dissolved substances, especially the alkaline compounds, become potent agents to effect new chemical decompositions. Thus these substances are not a finality but a means to an end.

A familiar example of solution and chemical decay, and a very common one in Maine, is the weathering of the feldspars. By degrees the more soluble alkaline silicates are dissolved and carried away, leaving an insoluble residue, composed largely of kaolin, the characteristic ingredient of clay. In like manner the pyritiferous slates and schists are readily disintegrated. In the presence of rain water the pyrite (or marcasite) is oxidized and hydrated so as to become ferrous sulphate, or copperas. In Maine there are many places, known as "copperas ledges," where the rock contains so large a proportion of pyrite that the copperas is produced in considerable quantities, and after rains in hot weather there is a strong odor of sulphureted hydrogen. At the Katahdin Iron Works the chemical reactions are still more complex; the pyritiferous slate is being rapidly decomposed, the resulting ferrous sulphate being changed to ferric hydrate by organic matter.

In addition to the insidious weakening caused by chemical decay, we have the subsequent process of fracture, by both physical and mechanical forces. The most common physical causes of fracture are unequal expansion and contraction under heat and cold, and the expansion of freezing water. Various forces act mechanically to produce fracture, such as movements of the earth's crust, the pressure of overlying rock, and the impact of moving bodies. The solid rock may be fractured to a limited extent by the

direct impact of fluids, such as air or water; but most of the fracturing and abrasion effected by moving fluids is due, not to the mechanical impact of the fluid, but to the solid masses which the fluid hurls or drags against the opposing rock.

In this complex process of leaching, decomposition, and fracturing is seen the explanation of the formation of soil, subsoil, and bowlders in those places where the rock of the earth's crust has been long exposed to the weather. Most rocks fracture naturally into angular and rather prismatic forms. The subsequent action of the weather variously modifies their primitive shapes. Pieces broken off from the solid rock by natural means have received many names, such as rock débris, cliff débris, fragmental débris, angular gravel, float rock, disintegrated rock, weathered rock, moraine stuff, angular blocks, stones and bowlders of decomposition, and, when at the foot of a cliff, talus. The words soil, subsoil, sand, and clay describe certain states of weathered rock. Piece after piece is broken off from the blocks into which the solid rock was originally shattered, until the whole is reduced to a fine powder, known as soil; and since the weathering usually goes on faster at the angles, the prismatic blocks resulting from the original fracture are slowly rounded at the angles and become rounded bowlders of disintegration.

Without the process of weathering there would be no soil on the earth except where streams and the sea had battered the solid rock to pieces. Take away the power of frost and heat to shatter and the weakening effects of chemical decay, and the earth as we know it would no longer exist. When first upheaved above the sea, the land might be covered by sand, gravel, and clay, imperfectly fitted to be a soil. This would soon be eroded away by the rains and streams, and then the continents would consist of piles of bare rock fit perhaps to bear lichens, but with none of the soils, subsoils, and drift which now bury most of the solid rock out of sight and which are necessary to the existence of the higher plants and animals.[1]

---

[1] The process of chemical decomposition of the rocks and soils is greatly aided by the changes of atmospheric pressure. On a grand scale these changes are due to the passage of areas of high and low barometer; locally they are often due to varying pressure of the winds. As the atmospheric pressure increases, air is driven down into the cavities of the earth, and when the pressure is diminished part of this air is driven out again by expansion from within. In this manner new supplies of oxygen and carbonic acid are continually being introduced into the rocks and soils. The process is also greatly aided by the rains.

TRANSPORTATION AND THE DRIFT AGENCIES.

A vast amount of matter, held in solution by subterranean waters and by surface streams, is constantly being carried off to the sea. A still larger quantity is being transported in the solid condition by various other agencies. The term "drift," as here employed, denotes solid matter which for any natural cause has left its original position in the rocks, especially if it has traveled a considerable distance.

TRANSPORTATION BY LANDSLIP AND SOIL-CAP MOVEMENT.

Geologists long ago declared that every particle that has become loosened from its parent rock is on its way to the sea. As the result of weathering, isolated fragments frequently become detached and fall rapidly and far down steep cliffs; thus, for instance, are stones precipitated upon the Alpine glaciers. Other fragments are so slowly undermined that they fall only a little way at a time, or at so slow a rate that they slide rather than roll down the slope. In the canyons of the Rocky Mountains, and on such of the slopes of those mountains as are covered with disintegrated rock, many large bowlders of stratified limestone and sandstone have slid down the mountain sides many, sometimes hundreds, of feet. The gravel in which they are partially embedded slowly weathers or is washed away, and the bowlders sink with so little disturbance that the lines of stratification are now nearly parallel with their original direction, although long ages have elapsed since the bowlders began their journey toward the ocean. Every talus or soil shows this imperceptible creep of the separate fragments, and the term "soil-cap movement" has been applied to the process. The simplest case is where fragments move under the action of gravity alone. A more complex case arises when they also sustain the weight of other solid particles, as often happens in cases of rock avalanche and landslide, which in mountainous regions are important drift agencies. Landslides are especially common during the rainy season, not only because of the lubricating and loosening effect of water on a porous stratum, but also because of the weight of the absorbed water. As is well known, extensive landslides have occurred in the White Mountains, and they are not uncommon in Maine.

At the great landslide at Goldau, in Switzerland, flashes of light were seen to be emitted from the moving earth. This heat and light must have

been caused by the heating of particles of crushed rock. The friction of the loosened mass upon the underlying rock, as well as the mutual friction of the moving fragments, must produce more or less polishing and scratching of the stones. It is probable that it would be difficult to distinguish such stones from those scratched beneath a glacier.

On hillsides in Maine the slow, imperceptible sliding characteristic of the soil-cap movement has often given an imperfect stratification to fine, clayey till. The till becomes softened and somewhat plastic when saturated by the rains or upheaved and loosened by the frost. When the ground settles, the flat fragments tend to a horizontal position, and on hillsides the shearing force caused by the slow downward movement causes the laminæ of clay and plastic materials to become arranged parallel with the slopes. In such situations the till often weathers in layers as regular as those of clay deposited in water. Part of this quasi stratification is doubtless due to the pressure and shear to which the particles of the ground moraine of the ice-sheet were subjected as the ice dragged its vast bulk over them.

In the modes of drift transportation above mentioned gravity acts directly as the impelling force. Another class of drift agencies comprises those cases where the transportation is effected by moving liquids or gases, including plastic solids, such as ice. In such cases gravity acting directly on the transported matter often does not aid the movement; instead, the weight of the transported body often has to be overcome by the moving fluid.

TRANSPORTATION BY WIND.

Where the winds are in general moderate, as they are in Maine, and where rains or snows fall at frequent intervals, the climate is not well adapted to wind transportation. Yet there are in the State large areas of sand now drifting, besides multitudes of dunes long since overgrown with vegetation. Thus the wind is seen to be an important drift agency.

Most of the drifting sands were originally assorted and deposited by water. The process of drifting generally begins at some small depression in the sand, such as the burrow of an animal. By degrees the depression enlarges, and the sand taken out of the hole goes to make up a low ridge in the direction in which it is blown by the prevailing winds. It is the dry wind that transports sand, rather than even higher winds accompanied by rain. The sand grains on the windward side of the ridge, being exposed

to the full force of the wind, are blown up and over the ridge, soon to be followed and covered by other grains. When the wind changes, these sand grains may all be blown back again. As the dry winds in Maine are most frequently from the west, the net result of this movement back and forth is an unsteady march eastward. In places the dunes have traveled from 1 to 3 miles up and over hills 200 to 300 feet high. Often a layer of sand is left on the ground passed over by the main dune, and then the vegetation characteristic of a sandy soil appears. Thus, in western Maine a growth of white pines on high hillsides is almost always found on a dune of blown sand or on ground passed over by one.

It is fortunate that blown sands so often leave a trail behind them, for the foremost or principal dune thus becomes gradually smaller and its power to do mischief is lost unless other dunes follow and overtake it, which may happen if the sand is very abundant at the place where it began to blow. A large proportion of the dunes now overgrown with vegetation have traveled away from the sand plains where they originated into regions once covered by till, clay, or gravel. In most cases it is possible to distinguish blown sand from that deposited in its present situation by water, even when both are covered by vegetation. The blown sand will be found at very irregular elevations and on western slopes, except where it has been blown up the western slope of a hill and over its top and has come to rest on the eastern slope. Blown sand contains no very large pebbles, and is not overlain by bowlders. The dunes form rounded ridges, domes, or terraces, and their forms are such as to be recognized at once by the practiced eye. Usually the country to the west of a dune is covered with more or less sand, a sign that the dune has passed over it. These features are sufficiently different from those shown by water-deposited sand in similar situations to enable us usually to distinguish them. Fine sand is the only material subject to wind transportation on a large scale, yet each

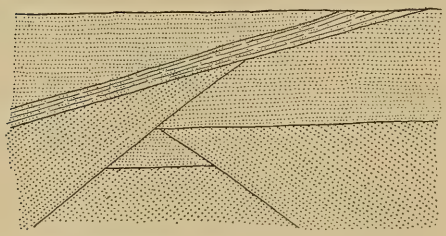


FIG. 1.—Stratification of wind-blown sand; Lockes Mills.

year there is considerable blowing of the clay and the finer grains of the till or gravel, especially on dry hillsides. It is this blown soil which so often covers the snow in winter. It is well known that in exposed situations fall plowing results in a considerable loss of soil. Often in hillside pastures little cliffs of wind erosion can be seen, worn away partly by the direct impact of the wind and partly by the sand and small gravelstones blown against their sides. In this way considerable areas have been denuded of their surface layers. To this process I have elsewhere given the designation "till-burrowing." It is by far most active along the borders of drifting sand dunes, partly because the protecting vegetation has been killed by the sand, and partly because in such situations the surface is drier than usual. Thus on a hilltop about 1½ miles northwest of Wayne Village, cliffs in the till were 3 feet high and the till was eroded to the solid rock. The finer parts were driven away and the rock was strewn with the larger stones of the till. The gravel thus left is to be distinguished from the other forms of gravel.

The process of till-burrowing is often aided by sheep, which have a habit of digging into hillsides in order to lie in the shade of the small cliffs thus formed.

TRANSPORTATION BY RUNNING WATER.

This is the most common and familiar of all the natural processes of drift transportation. The power of running water to transport solid fragments depends on several elements: (1) According to Hopkins, other things being equal, the power to transport increases as the sixth power of the velocity. (2) Since in general the force of gravity is to be overcome, it is obvious that the specific gravity of the drift matter is to be taken into the account. (3) The shape of the fragment to be transported must also have an influence on the result, since this determines the relative amount of surface presented to the force of the current and often the friction to be overcome; thus spheres are more easily transported than slabs having the same weight. (4) The volume of the current must also be considered. Rocks of the ordinary kinds have a specific gravity of 2.4 to 3. When submerged they lose one-third or more of their weight, and they will be more easily transported when there is volume of water sufficient to wholly submerge

them. It has been estimated[1] that the transporting power of different rates of river flow is as follows:

Transporting power of different rates of river flow.

Rate per second.	Rate per hour.	Power of transportation.
Inches.	*Miles.*	
3	0.170	Will just begin to work on fine clay.
6	.340	Will lift fine sand.
8	.4545	Will lift sand as coarse as linseed.
12	.6819	Will sweep along fine gravel.
24	1.3638	Will roll along rounded pebbles 1 inch in diameter.
36	2.045	Will sweep along slippery angular stones of the size of an egg.

The specific gravity of the gravelstones is not stated, but presumably it is that of ordinary rocks.

The fragments transported by water are of various sizes, and have received names accordingly. The following names have been proposed by Prof. T. C. Chamberlin:

For the very finest particles, *mud* or *clay;* for fragments up to size of a pea, *sand;* for fragments varying from the size of a pea up to about 1 inch in diameter, *fine gravel;* for fragments from 1 inch to 3 inches in diameter, *coarse gravel;* for rounded stones less than 3 inches in diameter, *pebbles;* for rounded stones from 3 to 6 inches in diameter, *cobbles;* for masses from 6 inches to 15 inches in diameter, *bowlderets;* for masses over 15 inches in diameter, *bowlders.*

In this report stones from the size of a pea up to 1 inch in diameter are called *gravelstones*, and the transitions between mud and sand are termed *silt.*

That rivers are carrying drift matter to the sea is a matter of common observation. The sound of gravelstones and pebbles rattling against one another and rolling along the bottom of the upper courses of streams can often be heard by one who puts his ear near the bottom of a boat or into the water. Everyone has seen streams tear down portions of their banks and carry them away. The muddy color of many streams, especially in

[1] David Stevenson, Canal and River Engineering; quoted by Geikie, Text-book of Geology, p. 380, 1893.

time of flood, is due to earthy matter suspended in the water. These facts are too obvious to need elaboration.

SEDIMENTATION.

For the present purpose it is not needful to go into an elaborate discussion of that difficult subject, the hydraulics of streams and other moving waters. We have seen that an increase in velocity of current causes an increase of transporting capacity proportioned to the sixth powers of the velocities. A decrease in velocity causes, therefore, a proportionately large decrease in carrying power. Now, the velocity of a stream depends, assuming the force of gravity as constant, partly on degree of declivity and partly on the friction to which it is subjected. The friction includes the viscosity of the water, the friction of the water and of the suspended particles against the sides and bottom of the bed, and the friction of the suspended particles against one another. In the case of currents containing a large amount of solids in suspension, the friction resulting from the presence of the suspended matter becomes so great, as compared with the other sources of friction, that the velocity is determined chiefly by the load of sediment the stream has to carry. Any enlargement of the channel of an ordinary stream, unless accompanied by a corresponding increase of water supply, causes a slowing of the current. Conversely, a narrowing of the channel acts like a partial dam; it increases the slope of the surface and is accompanied by a more rapid flow. Any slowing of the current will cause matter which could just be transported at the former velocity to be thrown down. Such matter is called *sediment*, and the same term is often applied to particles of solid matter while they are yet held in suspension. Aqueous sediment naturally settles in successive layers, and such drift is said to be *stratified*. When the current is of uniform velocity, the particles deposited are of uniform size. Upon this depends the sorting or classifying power of water.

One of the most common applications of these principles is seen when a sediment-laden stream flows into a large body of rather still water, like the sea or a lake. The currents are checked gradually, and there is a horizontal assortment of sediment, the coarsest matter being deposited near the mouth of the stream and the sediment becoming progressively finer as the

current gradually loses its motion. Such delta deposits are exceedingly common in Maine.

Aqueous sediments are termed *torrential* when deposited by very rapid streams, *fluviatile* when deposited by ordinary rivers, *lacustrine* or *lacustral* when deposited in lakes, *marine* when in the sea, and *estuarine* when in that portion of a river subject to the ebb and flow of the tides. While in one sense a portion of the sea, the estuary is inclosed like a river, and therefore its deposits differ from those of the open sea. The water is more or less brackish, and only the remains of animals naturally frequenting such places are found in estuarine sediments.

The sediment deposited by rains and streams on the land is termed *alluvium*, and when in the valleys of ordinary streams it is often named *valley drift*. Observations in all parts of New England show that a very large amount of alluvium was deposited in the larger valleys at or near the close of the Glacial period. So characteristic is this alluvium that the period has sometimes been termed the Valley Drift period.

The principles enunciated above enable us to estimate approximately the velocities of the rivers at the time the valley drift was deposited. The size of the fragments contained in the valley drift is such that the velocity necessary to transport them is generally less than 4 or 5 miles per hour, but among the hills it may have reached 8 or 10 miles. This refers to the velocity near the bottom of the streams. The slope required to produce these velocities varies according to the breadth and depth of the stream, etc.

The viscosity of water is so small that only very swift currents can transport large stones and bowlders up and over a steep obstacle. The water at the bottom is embayed or dammed by the obstacle, so that the rest of the stream flows over and around the embayed water as well as the obstacle. Hence, the mutual adhesion of the pebbles of a gravel bank is often sufficient to protect the bank from erosion when the velocity of the current is far greater than would otherwise suffice to transport the pebbles. The pebbles become wedged together like paving stones, so that they can not be moved without friction, and they resist erosion by swift currents as the gravels of the seabeach resist the surf.

A practical application of these principles involves the vexed question: How can we account for the presence of stones several inches in diameter in the midst of fine sand and clay? It has been usual to refer the cobbles

and bowlderets found in the valley drift to ice floes. No doubt ice floes often deposited such stones, as well as large bowlders, but I have lately made some observations in Colorado which show that large stones, and even bowlders, may be deposited by water upon and within sand. I have examined the track of several so-called cloudbursts soon after they occurred. Near the centers of these violent thunderstorms a fall of 6 or 8 inches of rain and hail is not unusual. This great precipitation takes place within a few hours, sometimes within a few minutes. The rain water soon collects on the lower slopes, fills the beds of the streams, and then covers their flood plains to a depth of several feet, sometimes overwhelming a broad prairie. As the waters flow down the hillsides the hail is rolled along in front as a sort of moving dam several feet high. Here and there the waters break through this dam and shoot with great velocity down the slopes of the prairie, soon to be stopped again by the hail. In this way the waters are soon concentrated and confined within channels varying from 10 feet to several hundred feet in breadth, bordered by walls or dams of hail from 1 to 4 feet high.

During one of these floods in El Paso County the flow was so rapid as to transport slabs of sandstone 4 feet square and 2 feet thick. These bowlders were iron-cemented and heavier than ordinary sandstone. The velocity of the current must have been 10 miles or more per hour. In narrow ravines of erosion (washes or arroyos) the erosion was very great. Blocks of clay were undermined and rolled along in the boiling torrent until they were nearly round. A stream 200 to 300 feet wide, and about 20 feet in depth at the deepest place, issued from the mouth of a narrow valley at Templetons Gap, near Colorado Springs. It became somewhat wider as it entered the broad open plain, yet for one-third of a mile it was swift enough to transport the bowlders above mentioned. Previous to the flood the plain at this point was composed of sand loosely grassed over. The bowlders were dropped upon the sand plain, which was but little eroded by the swift currents. Then as the flow slackened, sand was deposited upon and around the bowlders to the depth of from 1 to 3 feet. The geologist of the future will find the bowlders surrounded on all sides by stratified sand. Before I saw and studied these cases it would have seemed to me impossible that water could have deposited fine sand and large bowlders in juxtaposition in this way. Two or three miles farther down on

the plain, the flood crossed recently plowed fields. The surface was eroded somewhat and was left with numerous swells and hollows, up to a foot in depth, yet this small erosion was produced by currents swift enough to roll along mud lumps a foot in diameter. About 5 miles below where the flood issued from the narrow valley, it became concentrated between banks of hail and swept away a house situated on an open plain in the city of Colorado Springs.

These and numerous similar observations in Colorado, both in the recent water drift and in that of Tertiary age, show bowlders of considerable size surrounded by fine sand and gravel and occasionally embedded in clay. It thus appears that swift currents can flow over a stratum of fine sediment having an even or level surface without eroding it much, due largely to the fact that the lower part of the water is nearly stopped by friction. The stream can not, so to speak, get at the sediment while it remains coherent. But when a stream impinging against a vertical bank undermines a portion of it, the alluvium usually loses its coherence the moment it is precipitated into the water. The particles now being isolated are no longer able to protect one another by mutual cohesion and friction.

These observations have a bearing not only on the occurrence of large stones and bowlders in the valley drift, but also on the bowlder beds found in ancient rocks. I consider it certain that large stones and even bowlders may be deposited by running water in the midst of sediments as fine as sand, and even in clay. What is required is a rapid current moving over an even surface and acting for a rather short time. The sudden storms of the Rocky Mountains furnish the required rush of water, and it is quite possible that the spring floods of the Valley Drift period also afforded the necessary conditions.

Large stones found in the sedimentary marine clays must have been dropped from above by ice or other floating body.

TRANSPORTATION AND EROSION BY SPRINGS AND SUBTERRANEAN STREAMS.

This important means of erosion and transportation has not hitherto received from students of the drift the consideration it deserves.

The action of subterranean water is not very rapid, but it is persistent. The rain seeping down through the earth dissolves some of its ingredients. At depths below the reach of frost this process slowly enlarges the spaces

between the particles. Under favorable circumstances the interspaces by degrees become so large that minute sand or clay particles are carried along by the water, and thus mechanical attrition helps to enlarge still more the passages between the grains of earth. In numerous wells in the glacial till the water has been reported as being found in "gravel." I have examined several such wells and found that subterranean waters had percolated through the till until they had carried off the finer particles, leaving the larger stones somewhat rounded by the flow. I infer that when the till was first formed the water percolated through all parts of the mass at a nearly uniform rate. By degrees the seeping became more rapid along certain lines or layers, where there was the largest water supply or the most matter readily removable. These layers soon became more porous than the rest of the till and formed a system of subterranean streams or "veins." In my early studies of the till I was often puzzled at these apparently water-washed beds of gravel in what would otherwise be amorphous till. This phenomenon occurs in the granitic and clay-slate regions as well as elsewhere. In such regions the surface waters do not sink down into the till in large streams, like the sinks of a limestone region, and the till is in most cases, perhaps in all, compact enough to thoroughly filter the water before it has penetrated many feet. The presence of muddy water in a deep well that is protected from surface wash around its mouth indicates subterranean erosion rather than access of muddy surface waters. Such cases have happened to my knowledge. However, this erosion is rarely so rapid as to muddy the water perceptibly. Obviously the longer the process continues the more porous the subterranean channels become, and the escape of the waters will be more rapid with correspondingly rapid erosion.

When water is flowing through a porous stratum, especially of sand, with such velocity as to overcome the mutual adhesion of the grains and to carry them along with it, we have what is known as quicksand. In like manner, gravel will flow like a liquid if water flows rapidly through it. This is the cause of the very great amount of erosion effected by what are known as "boiling springs." I have elsewhere recorded instances of large areas—square miles—of porous gravel eroded and removed by boiling springs assisted by surface waters. When a stream impinges against a gravel bank, the stones by their mutual adhesion protect one another from

the force of the current. But when water passes from beneath upward through the gravel, the surface stones and grains are one by one lifted from the others and the water bears them away as if they were a part of itself. Thus the principal eroding and transporting work of subterranean waters is done as they approach the surface as springs. There is an increased velocity as the water nears the place of its release, and all loose matter approaches the condition of quicksand. Clay and till are so compact that they have suffered comparatively little in this way, but the quantity of porous sand and gravel thus removed is surprising.

TRANSPORTATION BY GLACIERS.

For the purpose of this report it is not needful to discuss questions relating to the structure or behavior of glaciers, except so far as pertains to the geological work performed by them. We assume that snow which lasts from year to year finally becomes consolidated into ice. Above the line of perpetual snow the ice and semiconsolidated snow are known as the névé, or firn; below that line, as the glacier proper. Under favorable conditions the ice slowly flows, at a rate varying according to the temperature, the pressure from behind or the tension from before, the friction, the declivity of the surface over which it moves, etc. Whether this is a true molecular flow or only the apparent flow of a plastic body—of masses larger than molecules—it is not necessary now to determine. Under sufficient tension, or stretching force, the ice breaks, producing cracks called crevasses, which are known as longitudinal or transverse according to their direction with respect to the length of the glacier, or marginal when at the sides. When fractured surfaces of moist ice are brought together, they at once cohere, and surfaces of dry ice brought together under sufficient pressure also cohere. Thus, no matter how often the glacier is rent and torn, it has the power to heal its own wounds and to flow on, practically as solid as before.

Glacial movement conforms to the general laws of flow of fluids. The flow is from where there is greater pressure to where there is less, and it is retarded by friction at the bottom and sides of the glacier. This friction is but another name for the force which the glacier exerts in its efforts to push along the rock and other substances in contact with it.

When weathered rocks project above the glacier, more or less cliff débris tumbles down upon the ice. This débris is known as moraine stuff,

and a mass of it is called a *moraine*. Moraines are lateral, medial, basal, or terminal, according to their situation with respect to the glacier. Moraine stuff falling into crevasses is carried forward by the ice, and in this transportation the stones often scratch one another or the solid rock. Moraine stuff beneath the ice is known as a *moraine profonde*, or ground moraine. In ordinary valley glaciers, such as those of the Alps, the ground moraine forms but a small proportion of the moraine stuff. But where the whole country is covered by ice, and no cliffs project above it, the whole of the moraine stuff is beneath the ice or distributed through it. Most of the melting of the ice takes place at the surface. The melting waters then run along on the surface until they reach a deep crevasse, down which they pour, and make their escape by tunnels beneath the glacier. In this way each glacier is drained by one or more subglacial streams. The waters of these streams are usually muddy and heavily loaded with the finer detritus resulting from the grinding of moraine fragments against one another and against the underlying rock. In its impetuous course the subglacial stream erodes its bed, sand-carves the rock, and forms potholes, like other swift streams. During the winter, when the supply of water is diminishing, the lower portions of the tunnels of the subglacial streams become clogged with rounded sand and gravel. When the ice is thick, it is able to push this gravel onward and finally deposit it as a part of the terminal moraine, but a thin glacier will flow over its subglacial sediments without disturbing even the lines of stratification.

The general nature of the work done by glaciers, as stated in this brief outline, has been established by the observations of so many persons that it is here assumed without attempt at proof. Some controverted points will be discussed hereafter.

TRANSPORTATION BY FLOATING ICE.

Icebergs.—These are masses broken off from the front of a glacier. They carry more or less moraine stuff, which sinks to the bottom of the sea or lake when the ice melts.

Ice floes.—These are composed of the ice formed along the shores of the sea or of a lake. They often contain numbers of the stones and bowlders of the beach, frozen fast in them. Other things being equal, ice floes are thickest where the tide rises and falls. In the spring they first melt nearest

the readily warmed shore, and thus become detached. They then drift hither and thither under the action of winds or tides, and finally drop their burden of drift upon the floor of the sea or lake, or upon the shore where they may have been stranded.

River ice.—This differs from the floe of shore ice only in situation. The ice of rivers freezes fast to stones and bowlders, either on the shores or in shallow channels. When the ice breaks up in the spring, these stones and bowlders are often transported long distances. Frequently as the ice goes out it forms jams or gorges in its channel. When the dam at last yields to the pressure of the water behind it, the ice often pushes along with it large quantities of bowlders and other drift. The moving ice dam acts as a sort of glacier, the units of ice motion being the blocks of ice, and not indeterminate masses, as in the glacier. Similar dams must frequently form in the channels of superficial streams on the ice, as well as in those of the subglacial streams.

SHAPES OF DRIFT FRAGMENTS.

Crystalline forms, or those due to crystalline cleavage.—In Maine, not unfrequently, crystals of garnet, quartz, and other hard minerals can be found in sand and other forms of drift. Easily cleavable minerals, such as feldspar, are usually found in their cleavage forms, more or less modified by attrition.

Fracture forms.—These are the angular, prismatic, or more or less irregular forms into which rocks and minerals fracture under the influence of heat and cold, joints, etc. The forms vary according to the composition and structure of the rocks, each kind of rock having a prevailing form peculiar to itself. These forms are so characteristic that one can often know the nature of a bowlder from its shape alone.

Weather-rounded forms.—When rocks are of rather uniform composition and structure, their fracture forms naturally weather faster at the exposed angles, and thus tend toward the spherical form. For instance, the surface of a weathered granite bowlder is somewhat rough, being composed of a great number of small crystalline, fracture, and cleavage surfaces, but its general shape is rounded. The most of the granitic and syenitic bowlders owe their rounded shapes, not to the attrition of the glacier, but to weathering. They are no rounder than similar bowlders under the tropics in Egypt. A good example of the progressive changes from angular blocks of fracture to

rounded bowlders of weathering can be seen on the southern brow of Russell Mountain, in the town of Blanchard, Maine.

Weather-carved forms.—When the composition or structure of a rock is not uniform, the weathering may proceed in some directions more rapidly than in others. The longer such a rock is exposed to the weather the more irregular its shape becomes. In this way curious depressions have frequently been formed on granite or other crystalline and nonfossiliferous rocks, which have often been supposed to be the tracks of men or the lower animals or of infernal beings. On the islands of Monhegan and Menana, off the coast of Maine, are certain markings on the rocks which have been described by archeologists as inscriptions. The rather shallow depressions forming the so-called letters are formed along three systems of joints of the rock. Not a "letter" could I find that had not a crack (often minute) in the rock at the bottom of the depression. In numerous instances fractures of the rock near by have depressions along them, but no cross fractures or depressions to form letters. It is evident that weathering would proceed most rapidly on each side of such cracks, and thus in time a depression would be made along the line of fracture. The geological evidence is thus conclusive that the markings *may be* simply freaks of weathering along the fracture lines of the rocks, and that no human agency is needed to account for them. Yet if these markings prove to be capable of decipherment, we shall have to assume the existence of a race of men acute enough to take advantage of natural fractures and to form letters along them.

In the western part of Oxford County are many bowlders of a black eruptive rock which often have very uncouth and unusual shapes. This is due to unequal weathering of the stones. When gathered and placed in trains along the walks near the houses, they remind one of the purposed hideousness of heathen idols.

Water-rolled forms.—Water has but little ability to grind and polish rock by its own impact and friction. It derives its great power immediately from the solid matter which it is able to move. In rolling drift fragments it acts in two ways—by concussion and by attrition. In the first case the fragments are hurled against one another or against the solid rock, and since the angles are most exposed to the blows and are also most easily broken, the stones are reduced to the well-known rounded form of beach pebbles. In the second case the fragments are pushed past one another,

grinding themselves and wearing away the underlying rock. Concussion and attrition usually accompany each other, and it is sometimes difficult to distinguish between them. Concussion alone would leave the surfaces with small granular projections. It is the office of attrition to rub these off. The attrition scratches of water-transported fragments are necessarily short, since friction against the sides of the stones causes them to rotate, thus giving them a tumbling motion, with consequent concussion. The distance traveled by water-rolled pebbles in becoming rounded must depend on many circumstances, including the velocity of the current, the abundance of the drift, the condition of the bed of the stream (whether a uniform declivity or a series of waterfalls and rapids), and the size, specific gravity, hardness, brittleness, etc., of the fragments.

Forms carved by water-borne sand.—Friction is rhythmical, and whenever the solid rock or fragments, which for any cause are stationary for a considerable time, are swept by rapid currents bearing sand and gravel, they are carved into conchoidal depressions or furrows separated by rather angular ridges usually tranverse to the motion. Sand carving shows what sort of work is constantly being done by the finer detritus—if not too fine—transported by a stream. Stones which from time to time are moved into new positions owe their shapes to concussion and attrition of large stones as well as to sand carving, and do not show the peculiar depressions due to the rhythmical movement of the water over a stationary surface. Instances of sand carving can be seen at most of the rapids and waterfalls of Maine where the rock is hard and resists weathering sufficiently well. Quartz veins in granite afford the finest examples of this process, as, for instance, those at Rumford Falls. Sometimes the peculiar markings of sand carving are very distinct on small stones which have become wedged into a cavity of the solid rock. I found some such near the head of Rumford Falls which might have remained fixed in position for several years. The upper extremity was faceted to a plane surface, except that it showed the conchoidal grooves characteristic of sand carving as distinctly as any of the rock in situ. The pebbles of sea and lake beaches are perhaps rounded more by concussion than by attrition. According to Sorby and Daubrée, very fine sand grains remain angular after motion in water.

Forms carved by wind-blown sand.—Sand and fine gravel, when impelled by the wind against bowlders and other stationary objects, rapidly wear them

away. In this manner the upper surfaces of stones barely projecting above the ground are faceted to nearly a plane, but with more or less of the tremulous grooving due to the rhythmical friction of the wind. The grooves are usually a little deeper, as compared with their breadth, when made by the wind than when made by moving water. Sand-carved bowlders are very common in western Maine near the White Mountains, especially on hillsides facing the north and west. Thus certain bowlders of peculiar shape were discovered by Dr. N. T. True at Bethel Village, and were described in 1861 by Prof. C. H. Hitchcock, in a general report upon the geology of Maine.[1] As I have elsewhere stated,[2] these bowlders owe their unusual shapes to sand carving under the action of the wind. Occasionally I have noted sand-carved bowlders in eastern Maine, and many ledges near the seashore are carved with sand by both the wind and the surf. The process must be common elsewhere, but it can be recognized only where it is more rapid than the process of weathering. The striæ made by wind-blown sand and gravel are usually invisible, and when best developed are very short, owing to the ready rotation of the flying grains and stones when they strike obliquely against a stone or bowlder.

Forms scratched, planed, and polished by ice and rocks.—(1) By glaciers. Stones subjected to attrition by glacier action are said to be glaciated. Many of the glaciated stones show distinct scratches, furrows, or striæ. But where, as is often the case in the till, the stones were rubbed by the finer detritus beneath or within the ice, the surfaces received a very fine polish and show no distinct scratches to the unassisted eye. Glaciated stones are often faceted and are almost always unequally glaciated, some place still retaining its original surface or fracture. (2) By icebergs. When icebergs grind off a coast, the underlying rock must be corraded and scratched by any stones that happen to be in the lowest part of the ice and by any sand or other detritus or rock fragments resting on the floor of the sea. The fragments would also be scratched and ground. (3) By shore ice, ice floes, and river ice. As shore ice rises and falls with the tide or is urged toward the land by winds and the pressure of ice floes, there must be considerable attrition of the beach pebbles. Floating river ice must also produce a similar effect, especially when ice gorges have been formed. (4) By landslips.

[1] Sixth Annual Report of the Secretary of the Maine Board of Agriculture, pp. 266-267, Augusta, 1861.
[2] Am. Jour. Sci., 3d series, vol. 31, pp. 133-138, Feb., 1886.

The immense amount of earth involved in the Willey Slide in the Crawford Notch, and in several other large slides in the White Mountains, which were from one-half mile to near 3 miles long, makes it certain that there must have been a vast amount of friction of the moving fragments against one another and against the underlying rock. The motion of the landslip is very much more rapid than that of any glacier, and this would be favorable to the scratching and faceting of stones. No one appears to have reported finding such stones under circumstances showing conclusively that they were formed during the slip.

CHAPTER III.

PRELIMINARY DESCRIPTION OF THE SUPERFICIAL DEPOSITS OF MAINE.

A brief general description of the drift of Maine will be given in language which for the greater part is consistent with any theory as to the origin of the drift.

Erosion is the general name given to the process whereby a portion of the parent rock is removed from its place by any geological agency. It is a complex process, consisting of the preparatory work of detaching fragments from their original position by solution, chemical decay, weathering, water-logging of porous beds, abrasion, concussion, and all other forms of fracture, and of their subsequent removal by some drift agency. The word is sometimes used for the preparatory work only, exclusive of the subsequent removal.

PREGLACIAL DEPOSITS.

So far as yet determined, all the rocks of Maine are Paleozoic or still more ancient. The fact that no marine beds of Mesozoic or Tertiary age are found proves that the area within the State has been above the sea since Paleozoic time—unless, indeed, deposits of later age have been eroded or remain to be discovered. At Brandon, Vermont, are sediments deposited in a Tertiary lake of fresh water. Although they were not so firmly cemented and consolidated as the ancient rocks, the great glacier was not able wholly to erode them. Similar beds might have been laid down in Maine, and, if extensive, might have escaped erosion by the ice-sheet. I have, therefore, carefully examined the till, especially in the vicinity of the deeper lake basins, but thus far have found no fragments of such Tertiary beds. It has long been known that marine beds of Tertiary age are found on the coast of southeastern Massachusetts, and fragments have been dredged off

the coast a short distance north of Boston. Such beds must have been formed on the coast of Maine as it existed at that period. Where are they? That they are now beneath the sea is indicated by the contour of the coast. Prof. J. D. Dana has rightly urged that the narrow bays of the coast of Maine correspond to the fiords of Scandinavia and prove that the land formerly stood at a higher level than at present. These bays were once valleys of subaerial erosion, now in part submerged. The obvious conclusion is that the only Tertiary beds likely to be found are those which may have been deposited in fresh-water lakes. So far as our present knowledge extends, it must be admitted that no lake or river drift of the geological ages immediately preceding the coming of the ice-sheet has escaped the terrible ordeal of ice. Peats, soils, vegetable mold, and the bones of land animals must have abounded, but they were either removed entirely beyond the State or were crushed to powder and so incorporated with the rest of the till that no one has been able to recognize them. But negative evidence must not be accepted as conclusive. That such sediments have not been found by no means proves they do not exist and may not yet be discovered.

But while sedimentary rocks of the ages immediately preceding the coming of the Ice age have not been found, I have noted many instances of rock weathered in preglacial time. One of the most instructive of these is at one of the slate quarries of Brownville. Most of the rock was planed by the ice to a very level surface. In the midst of the glaciated surface was a depression showing a U-shaped cross section. This was probably a valley transverse to the section, but its true shape could not be determined. The depression was about 6 feet wide and 4 feet deep. The upper and central parts of the depression were filled with the clayey, bluish-gray till characteristic of the slate region, while in the bottom next the rock was a rather pale, brownish-red earth, mixed with fractured and weathered slate. Some of the nearly vertical cleavage laminæ of the slate had weathered away or fallen to pieces, leaving the more enduring laminæ projecting into the reddish earth from 1 to 4 or even 6 inches, thus forming a very rough and serrate surface. This depression was cut across by the quarry excavation, and at the depth of a few feet below the depression the slate appeared as solid as the rest of the quarry. Hence there was no reason to suspect the slate of being unusually soft and easily weathered or decomposed by waters beneath the till. Besides, the till was compact and unstained by

percolating waters. As elsewhere stated, this roofing slate resists weathering to a remarkable degree. All the circumstances make it certain that so great an amount of weathering as is shown by the slate in the bottom of this depression could have been accomplished only in the long eons of preglacial time. The bronwish mass in the bottom of the depression is a residual earth, a soil of preglacial weathering. This subject will be referred to hereafter.

GLACIAL DEPOSITS.

THE TILL.

Resting upon the glaciated rock (or here and there upon the small areas of nonglaciated rock weathered in preglacial time) is the till. It is an endless study. So varied are its forms and developments that no attempt can be made within the space allotted to this portion of our subject to do more than refer to those properties especially related to the subject of the glacial gravels. At the present time we do not need to theorize concerning the existence of a great body of land ice over northeastern North America. Assuming that the area of Maine was covered by a series of ice fields that were practically confluent, so as to form an ice-sheet, we interpret the facts as to the till in accordance with the glacial hypothesis.

The names given to the till in Maine deserve notice. A very common name for the formation is "hardpan." This no doubt refers to the compactness of the formation and the difficulty of digging into it. Another common name is "pin gravel," though the same name has also been applied to any recent conglomerate or water-washed gravel cemented into a firm rock by carbonate of lime or by iron oxides or hydrates. The till usually contains many stones and bowlders of all sizes, and a soil composed of weathered till is commonly known as "hard, rocky land," or as "rocky, upland soil." It is often called "hard-wood soil," also "orchard land." It is unfortunate that the term "gravel" is so often associated with the till. In Maine when soil is described as "gravelly," in most cases it is meant that the soil is composed of till. "Gravelly loam" almost always means till, but sometimes it means a thin stratum of marine clay overlying and partially mixed with true water-assorted and rounded gravel. Many know the formation as the "bowlder clay." To apply the terms "gravel" or "clay" to the till is a fruitful source of confusion, causing the till to be confounded with water-

washed gravel on the one side and with sedimentary clay containing bowlders on the other. The term "bowlder clay" may still have its uses, to describe certain disputed formations, but in New England it ought to be replaced by the word "till." This word is short, convenient, and implies no theory either as to the composition or the origin of the deposit. The till constitutes what was known to the older geologists as the "drift" or "unmodified drift."

In Maine the most constant characteristic of the till is that it is composed of drift fragments of all sizes, from the finest particles of clay and rock flour up to the largest bowlders, all indiscriminately mixed together in a pellmell mass, except that the lower layers contain more fine matter than the upper and a much larger proportion of distinctly scratched or glaciated stones. In the area of sedimentary rocks in the northeastern part of Aroostook County the till consists almost wholly of sand and clay, most of the larger stones having been broken into their constituent grains or ground into powder, so as to resemble a soil of preglacial weathering, and over large areas bowlders are almost unknown. Although almost all of the till has drifted toward the south and east, the distance traveled varies greatly. On Matinicus Island I found fossiliferous bowlders of Oriskany sandstone which must have traveled 140 or more miles. By count of the stones large enough to be plainly recognized lithologically, I have found that by far the greater number, especially of those in the lower part of the till, were derived from rocks not many miles away. Repeatedly the lower till has been seen to be derived chiefly from local rock, while the upper layers were derived from a rock that outcropped not far north. On the other hand, I have sometimes found near the bottom of the till much matter from a distance. Apparently the relative proportions of near- and far-traveled matter in the till vary, but I have been unable to discover the laws and causes. Sometimes I have suspected that the till of two different glacial periods is mixed, but have not been able to find the necessary field evidence. That the character of the till changes rapidly as we pass from slaty into schistose or granitic areas is proved not only by count of fragments but also by the general appearance and the physical properties of the soil, and often by the vegetation. The greater part of the till of Maine, and especially the large bowlders, must on the average have drifted but a few miles.

DISTRIBUTION OF THE TILL.

The depth of the till varies greatly. Numerous small areas are bare of it. More often these bare places are in the valleys or on the tops of hills, especially in the slaty regions. No account is here taken of the areas of bare ledges near the sea, denuded by the waves, or of steep hillsides, denuded by landslides. In many places bowlders are arranged in trains, presenting the appearance of the moraines of modern valley glaciers. I have elsewhere described several terminal moraines, most of which appear to have been formed in the sea at the extremity of the ice at a time when the ocean stood at a higher level than now. So also there are masses of till of various shapes, mostly short ridges and irregular heaps, found in low depressions of the higher east-and-west ranges, or bordering these passes. They are more numerous on the north than on the south slopes of the passes. Such passes and low cols would for a time during the decay of the ice-sheet afford exit southward for tongues of ice after the glacier had become too thin to permit flow over the higher hills. These heaps have not so steep slopes as the ordinary terminal and lateral moraines of mountain glaciers have, and the shapes of the morainal masses deposited by glaciers bearing matter which fell on them from above are evidently different from those into which the moraine stuff was incorporated from beneath, if we except the extreme terminal moraine. It is an interesting study to determine whether thick masses of englacial till can be accumulated within the ice by ice movements. The term moraine was first definitely applied to masses that accumulated on the surface or at the extremity of the ice. It has also been applied to the matter beneath the ice. Can it properly be applied to a mass of the ground moraine of unusual thickness or to similar masses of englacial till? In this report I have not applied the term moraine to masses of till unless they present the external and internal characters of the moraines found on the surface or at the extremities of ordinary living glaciers; except that ground moraine is used as a generic term to indicate the whole of the subglacial till, but not individual masses or accumulations of it.

In the hilly parts of the State the phenomena of "crag and tail" are well exhibited. This term refers to the accumulation of till which collected in the lee south of projecting hills, especially conical peaks. These accumulations consist of ridges or deep sheets of stony till, generally of loose structure and rather easily eroded by springs and rains.

On the northern and northwestern slopes of rather high hills deep sheets of fine, clayey till abound. The till is in general thinner on the hilltops and in the valleys than on the intermediate slopes. This fact, combined with the rounded, flowing outlines of the mass, gives to these hillside accumulations of till a shape somewhat lenticular in cross section, but they often extend for miles along the sides of a ridge.

In the southwestern part of the State, hills of mammillary or lenticular shape abound, but they are not so large or numerous as the lenticular hills

FIG. 2.—Section across deep lenticular sheet of till; Kents Hill, Readfield.

of till so abundant in certain parts of New Hampshire and Massachusetts. Sometimes, as at the eastern end of Portland, there is a rock nucleus, above and around which the till collected; but more often no such nucleus appears anywhere on the surface, and if it exists it must be of small size as compared with the whole hill.

Professor Hitchcock and Mr. Warren Upham named them "lenticular hills" in the reports of the New Hampshire survey. Similar masses appear to have previously received the name of "drumlins" in Great Britain and Ireland, and this name is now generally adopted. In Maine the drumlins of the southwestern coast region are mostly roundish or slightly elongated. Back farther from the coast, and especially in the eastern part of the State, there are many which take the form of ridges, sometimes a mile or more long, with arched cross section, like the osars. They contain no water-washed material like the osars, and are substantially parallel with the glacial scratches of the region. Often I have traveled a long distance in the wilderness in search of a "horseback" which had been described to me, and which I anticipated finding to be an osar, only to find it a mass of till. Such a ridge has been cut by the Penobscot River at the mouth of South Twin Lake. The local

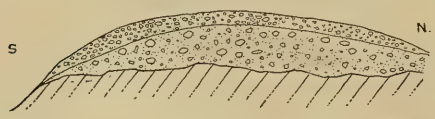


FIG. 3.—Section across Munjoy Hill, Portland. Rock overlain by lenticular mass of till, and that by glacial gravel.

rock is slate. The till next the rock is intensely tough and clayey, being mostly derived from the clay slate. The ridge proper rests on this sheet and contains a large proportion of granitic matter derived from the granite outcrop near Mount Katahdin. The ridge has a sort of lamination, as if accumulated in successive layers parallel with its arched surface; yet it is true till and at the exposures examined contains no sedimentary matter. Near East Vassalboro and elsewhere are a few symmetrical cones which on the surface are composed of sandy till. They are found suspiciously near the discontinuous kame systems, and this suggests genetic relationship with the conical and lenticular kames. As suggested elsewhere, a glacial stream that plunges down a crevasse will enlarge its shaft at the bottom and form a conical cavity, in which a conical kame will collect if the stream brings down coarse sediment. If the stream should for some reason cease to flow at this place, it is possible that till might subsequently collect in the ice cavity around the original kame as a nucleus; and if little or no gravel collected in the cave, still it might in some way become filled with till after the flow of the stream ceased.

Irregular heaps and ridges of till, which appear to be mostly composed of englacial matter, abound in all parts of the State. When these are mapped and masses of the ground moraine distinguished from the englacial till, it will be possible to write out almost the whole history of the ice movements. The till is more unequally distributed in the granitic and coarsely schistose regions than in the areas of slates and sedimentary rocks, and its distribution is more irregular near the coast than in the interior.

THE UPPER AND LOWER TILL.

The upper layers of the till are less compact than the lower, perhaps owing in part to the heaving of the frost. No doubt frost has in some cases brought up bowlders toward the surface, and this partly accounts for the fact that most of the larger bowlders are found on or near the surface, but only partly, for in the granitic regions bowlders are often piled one above another in such a manner that the frost can not have changed their relative positions, and here the larger bowlders are more often at the top.

The most probable interpretation of the facts is that the finer and more intensely glaciated lower portion of the till was deposited in its present

position and shapes beneath the ice as a ground moraine proper, while the upper part of the till, of less compact structure, less marked glaciation, and containing the largest bowlders, is composed of matter which was distributed throughout the lower portion of the ice. The classification of the till into a lower and an upper member, early adopted by Professor Hitchcock in the New Hampshire geological reports (substantially that proposed by Torell), seems to have a basis in fact. At one time I thought it possible to distinguish in the field between the ground moraine and the upper till, but subsequent observations have shown many places where this is difficult, if not impossible. Indeed, it appears probable that the two formations often blend with each other, so that there is no sharp line of demarcation between them.

It is well known that in the Mississippi Valley there are two or more layers of till separated by strata containing peat and other traces of a warm interglacial period. No such signs of two general glaciations have yet been found in Maine. The few facts that indistinctly point that way seem as yet to be capable of other interpretations, although during the final melting there may have been alternate retreat and advance near the ice margin.

SEDIMENTS TRANSPORTED BY GLACIAL STREAMS.

These deposits of water-assorted drift have attracted attention all over the world wherever they are found. Their most obvious characteristics are the following:

External forms of deposits.—The simplest form is that of a cone, dome, or hummock, and we find all transitions between these forms and the elongated, two-sided ridge. When enlarged on all sides, the dome becomes a rather round plain with flattish top. The single ridge may fork into two ridges, which soon come together again, thus inclosing a basin or kettle-hole, which not infrequently contains a lakelet; or it may divide into a large number of branches which are themselves connected by transverse ridges, the whole forming a plexus of ridges inclosing depressions of all shapes. Such networks have been called reticulated ridges by Prof. N. S. Shaler. The depressions inclosed between these ridges are of various shapes and have received many names, such as basins, sinks, funnels, kettle-holes, punch bowls, hoppers, Roman theaters.

HUMMOCK OF GRANITIC TILL; CASCO. LOOKING NORTH, NEARLY OPPOSITE TO THE DIRECTION OF GLACIATION.

Characteristic mass of englacial till in granitic regions. This hill is locally known as the "Broken Pepper-box."

Names.—These gravel deposits have such curious and distinctive shapes that they have received local names wherever they occur. The Scandinavian osars, the Irish eskers (or eskars, or eschars), and the Scotch kames are supposed to be the equivalents of the gravel ridges here described, or nearly related to them. These deposits contain matter of various sizes, from fine clay to large bowlders, but gravel is by far the most abundant. I have found the term *glacial gravel* a convenient general title for describing every kind of coarse sedimentary formation which was deposited by glacial streams. The term has the disadvantage of implying a theory as to the origin of these sediments, and it does not describe their composition in all cases, yet it is often convenient as a generic name when there is doubt what specific name should be given to a certain deposit, whether kame, osar, etc.

In Maine these deposits have received many local names. The most common name is "horseback," but this name is also applied to a hill or ridge of any other kind of material, whether loose material or solid rock. They are also known as "whalebacks" and "hogbacks." Sometimes one of these ridges is known as the Ridge (as Chesterville Ridge), and they are not infrequently known as "windrows," "turnpikes," "back furrows," "ridge furrows," "morriners," and sometimes as "hills." Several of these ridges used to be known as "Indian roads," because Indian trails were made on top of them in the midst of a swampy region. In one place a ridge of this kind was called the "Indian railroad." It may be suspected that those who gave it this name had in mind certain archeologists who have thought that the osar ridges were built by the Indians. It would certainly be remarkable if the Penobscot and Passamaquoddy Indians or their predecessors had been so industrious in former ages as to outdo the mound-builders and build several thousand miles of these embankments—embankments far surpassing in size all the mounds of the Mississippi Valley and the railroads of Maine combined. Cones of glacial gravel are frequently known as "pinnacles," "hills," "peaks," or even as "mountains." Broad, flat-topped ridges have attracted much less attention than the two-sided ridges and the cones; yet many of them are locally known as "plains," and this is the common name in Maine for a plexus of the reticulated ridges, or for any broad mass of sand and gravel, especially when overgrown by blueberries and other bushes.

Briefly stated, the glacial gravels are found in the form of every kind of ridge, terrace, cone, dome, heap, mound, and plain into which loose, water-washed matter can be piled, and with both steep and gentle slopes.

Topographical relations.—Generally these deposits of water-assorted sand and gravel are heaped up above the surrounding level. They also take the form of flattish-top terraces on hillsides, or they may fill a valley from side to side as a plain of level cross section but inclined longitudinally at the same slope as the valley. They often form long systems with average trend from north to south and nearly parallel with the glaciation. Sometimes they are found in the valleys of existing streams, but more often where no ordinary surface stream larger than a mere brook can ever have flowed, even in the time of the most violent floods. Many of the shorter systems are only from 100 to 400 feet above the sea at their northern extremities, while the longer systems originate at the north at elevations of 700 to 1,600 feet, a few ridges nearly 2,000 feet high being known. The northern ends of the distinct systems are higher than the southern ends, but the gravels do not follow a uniform slope. The map shows well how often they leave the valley of a stream and pass over a divide or low col into the valley of another stream. In so doing they not only rise above the average grade line of the system, measured from one extremity to the other, but they also rise in actual elevation above the sea. Throughout the greater part of the State I do not know of any of the systems crossing hills more than 200 feet higher than the valleys lying to the north of them. But in the southwestern part of the State they repeatedly go up and over hills 200 to 250 feet, in one case 400 feet, high (measured on the north). Since the height of the hills which the gravel systems could surmount was limited, they always penetrate high ranges of hills by low passes. These passes are not always the lowest that could have been chosen, nor are they always the most direct. Probably in the larger number of cases the glacial rivers took the best routes for getting from one end to the other, taking both grade and directness into account.

An experienced engineer wishing to construct a railroad between the termini of the longer systems as economically as possible, by the shortest route consistent with the minimum amount of rise and fall, would in a surprising number of cases find himself following the same route as the gravel systems. A good topographical or relief map of the State would reveal

this fact much more plainly than the existing maps do. Where these gravel ridges cross a level and swampy region, they often form a remarkable feature of the landscape. In many cases they form natural roadways across the swamps and have been utilized for this purpose by both Indians and whites. When an explorer has followed one of these great embankments for 50 or 100 miles, crossing rivers and valleys, climbing over hills, now skirting hillsides far above the valleys, now meandering across a plain where nothing now exists to cause meanderings, and bending abruptly in order to penetrate some low pass—by the time he has seen all this and noted how, within certain limits, these gravel systems disregard the surface features of the land, he will be ready to admit the utter impossibility of accounting for the existence of water-rolled gravels in such situations by any form of fluviatile, marine, or lacustrine agency, or by any known means except by streams confined between walls of ice that have now disappeared.

Sizes and lengths.—The narrow two-sided ridges are sometimes barely 3 feet high and three or four times as broad, and all sizes exist up to 100 or more feet high, with corresponding breadth. The broader ridges or plains vary in height to a maximum of about 150 feet. The deepest kettlehole measured was about 100 feet in depth. Many of the ridges are barely wide enough for a road on the top, while massive plain-like ridges are found which are from one-eighth mile to more than a mile wide. The plains of reticulated ridges are sometimes 3 or 4 miles wide, and the marine delta-plains are still broader. Where the gravels, when mapped, are plainly seen to be arranged in lines along routes that do not cross very high hills, they are assigned to the same system. The gravels of a single system are supposed to have been deposited by a single glacial river. The gravel is not continuous throughout the course of a system. Sometimes the gaps are due to erosion of the gravel, but more often they are due to failure of the glacial river to deposit gravel throughout its whole course. The gaps are usually less than one-half mile across, but in some cases 2 or 3 miles. When gravel deposits are separated by such long gaps, I have never assigned them to one system without special proof according to the principles laid down here and elsewhere. Several of the systems are 100 or more miles in length.

Branchings.—The branches of the longer gravel systems may be classified as follows: (1) Tributary branches. The map shows that many of the

systems receive branches which converge toward the south, like the tributaries of ordinary rivers flowing in that direction. This sort is especially noticeable in the eastern part of the State. (2) Delta branches. Systems often divide into two or more branches diverging toward the south, like rivers at their deltas. The most remarkable examples of this class of divergent branches are found in the southwestern part of the State. When both kinds of branches are found in the same system, the tributaries are toward the northern end of the system and the delta branches toward the southern. Assuming that the glacial gravels were deposited by glacial streams, we see that these streams in many respects conform to the habits of ordinary surface streams, though their causes and environment were different.

Meanderings.—The map shows that the longer systems follow tortuous courses. Many of these deflections were taken because of the surface features of the land, such as the positions of the high hills and low passes. There are also many short zigzags which plainly resemble the meandering of streams, yet they are found in level regions where there are no surface features to cause them. Apparently many of the minor curves and meanderings of the glacial rivers were caused by conditions of the ice which did not depend on the land surface beneath the glacier.

Directions of their courses.—The average direction of the gravel systems is a little east of south, varying all the way from southwest to south and east, and in a few cases for a short distance even a little north of east. While there is often a tendency to follow the lines of glaciation, yet there are many notable exceptions. Thus, in eastern Maine there is a remarkable convergence of several gravel systems toward Jonesboro and Columbia Falls. There is a convergence of the glacial scratches toward the same points, but it is not so great as that of the gravels. The convergence of the gravel systems and that of the scratches are nearly uniform toward Belfast Bay. Most of the discontinuous systems are nearly parallel with the scratches. At Danforth Village the glacial river abandoned a low pass and took a higher one more nearly parallel with the glaciation. On the other hand, there is but little convergence of scratches toward Penobscot Bay; yet several long glacial rivers which were widely separated at their northern ends, united to form a single river a few miles north of the bay. The Holden-Bucksport and the South Albion-China systems both take a southwest course on account of high ranges of hills. At North Waterford

a glacial river at one time flowed southwest to Lovell and at another time followed the valley of Crooked River for a few miles east and south. So also at the south end of Hogback Mountain Pass, in Montville, a glacial river took two diverging courses, either simultaneously or at different times. In both of these cases the larger flow was along the southwestern course and over hills of moderate height, while the lesser flow took place down valleys of natural drainage and more nearly parallel with the glaciation.

Composition.—These deposits are normally composed of water-assorted sediments. The fragments vary in size all the way from the finest clay up to sand, gravel, pebbles, cobbles, bowlderets, and bowlders 3 to 4 and even 5 feet in diameter. Gravel is by far the most abundant material. Clay seldom appears except as thin beds in the midst of the coarser sediments. Occasionally there are masses in these deposits closely resembling till, yet in general the finer matter has so plainly been washed out that there is no difficulty in distinguishing them from the unmodified till. They are in fact the till more or less water washed, i. e., the residue left after the fine parts of the till have been removed by glacial water.

Internal structure.—Most kames and osars are stratified in a very complex manner. Both transverse and longitudinal sections of the kame ridge will frequently show cross bedding. In the longer ridges the oblique laminæ generally dip toward the south and obliquely outward toward the sides of the ridge, so that in cross section the strata appear to be arched. In the broad level-topped plains the stratification is often nearly horizontal. The strata are sometimes inclined at very high angles, almost vertical, but only locally over small areas, so far as I have observed. In some cases the lines of stratification are curved and twisted, probably the result of distortion since the original deposition. In a dome or cone the stratification is often quaquaversal, and sometimes monoclinal, either parallel or transverse to the gravel system, as if the deposition took place from the top of the cone downward in all directions, or sometimes only at one side of the channel of the glacial river.

In some osars a portion of their length shows no lines of stratification. The finer débris has been washed out of them, and the stones even in the pellmell portions are plainly rounded by water. It is more probable that the present pellmell condition of the sediments is due to the obliteration of an original stratification by unequal and irregular settling and sliding

rather than to any freak of sedimentation whereby no stratification was produced. If the sediment was deposited upon the ice it would naturally lose its structure during the melting of the subjacent ice.

Shapes of the constituent fragments.—In the glacial gravels we find all degrees of water wear. In some of the shorter systems and toward the northern ends of many of the longer systems the stones and grains are but barely polished at the angles and differ so little from till in their shapes that the mass may be regarded as a slightly water-washed till. On the other hand, most of the stones and grains of the kames and osars show a very large amount of attrition and rolling and are very much rounded.

Direction and distance of glacial-gravel transportation.—In small cones and domes the lines of lamination frequently dip outward in all directions, as if the water came from above at the center of the cone and flowed downward and outward on all sides. In the case of ridges, the frequency of transverse and oblique dip shows that much of the drift was first at the top and center of the ridge, and thence was washed partly lengthwise of the ridge and partly sidewise or downward. At the fan-shaped delta localities, where glacial streams flowed into broadened channels, or into glacial lakes, or the sea, there were many local whirls and eddies where kame matter was transported northward for short distances. With the exception of these accidents of water motion within the tortuous channels of the glacial rivers or near their mouths, the proof is in most cases conclusive that kame and osar transportation was southward. In a few places I have found no positive proof of the direction of motion. The direction of flow is proved by the following considerations: The prevailing southward dip of the laminæ of the ridges; the higher elevation at the north end of the systems; the direction of the flow of the glacier and the position of the terminal moraines; and directly and positively by observations on the osar drift itself. Where an osar passes from an area of one kind of rock into an area of a different rock, the osar drift changes just as the till does, but not so abruptly; it is thus proved that the average distance of transportation was greater in the case of the osars than in the case of the till, and also that the drift was in the same direction. Proofs of this are given elsewhere. Naturally when one sees gravel systems going up the northern side of a hill to a height of 200 feet or more, it seems incredible that a stream could flow southward over such a barrier. That they actually flowed over such barriers is strong evidence of the

existence of ice. The pressure and head of water necessary to drive streams up and over such hills could be secured only in channels or tunnels within the ice.

MARINE DEPOSITS AND GEOLOGICAL WORK OF THE SEA.

The geological surveys of both Jackson and Hitchcock presented abundant proof that clays and sands containing marine fossils are found in Maine far above the present level of the sea. Lists of fossils were published, and these were afterwards enlarged by Packard and Shaler. Fossils from these beds have been collected by numerous observers, including Mr. C. B. Fuller and Dr. William Wood, of Portland; Prof. C. H. Fernald, of Orono; Prof. L. A. Lee, of Brunswick, and Prof. R. Stanley, of Lewiston. A fine collection of these fossils, made at Gardiner and known (from the donor) as the Allen Collection, is now in the cabinets of Bowdoin College. The highest level at which fossils have been found, so far as known, is 217 feet (Hitchcock's report). There can be no accurate study of the drift without distinguishing between marine and glacial gravels. It therefore becomes necessary to describe in some detail the nature of the work which the sea has done over that part of Maine which in the so-called Champlain time was submerged in the ocean.

BEACH AND COVE GRAVELS.

At hundreds of places along the coast I have examined the slopes of the higher hills for traces of old beaches. For the same purpose many of the islands were visited, the most important of which lie farthest from the coast, viz, Monhegan, Matinicus, and Ragged islands, Isle au Haut, and Mount Desert.

The best place, perhaps, to begin our investigation is at the island of Monhegan. This island is located 9 miles off the mainland at Pemaquid Point, is surrounded by pretty deep water, and is consequently far from shore ice and exposed to the full force of the ocean. The central parts of the island form a sort of plateau, from which several small hills rise to a height of 120 to 150 feet above the sea. The marginal slopes are rather steep on all sides, except at a few narrow coves and on the west side, where there is a small sand beach, also the harbor, partially protected by the neighboring island of Mananas. The island is about 2 miles long from northeast to southwest, and its breadth is about three-fourths of a mile.

Its longer side is thus presented to the open ocean in the direction from which the largest storm waves come. Considering the small size of the island, its position so far from the land, and the exposure of its flank to the storm waves, it is doubtful if any place can be found on the whole coast where the sea could act to better advantage. Here we may know what the utmost fury of the sea could accomplish, remembering that when the ocean stood at higher level than now the island would be still farther from the mainland and still more exposed to waves from every direction.

Except near the harbor and at a few small coves, the island is bordered by cliffs of erosion at the present level of the sea. On the more exposed (east and southeast) sides these cliffs vary in height from a barely perceptible roughening of the rock to 30 feet, and in a few places they are even higher. They show the irregular and honeycomb appearance character-

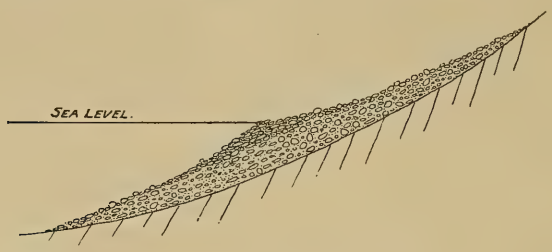


FIG. 4.—Longitudinal section of cove gravel.

istic of the cliff of wave erosion. In a few places, not far above high tide, quartz veins show conchoidal depressions and uneven groovings, due to sand carving under the action of the surf. At the head of one of the coves are several potholes 10 to 15 feet above high tide. The waves become narrowed, and consequently higher, as they advance up the cove. They rush swiftly up the slope at the end of the cove to a height of 20 or even 30 feet above high tide, and then the undertow flows swiftly back. During this alternate rush of water in opposite directions the stones and bowlders are set whirling in any depressions there may be in the rock, and thus potholes are in time eroded. A section across one of these coves or small bays shows a mass of beach gravel and bowlders occupying the bottom of the valley that slopes down to the cove. In cross section the top of the beach matter is nearly level. A longitudinal section shows that it slopes rather

steeply up from the sea to a height determined by the waves, while at the same time the undertow has taken a portion of the beach matter out into the sea, as shown in fig. 4.

The distance the finer matter is drawn back into the sea depends on many circumstances, such as the height of the tides, the outline of the coast, the slope of the shore, the depth of the water, etc. When the slope is sufficiently gentle, the forward push of the breakers is greater than the backward pull of the undertow, and a ridge of shingle is formed across the bays, as shown in fig. 5. Such ridges are named sea walls in Maine, and are common on the exposed coasts. The material is derived from the erosion of the projecting headlands or is driven up from the sea bottom when the slope is very gradual. Indeed, there is always a sort of shelf or terrace near low tide, where the force of the undertow is checked by the sea, even in the steeper coves. If, now, the slope should become more gentle, the forward push of the waves would soon change the terrace into a

FIG. 5.—Transverse section of sea wall.

ridge rising above the land back of it. Such are the beaches of the glacial Lake Agassiz, as described by Mr. Warren Upham, and the old beaches of Lake Ontario observed by me in central New York. Occasionally such a sea wall was formed in Maine in the period when the sea stood above its present level, though the ones examined by me were neither so high nor so long as those of the coast to-day. Having the form of an artificial embankment across a valley, which they are likely to dam, producing a lake, they have sometimes been supposed to be prehistoric, built by the inevitable Indians.

It is important to note the action of the sea waves upon projecting capes. As the waves strike a point of land they are divided, and the water is forced obliquely or laterally along the coast toward reentrant parts. Loose débris is at the same time driven obliquely away from the projecting capes and collects in the bays as beaches or as sea walls. So, also, the waves are constantly changing their direction under the action of varying winds, and beach matter is transported laterally along the coast whenever

the waves strike the shore obliquely. As the result of all these causes, together with the tidal currents, the projecting parts of the land are denuded of loose matter, while the bays and coves are strewn with beach gravels.

Such are some of the most common modes of wave action as exhibited along the present beach. Rising above the beach cliffs, we find that a considerable part of the island of Monhegan is bare of soil. The local rocks weather very unequally. Many of the bare ledges of coarse-grained syenitic granite have already been shattered into bowlders and cliff débris. Wherever the rock weathers slowly the rounded forms of the roches moutonnées are beautifully exhibited. Everywhere a thin layer on the surface has weathered away, and I could find no glacial scratches on rock long laid bare. On the north shore was a place where the surf had recently undermined and removed the till. Here the scratches were well preserved and the rock bore every appearance of having been as violently glaciated as it was anywhere on the mainland. It thus appears that the rounded bosses of rock which cover a large part of the island are true roches moutonnées and owe their shapes to glacial action. As the ice-sheet passed over the island, it ought to have left as large a proportion of the surface covered with till as it did elsewhere on that coast. But the proportion of bare rock is unusually great on this island. If we assume that the whole surface was originally covered with till, we find that the greatest amount of work that can be assigned to wave action at levels above the present beach cliffs consists of (1) the erosion of a considerable part of the till, and (2) some attrition, which may have erased the glacial scratches but did not obliterate the characteristic forms of the roches moutonnées. When we compare the ragged and uneven cliff of erosion at the present beach with the still moutonnéed ledges at higher levels, it becomes evident that the sea has stood at or near its present position many times as long as at any higher level. At the higher elevations the surf had time to erode the till from the more exposed shores, but it had not time to form a cliff of erosion in the solid rock before a change of level transferred the wave action to higher or lower rock. In other words, the changes of level of the sea were relatively rapid.

In a few places undisturbed till was observed resting on the glaciated rock, but over most of those parts of the island covered by soil the superficial deposits consisted of a formation needing careful study in order to

make clear its origin. At first it appeared to be till, but it was soon seen to have lost the finest matter of the till. All material except the finest remained in a rather obscurely stratified condition. On the northern slopes of the island the stones have been changed but very little from their till shapes; but on the side next the open ocean the stones are much more rounded and polished, though seldom showing such very round shapes as those of the stones of the present beach. A section from east to west across one of the north-and-south valleys of the island is shown in the accompanying diagram.

The slopes are somewhat exaggerated in the diagram. The bare ledges on the tops of the hills have become weathered into bowlders of decomposition. Some of these are in place; others have tumbled or slid a short distance down the slopes, as is proved by their identity in composition with the rocks that compose the ledges. Are these bowlders the result of a former marine erosion? The lower part of the valley is shown in fig. 6 to be filled by a mass which we now recognize as beach gravel, composed of the till and any rock which may have been eroded or washed up by the surf. This is overlain by a thin soil composed of peat and vegetable mold, rain wash, weathered drift, etc. An examination of the till and the beach gravels at high levels showed that both are composed almost wholly of rocks found on the mainland to the north of the island. I did not succeed in finding a single fragment of the same kind of rock as that on the island. The beach gravel is evidently the residue left after the erosion of the far-traveled till brought hither from the north by the ice. The finest matter of the till was washed out to sea and lost, but the coarser matter remains, and consists of sand and gravel mixed with larger stones and bowlders, all more or less polished and rounded by water. The rarity, perhaps total absence, of local rock in this ancient beach is a proof that the sea did not form cliffs of beach erosion in the solid rock, though it was able to remove large areas of till. It also justifies the inference that, at least in all the cases

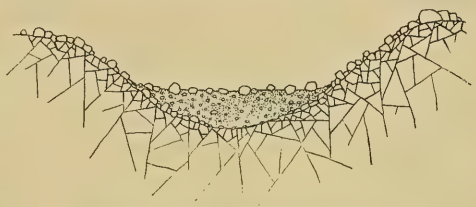


FIG. 6.—Transverse section of ancient cove gravels.

examined, the bowlders of local rock found lying upon the beach gravel and the soil are due to recent weathering and sliding of the rock, and not to wave erosion.

Fig. 6 is drawn across the valley. Lengthwise of the valley the surface of the beach gravel has about the same slope as the solid rock of the island. In some cases one of these plains of cove gravel can be followed all the way up a valley to the top of the island and then downward to the sea on the other side. The structure lengthwise of the valleys is shown in the diagram, fig. 7.

If the summit is narrow and rooflike, the gravel is scanty or absent at that point; but where the top is a rounded plateau the beach gravel is continuous across the whole island. The mode of formation of these continuous sheets of gravel, filling the valleys and extending across the whole island, is evident. As the sea rose or fell, a valley would always be

FIG. 7.—Ancient beaches sloping up from shore.

occupied by a bay or cove, and a hill would form a cape. The till would be washed away from the hills (then capes) and would be drifted obliquely into the present valleys (then bays). If the changes in level went on at a uniform and rather rapid rate, a continuous sheet of beach gravel would be formed across the bottom of the valley from the top of the slope down to the present sea level. If there were pauses in the process of change of level, then terraces or cliffs of erosion would interrupt the even slopes of the beach. I saw no trace of any such pause, unless at about 25 feet above the present beach, where there is an obscure terrace. The valleys which have been covered in this way by beach gravels are not, on the island of Monhegan, more than one-fourth or one-third of a mile in extreme breadth. It is evident that the most violent waves must come from the side toward the open ocean, and the fact that this sort of gravel is more rounded on the south and southeastern slopes of the island is a proof that the stones owe their final shapes to beach action.

That most of the beach gravel laid down by the sea should thus be concentrated in the valleys in the form of long and rather narrow sheets, directed at nearly right angles to the shore, was rather contrary to my expectations, and was worked out only after careful study. There is here, on this uneven, rock-bound coast, nothing like the long horizontal terraces and ridges of beach gravel observed by Gilbert in the basin of the ancient Lake Bonneville in Utah, or by Russell along the old shore of Lake Lahontan in Nevada, or by Upham along Lake Agassiz—nothing like the "Parallel Roads of Glen Roy" in Scotland or the old beaches of Lake Ontario and of the other Great Lakes.

In several places on this island beach gravels are to be found abundantly on the north and northwest sides of small conical hills. These gravels are in part due to wave action from the northward, but there is no reason why waves from that direction should form beaches any deeper in such places than elsewhere on the northern slopes. A large part of this gravel was washed around and over the hill by the larger waves from the open sea toward the south. In other words, this gravel formed in lee of the peak which was then a shoal of rock or small island. Instances are also found in Monhegan where beach gravel was washed over the top of an east-and-west ridge and left in the northern slopes, but this form of beach is better shown elsewhere. Here the question is complicated by the fact that there was considerable wave action from the north and northwest.

Matinicus and Ragged islands are situated a few miles off the coast near the entrance of Penobscot Bay. They are very near each other and show nearly the same rocks. The eastern ends of both islands are nearly bare of drift of any kind, and are covered with granite knobs and bosses, well moutonnéed. The rocks of the western ends of the islands are schists, and show much more drift. The central part of Matinicus Island rises about 80 feet above the sea, and is covered with a broad, gently sloping, lenticular sheet of blue, compact till, 10 to 30 or more feet in depth. A large part of the till-covered area is strewn with several feet of beach gravel, little rounded or worn. The till and beach gravel are well exposed at the present beach where there are cliffs of erosion in the till. Evidently the sea was able to erode only a few feet on the surface of the till while at higher level than now, and the slopes of the island were so gentle that the eroded till was left as a broad sheet, there being no valleys in which it

could be concentrated into beaches at right angles to the shore. The rains easily penetrate the beach gravel, until they reach the more impervious till; they then seep along the top of the till in the gravel, and escape as small springs at the beach cliffs. The till is compact and clayey, and contains great numbers of scratched stones. It appears to differ in no important respect from the till found in the mainland north of this island. Ragged Island is more diversified by hills, and the till has been denuded from the southern slopes of the hills and drifted into the valleys, forming one or more plains of beach gravel extending across the island from south to north, as at Monhegan.

Isle au Haut is about 7 miles long from northeast to southwest, and about 2 miles broad. Its eastern and southern sides are exposed to the open ocean. On account of the number of fallen trees and the density of the scrub forest, the island is difficult to explore and it is impossible to get any general view of the old beaches. Near the southwestern extremity of the island I traced a line of beach gravel up a valley to a height of 225 feet by aneroid. Here the rolled gravel suddenly disappeared, and above that elevation only ordinary till could be found. Guided by the barometer, I then went nearly around the island at this elevation, and at every valley found rounded gravel and bowlders up to 225 feet, at which elevation the rolled gravel began to thin out, and the contour of 250 feet was plainly above the water-washed drift. From that elevation to the top of the highest hill (550 feet) not one water-washed stone could I find, though they were very abundant and easily found below. On the projecting angles of the hills (which would be capes with the sea standing at high levels) the till was extensively denuded. No cliffs of erosion were observed above the present beach.

Similar observations were made near Southwest Harbor and at many other points on Mount Desert Island, also at many favorable places on the mainland. One of the most accessible places for examining the highest beach is about 3 miles northwest of Rockland, in the valley of Chickawaukie Stream and Lake. This valley is bordered on the west by a high hill or ridge, rising 400 feet or more above the sea. For several miles along the southern and eastern base of this hill rolled gravels are abundant. In places the gravel takes the form of a distinct terrace on the

hillside, and for 30 to 50 feet above the terrace the rock is nearly bare of till. This terrace is very distinct along the west side of Chickawaukie Lake, where it has been excavated for road gravel. The stones are distinctly worn on the angles, but not so much so as in ordinary glacial gravel. This beach extends northward to the village of Rockville and then bends eastward and southward along the east side of the valley. When the sea stood at this elevation, the Chickawaukie Valley would be a bay nearly one-half mile wide, and since there would be few if any islands to the south, it would be well exposed to the waves. Three times in as many different years I have visited the place in order to measure by aneroid the height of this beach, and each time I have been prevented by local storms from making accurate measurement.

Another excellent locality for measuring the height of the highest beach is on the southern slope of a rather high range of hills situated about 3 miles north and northeast of Machias Village. The face of the hill is such that, when the sea stood at high level, there would be hardly any coves or bays, and it trends nearly east and west. The country to the south is low, so that it would all be submerged and this hill would be exposed to the unbroken surf. One can take aneroid readings and be down to the level of tide water in a few minutes. At 220 feet the top of a terrace of rolled gravel and cobbles was observed. The stones were distinctly polished and somewhat rounded at the angles. This terrace is from 10 to 30 feet wide, and is a prominent feature of the hillside. The gravel becomes thinner above the terrace, a sort of sheet overlying the till. Rolled stones could be found here and there at 240 feet. At 250 feet only ordinary till stones could be found, and from this point upward the hillside was searched for almost a mile, only till being found. The contrast in shape between the stones of the till and those of the beach gravel was so great that there was no difficulty whatever in distinguishing them. The sea did not here lay the rock bare, or at least did not leave it bare. The average of these and many similar measurements, with a good aneroid, give the height of the highest beach near the outer coast line as about 225 feet for the region east of Penobscot Bay, and 230 feet for the region between that bay and the Kennebec River. West of the Kennebec I have not yet been able to measure the height of the highest beach. A good

place for doing so is on Black Strap Mountain, in the western part of North Falmouth. It is desirable that the elevation of these old beaches should be measured by the spirit level.

It should be noted that in this report I am describing only what I have seen. The sea beach reported by Professor Hitchcock at Fort Kent (Geological Report, 1862) I have not had opportunity to examine. In this connection it should be added that Mr. R. Chalmers, of the Canadian Geological Survey, has determined the height of the highest beach in western New Brunswick to be about 220 feet, and it becomes somewhat lower toward Nova Scotia. Since the height of the sea rapidly diminishes southward in New Hampshire and Massachusetts, it appears that the average elevation of the sea on the Atlantic Coast south of Nova Scotia was greatest in the region lying between Portland and the Penobscot Bay, or perhaps near the mouth of the Narraguagus River.

To summarize: The rolled gravel of the old beaches is so different from the till in composition and shape of the stones, the raised beaches are so plainly to be recognized on all the exposed coasts of Maine up to the elevations above stated and then so suddenly disappear, that I feel justified in referring to the contour of about 230 feet as the highest elevation of the sea on the coast of Maine after the melting of the ice-sheet over the coast region. As to what may have happened in strictly glacial time, when the ice covered the land and extended far out to sea, and when the sea may have stood at far higher levels but was perhaps prevented by the deep sheet of ice from having access to the land and forming gravel beaches, unless possibly here and there at long intervals in the most exposed situations on the higher hills and mountains—concerning these possibilities it must be admitted that my observations, while not inconsistent with them, do not afford the necessary proof. Elsewhere are recorded facts showing that probably the sea was at a higher level 50 miles back from the coast than on the coast itself, i. e., the relative level of the interior and coast regions may not have been the same then as now, there being a greater submergence toward the northwest.

The foregoing remarks relate chiefly to beaches having a southern exposure. In many places where the waves swept over the tops of hills the till was denuded from the top of the hill and left as a beach terrace just north of the crest. The waves from the side of the open ocean had so

much more power than those from the coast side that much more beach matter was swept northward from hilltops than southward.

A good instance of this kind of beach is found a few miles south of Machias, at the terminal moraine which extends from a branch of Englishmans River northeastward to near the head of Little Kennebec Bay. On the seaward side of the morainal ridge the surface is strewn with bowlders and large stones. If they were once water polished, the polished surface has weathered away. On the northern slope is a deposit of stratified sand and gravel several feet deep, with a few larger stones, as shown in the accompanying cross section. The axis of the ridge is composed of till. Evidently the waves denuded the upper portion of the till on the southern slope and washed the finer matter over the top of the ridge.

An unusually fine exhibit of the same sort of beach is found on the northwestern slope of a northeast-and-southwest hill situated 1½ miles east of Boothbay Harbor. More or less beach matter is found all along the northern crest of the ridge. In addition there are several large bars of beach gravel which extend northward, obliquely down the hill, for about one-eighth of a mile. These ridges are situated directly north of low places in the ridge. Here, evidently, the higher parts of the hill were at one time islands, separated by narrow straits which occupied what are now the lowest parts of the ridge. The waves converged the beach matter and washed it through the narrow straits—now represented by the low cols—and a ridge was formed opposite each strait. Another fine locality is on the south side of the high hill which borders the Chickawaukie Valley on the west, about 1½ miles west from Rockland. Here a large amount of beach gravel gathered on the north side of a conical hill which lay a short distance south of the main hill. The place is situated just west of the lime quarries.

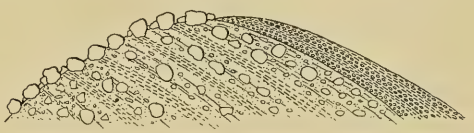


Fig. 8.—Section across terminal moraine near head of Kennebec Inlet.

In some of the most exposed situations the beach gravels extend continuously from the highest beach down to present sea level, but such places form the exception. As we pass inside of the outer islands the power of the waves rapidly decreases. Everyone who has sailed along the coast knows how much less violent are the waves in lee of even a small island. This

accounts in part for the absence of such long and continuous beach terraces as those of lakes Bonneville, Lahontan, and Agassiz. We have seen that changes in the level of the sea were rapid, so that the surf beat for only a relatively short time at any one level; but we must also remember that the land surface of most of the coast region of Maine is very uneven, consisting largely of hills and valleys. The hills are in general not high, but high enough to form a multitude of islands off the shore as the sea changed its level with respect to the land. As the sea rose and fell, not only did the shore outline change greatly, but the number and positions of the islands changed also. Each island more or less protected a portion of the mainland from the fury of the Atlantic waves. Although the waves must have beat against all that part of Maine situated below 230 feet, long horizontal beaches could not be formed, partly because of the converging of the beach outline into the bays, and partly because of the great numbers of protecting islands. The places were comparatively few which were so exposed that large beaches, measured either horizontally or at right angles to the shore, were deposited. The small beaches which must have been formed at that time in the landlocked bays and fiords are recognizable now either not at all or only with difficulty. Probably the rarity of long, continuous beaches is also due in part to shore ice. Even now, except on the most exposed coasts, the shore ice affords considerable protection against the winter storms. It is a fair inference that at the time the walrus came as far south as Portland the shore ice was more abundant than at present and somewhat resembled the Arctic ice foot.

Résumé.—For several reasons no long and continuous horizontal beaches were formed on the coast of Maine by the sea in late glacial and postglacial time while it stood above its present level:

1. The changes of level were too rapid to permit the formation of cliffs of erosion in the solid rock.

2. During the comparatively brief time the surf beat upon any one portion of the land the energy of the waves was chiefly expended in eroding the till and drifting it away from the capes into the bays.

3. The positions of the exposed bays and headlands constantly shifted during the changes in level of the sea, partly on account of the changes in the shore line and partly because of the appearance or disappearance of protecting islands off the shore.

4. The beach was more or less protected by shore ice.

5. The surf probably beat against the ice during all the time of its advance and until the ice had retreated north to the central part of Maine.

The net result of these causes was that recognizable beaches are found only at intervals. Most of that portion of Maine below 230 feet affords either no beach gravel or only scant quantities of it.

It follows from the above that the finding of a sea wall across a valley at a certain elevation, or of a beach terrace on a hillside, would not necessarily indicate a long pause of the sea at that level unless the relief forms of the adjacent land show that the sea waves would have as easy access at other levels as at that. The fact that those valleys of most uniform slope and exposure to the sea do not show well-defined beach terraces proves that at least the fall of the sea proceeded at a nearly uniform rate, unless the pauses at 225 to 230 feet and at 20 feet be exceptions.

FOSSILS IN THE RAISED BEACHES.

On the western slopes of Munjoy Hill, Portland, as pointed out to me by Mr. C. B. Fuller, the impressions of various shells and the burrows of divers mollusks, etc., are traceable in sedimentary sand and fine gravel at elevations of 50 or more feet above the sea. The top of the hill is covered with a sheet of glacial gravel, and the fossils are in beds which are stratified parallel with the slopes of the hill. The hills of Portland would not be in the most exposed situation when the sea beat upon their upper portions, yet there would be enough of a surf to erode considerable of the glacial sand and gravel from the top of Munjoy Hill. On the whole, I consider it more probable that the glacial sand and gravel containing fossils is not in the condition it was in when deposited by the glacial streams—that it was changed to beach matter by the waves of the sea, which washed it from the top of the hill and deposited it on the lower slopes. On the modern gravel beaches most, if not all, of the shells are being pulverized so rapidly by the beating of the surf that it is doubtful if many of them survive long enough to become embedded in the beach matter, unless it be below low tide. In several parts of the State I have examined excavations in the high beaches at 200 feet and found no shells and no impressions or casts of fossils large enough to be recognized by the unassisted eye, and no burrows.

At lower levels there are some fossils in the raised sand beaches, but I have found none in the coarse gravel and shingle beaches.

SANDS AND CLAYS.

Although the areas of denuded rock near the coast suggest that the quantity of raised beach gravel must be large, yet it is small when compared with the broad sheets of sand and clay deposited along the coast while the sea stood at higher levels than now. Only a small portion of these finer sediments can have been derived from the till and rock which were washed away and assorted by the ocean. There was not much wave erosion, except on the most exposed coast, and this was situated so far south that the eroded till must have been carried out to sea and can not have contributed much to the marine clays as we find them. The marine clays now exposed on the land are composed chiefly of the finer sediments poured into the sea by glacial streams or by swollen rivers. Practically they are marine deltas.

The facts as to the fossils of the marine beds are so well known that only the briefest reference need be made to them. All writers on the subject agree that about the time of the melting of the latest great ice-sheet of this region the sea stood considerably above its present level, varying from a few feet on Long Island Sound to 500 feet at Montreal. The sediments deposited in the sea after the ice retreated from the St. Lawrence basin are well represented along Lake Champlain, and were there studied at an early date; hence the corresponding deposits of this epoch have been termed Champlain by Hitchcock, Dana, and others. A few years ago a nearly complete skeleton of a walrus was found in marine beds at Portland, and is now preserved in the collections of the Natural History Society of that place. Bones of whales, seals, and molluscan life characteristic of an icy sea have been found in these beds in great numbers, as was early reported by Jackson, Hitchcock, Dawson, and others. In addition to the marine fossils, it is claimed that certain teeth, now in the Allen Collection at Brunswick, were found in the marine clay at Gardiner. These teeth were pronounced by several authorities to be those of the bison, and on this account Professor Packard, in his "Glacial Phenomena of Labrador and Maine,"[1] held that the higher lands were inhabited by the bison at the time the

[1] Memoirs of the Boston Society of Natural History, vol. 1, pp. 210–262, Boston, 1866–1869.

marine clays were being deposited; and if so, there must have been abundant land vegetation. These teeth have since, however, been submitted by Prof. L. A. Lee, of Bowdoin College, to Mr. J. A. Allen, author of "The American Bisons, living and extinct."[1] This expert, after comparing them with a large number of bison teeth, pronounced them to be probably cow's teeth, and of very modern date of deposition. In the present state of the argument it will not do to insist on the ancient date of these teeth, and the inference of a land vegetation in Maine at the time of the deposition of marine clays can hardly be considered sustained.

The Canadian geologists very generally employ the terms Leda Clay and Saxicava Sand for the lower and upper marine beds, respectively. The lower clays of Maine contain Leda and other fossils indicative of a muddy bottom, and occasionally in a sandy beach I have found Saxicava and other fossils characteristic of that sort of sea bottom. We have seen that the high beaches are not found continuously, but only here and there in favorable situations. Over almost all the area of the marine beds of Maine the lower clay (Leda Clay?) is not overlain by a fossiliferous sand. With respect to Maine it is doubtful if the terms Leda Clay and Saxicava Sand can be used in a stratigraphic sense as applying to deposits of different age laid down one above the other; but the terms may well be used to indicate the nature of the sediments which were deposited at different depths and under different shore conditions. On such an irregular coast as that of Maine the shore conditions would often vary rapidly. My investigations do not as yet enable me to give the chronology of the shallow-water sands and the offshore clays. As it is not my purpose to refer to the marine beds except as they are related to the glacial sediments, it is not necessary here to give particular descriptions of the fossils.

THE LOWER CLAYS: DELTAS DEPOSITED BY GLACIAL STREAMS.

As already stated, the lower clays are often richly fossiliferous, but the fossils are by no means evenly distributed. Thus, both at Brunswick and Gardiner the lower clays contain great numbers of shells; while at East Bowdoinham, intermediate between those places, the fine blue clay

[1] Memoirs of the Geological Survey of Kentucky, vol. 1, part 2, and memoirs of the Museum of Comparative Zoology at Harvard College, both Cambridge, 1876; also Ninth Annual Report of the U. S. Geol. and Geog. Surv. Terr., pp. 443-587, Washington, 1877.

which overlies the till contains very few fossils, and over large areas none at all could be found. The lower beds often vary in composition. Generally they are a fine blue clay, but in many places they consist of a fine sand, which is sometimes quicksand. These alternations of fine sand and clay are in a great measure independent of the relief forms of the land, and do not represent the horizontal gradations of sediment depending on depths of water. They are rather such variations as could be expected in a sea into which a great number of sediment-laden streams were pouring and where the fineness of the sediments was determined chiefly by the positions of the mouths of these streams. In the early part of this epoch the streams were smaller than they were later, and were mostly glacial streams. The positions of the mouths of the streams were constantly changing during the retreat of the ice, and would be affected also by changes in the level of the sea. As elsewhere noted, what appears to be a kame or osar border clay is sometimes richly fossiliferous. These fossils were probably deposited in bays in the ice, into which the salt water reached, and while most of the ice was still unmelted. They therefore date from an early part of the marine-clay period in Maine.

THE UPPER CLAYS: DELTAS DEPOSITED BY ORDINARY RIVERS.

In the upper layers of the marine clays and clay loams I have found but few fossils. As noted elsewhere, the same observations have been made by Professor Lee at Brunswick and Professor Stanley at Lewiston. The probability of finding fossils in the upper clays is greatest near the sea and away from the great river valleys. The clays are deepest in the larger valleys and near where the great glacial rivers flowed into the sea. The fact that fossils are rarest where the clay is deepest proves unfavorable conditions for marine life near the mouths of both the glacial rivers and the ordinary rivers. In other words, the vast influx of ice-cold and muddy fresh water during the final melting of the great glacier was destructive of marine life.

The rarity of fossils contained in the upper clays and silts makes it very difficult to determine where the marine beds end and those of estuarine and fresh water origin begin. For instance, a nearly continuous sheet of clay extends from the sea up the valleys of the Kennebec and Sandy rivers to a height of 450 feet or more. Below 230 feet this clay is usually dark

blue to brownish blue; above that it is bluish gray; otherwise, to the unassisted eye, the clay appears nearly the same throughout its whole extent. The absence of marine fossils does not prove the exact height of the ocean, for this clay is practically nonfossiliferous almost to the coast, 200 feet below where the sea has stood, according to the evidence both of fossils and raised beaches. This rarely fossiliferous sheet of clay is the basal clay of the river valleys above 230 feet and the upper layer of the marine clay below that elevation.

Above the clay which forms the lower stratum of the alluvium of the river valleys, we find in the upper portions of these valleys, overlying the basal clay, a stratum of coarse sand, or sand mixed with gravel and cobbles. This extends across the whole of the valley. As we descend the valley we find at a certain point that the coarse matter becomes finer, and soon passes by horizontal transitions into sand, which spreads far and wide and covers both the fossiliferous and nonfossiliferous clays. In general, the slope of the valley above the point of change from coarser to finer sediments is now not very different from the slope below that point. This rather sudden transition of sediments can easily be explained as due to the checking of the current where the rivers flowed into the sea of that time. Tried by this test, the sea may have stood at 400 or more feet above present sea level in both the Androscoggin and Kennebec valleys. This would imply a greater elevation of the sea in the upper parts of these valleys than is shown by the beaches near their mouths. There is as yet no fossiliferous evidence of such an elevation of the sea in the upper part of these valleys, and, as suggested elsewhere, if we enlarge our ideas of the size of the estuaries and lower parts of the rivers at that time, it is possible to interpret the facts as exhibited in the field consistently with the elevation shown by the fossils and raised beaches—about 230 feet. It is certain that in wide valleys or level plains the upper sands begin to spread laterally over the marine clays at not far above 230 feet. In the valley of the Androscoggin River these upper sands are well exhibited as delta sands deposited by the river in the sea. They extend all the way from a short distance above Lewiston to the sea at Harpswell, and send out a branch southward through Durham and Pownal to Yarmouth. In the valley of the Kennebec the river delta sands end on the south not far from Waterville.

SUMMARY.

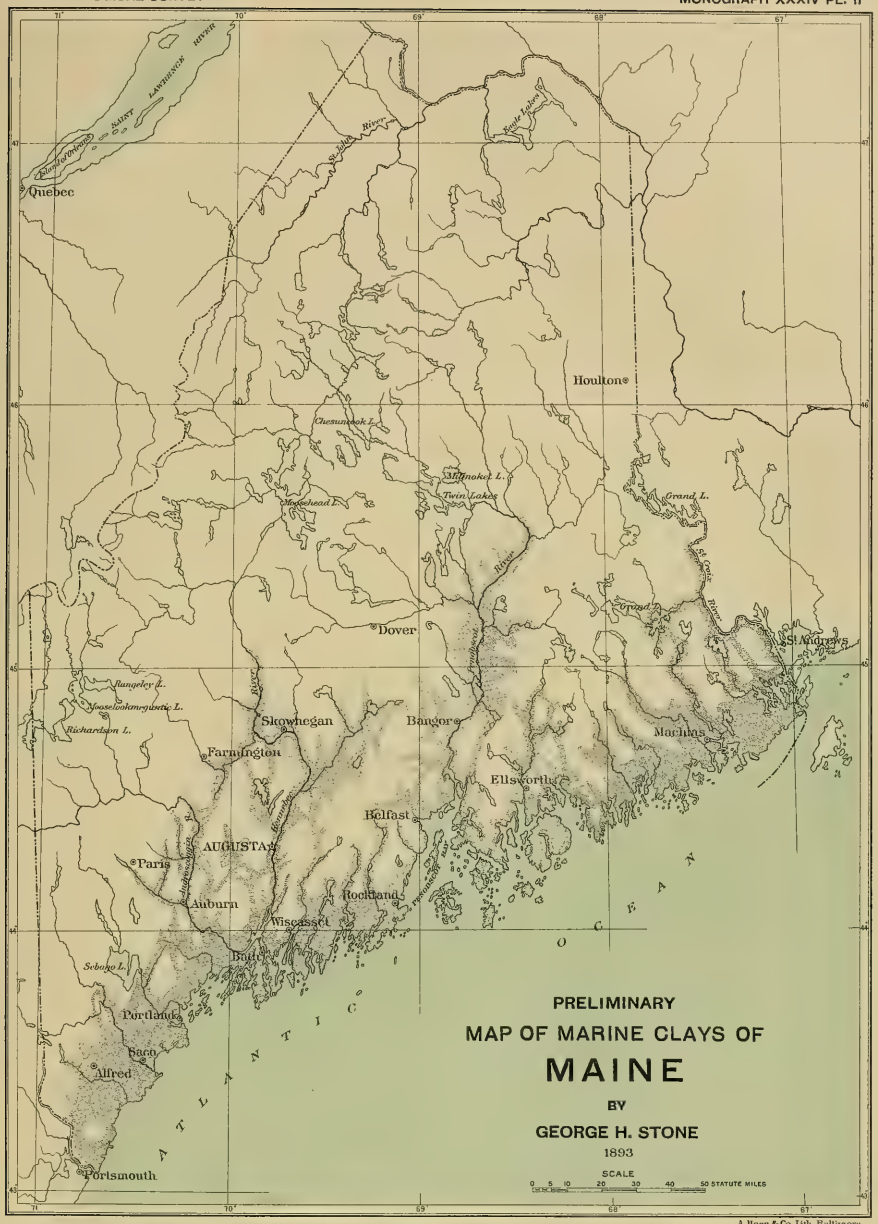
Marine erosion of the till and solid rock contributed but a small portion of the marine sands and clays of Maine. The lower marine beds of Maine are clays and very fine sands which are prevailingly fossiliferous. The upper clays are rarely fossiliferous, and appear to be contemporaneous, or nearly so, with the basal clay of the valley drift. Overlying the clay of the valley drift is a stratum of coarse matter, which changes to sand near the old shore line of the sea, and then extends for some distance seaward as a fluviatile, not a glacial, delta. The facts indicate that the lower clays are chiefly the finer sediments of glacial streams. The supply of sediment was at that time moderate, and marine life flourished. Later there was a great rush of glacial waters, and about the same time the ordinary streams began to flow. These conditions were unfavorable to marine life. Still later the sediments poured into the sea were almost wholly those brought by the present rivers, then swollen to great size. The sands last to be deposited border the river valleys and are plainly deltas formed in the sea off the mouths of the rivers. The earlier clays are more widely spread, and cover the whole area submerged by the sea, and their thickness bears a relation to the systems of glacial gravel rather than to the modern rivers.

The distribution of the marine beds is approximately shown in the accompanying map, Pl. II.

VALLEY DRIFT.

The mass of unconsolidated sediments which is found covering the bottoms of most of the New England valleys early attracted the attention of geologists. Various names have been given to it, the most common being terraces, valley terraces, and valley drift or alluvium. All agree that the material was transported to its present position by water, though sometimes it has been referred to marine rather than fluviatile action. The so-called "intervals" of the Maine streams are almost always plains of aqueous sediment, which are usually terraced. Elsewhere are given brief descriptions of the alluvium of the larger valleys of the State. A general discussion of this deposit is therefore postponed to a subsequent page. At present the attention of the reader is called to the more important facts.

Perhaps the most important fact regarding the sedimentary drift of the



A. Hoen & Co. Lith. Baltimore

valleys of Maine is that there is a profound difference between the sediments of the valleys above and below about 230 feet above sea level. Below that level the country was beneath the sea, and is covered with clays and other marine deposits. Unlike ordinary valley alluvium, the marine beds do not as a whole show a level plain in the bottoms of the valleys. Over large areas the surfaces of the clay plains undulate somewhat like the till beneath them, especially in the broad valleys which were arms of the sea, several to 20 miles broad when the sea stood at its highest level. As elsewhere noted, the clays are thickest near the mouths of the glacial rivers. Hence when we find marine deltas of glacial sediments in rather narrow valleys, the offshore clays usually extend over the whole valley and have a nearly horizontal surface across it. This closely simulates fluviatile sediments. The present rivers began to flow at the time the sea stood at its highest level. The fluviatile delta sands which these rivers at that time poured into the sea are easily recognizable and for a few miles extend entirely across their valleys, like fluviatile drift. A little below 230 feet the sands no longer spread over the whole space then under water, but form plains from 1 to 4 miles wide overlying the fossiliferous clays, and follow not only the main valley but also sometimes lateral valleys which were then straits, such as the line of sands that extends from the Androscoggin at Durham southward to Pownal.

Above the level of 230 feet we find sheets of sediments covering the bottoms of the valleys, usually terraced like the upper Connecticut Valley, and in most cases extending from one side of the valley to the other. In this portion of Maine (which was not in postglacial time beneath the sea) we find the valley drift comparable to that of the rest of northern New England. It will therefore be understood that the following remarks apply only to that part of the State situated above about 230 feet.

Over the more level regions the lowest layer of the valley drift is usually silt or clay, the upper layers consisting of coarser material, such as sand or gravel. As we approach the highlands the sediments become coarser in composition. Among the high hills the slopes are often 80 feet or more per mile, and the valley drift contains cobbles, bowlderets, and sometimes even bowlders. In general, the stones found in the valley sediments of Maine are very much less worn and rounded than those in the kames and osars. Some exceptions ought to be noted. Thus, near the

northern ends of some of the osars and in some of the smaller hillside kames the stones are but little waterworn, and the same is true of the stones at the margins of some of the osar-plains and of the smaller solid kame plains. On the other hand, the large stones of the coarse valley drift from the swift mountain streams are often quite well waterworn, though seldom as much so as those of the kames and osars. With the exception of these steep valleys among the hills, whenever in Maine we find a plain of apparent valley drift composed of stones considerably rolled and rounded, we are sure to find one of the following conditions:

1. A short distance up the valley the stream may have eroded a ravine or channel through a deep mass of till. In this case the stones are those of the eroded till, which were worn and rolled at the rapids formed while the stream was cutting through the till barrier. Such a formation occurs at Kingman and at many other places. The proof in such cases is not complete unless it appears that the deposit of well-rolled stones extends only a short distance below the channel of erosion, and that beyond that point the character of the valley drift changes.

2. If we trace both northward and southward such a plain of much worn stones, we may find it leaving the valley and going up and over hills to other drainage basins, or it may leave the bottom of the valley and go up along a hillside as a sort of terrace. In these cases the apparent plain of valley drift is an osar-plain, or broad osar, happening to occupy the bottom of a valley.

3. To the north such a plain of highly rounded stones may end in a kame or osar, while to the south the plain becomes finer in composition, passing from gravel to sand, and finally to clay. In this case our plain of well-rolled stones is a frontal plain of glacial sediments, consisting of matter that was brought down by glacial streams to the extremity of the ice (i. e., the end of the osar), and there was poured out into the open valley. From that point southward the sediment is spread across the bottom of the valley like purely fluviatile drift, yet the stones received their shapes almost entirely while being transported in the ice channels of the glacier, which at the time of deposition lay to the north. Several such frontal or overwash plains are described elsewhere.

In addition to the above-named glacial or semiglacial deposits, we also find, in a few valleys having a northward slope, sediments that were dropped

in local lakes which were confined between the ice on the north and the hills to the south during the final melting of the great glacier.

And now, after eliminating these more distinctly glacial sediments, how can we account for the remainder of the valley drift? A great part of it is frontal matter, derived from glaciers situated far to the north. Such sediment would consist mostly of clay derived from the muddy glacial streams, representing work done beneath the ice. In such a case the glacier of that time was so remote from where we now find the sediment that it is difficult to trace the connection.

RIVER TERRACES.

Here and there, at waterfalls and in the swifter parts of their courses, the streams of Maine have eroded all the superficial drift, and may even flow in channels excavated in the solid rock. A few of these rock channels approach the dignity of canyons, as those of the Kennebec above the Forks and of the Penobscot below Ripogenus Lake. In general, the streams flow in channels lying wholly or chiefly in the till or other superficial deposit. In addition to the erosion channels in which the streams flow when at their average height, we find most of the streams bordered by one or more terraces at higher level. The terraces consist of a somewhat horizontal portion, or shelf, ending in a rather steep bank or bluff facing the stream. The material of most of the terraces is some form of water drift, but sometimes it is till. In a few places where the channel proper lies in easily eroded sand, there are no terraces above the banks of the channel of erosion. This occurs when erosion and deposition are nearly equal, and when deposition is the greater.

River terraces may be divided into two classes.

1. Terraces of river erosion in drift which was not deposited by the rivers themselves. The till and the marine glacial and lacustral sediments were deposited under conditions independent of the streams which subsequently began to flow in the valleys of deposition, and the agencies by which they were deposited could not have formed a series of terraces to which the streams bear a causal relation. River terraces in these formations, or in blown sand, must be due to erosion by the rivers. They are as plainly formed by erosion on the land as a beach cliff is caused by waves and currents. The erosion terraces of Maine correspond to the rock bluffs

which border the streams of the Mississippi Valley and the Rocky Mountains, except that they have been excavated in unconsolidated drift and within a relatively short time. Below the contour of 230 feet all the higher terraces which border the rivers of Maine are the result of the erosion of till, blown sand, the marine sands and clays, or the glacial sand and gravel. Erosion of these formations, especially of the marine clays, has been effected on a grand scale. In many places the marine clays have been eroded into forms somewhat resembling the "bad lands" of the West. When a ravine once begins to form, it rapidly extends itself back into the clay. I have observed several ravines which, within five years, extended themselves from one-eighth to one-fourth of a mile and to a depth of 10 or more feet. These were formed where there were no permanent streams, and were wholly due to the wash of the rains. In the regions covered by the marine clays the streams having constant flow are bordered by cliffs of erosion, just like the narrow ravines, only the cliffs are situated much farther from one another, sometimes from 1 to 3 miles. The ravines and cirques of erosion are so characteristic of the clay-covered regions that by them one can recognize most of that part of Maine which was under the sea, even when deeply covered by snow. The till, being much harder to erode than the sedimentary drift, rarely shows cliffs of erosion at levels above the channel proper, except where the flow of the stream in time of flood is very much greater than the ordinary flow. Hence the scenery in the areas covered by till is very different from that of the clay regions. The methods of terrace erosion will be more fully considered hereafter.

2. Terraces composed chiefly of valley sediments. The simplest case is that of the present flood-plain terraces. They rise to only a moderate height above the present beds of the streams, and now and then they are overflowed in time of high water. The drift of the flood plain is of very composite origin. Part of it is usually the uneroded remains of a sheet of drift laid down previous to the flow of the stream at its present level—either till or the marine beds or valley drift deposited near the close of the Glacial period. Part of it is of recent origin, consisting of sediment deposited by the stream in time of flood or of matter brought down by the rains from the higher terraces and the hillsides. Wherever deposition equals or exceeds erosion, the flood plain is not nominally bordered by steep cliffs or banks of erosion, but it simply extends to the sides of the valley, sometimes being

perceptibly higher near the stream. In other words, the valley is filling with sediment. This is the condition of the stream and valley at the delta, provided the flow of water is sufficient to cover the whole valley from side to side. In a few places this is the present condition of the valleys, as, for instance, the valley of the Crooked River for a few miles north of Sebago Lake. Most of the more level portions of the larger valleys of Maine must have been in this condition at the close of the Ice age.

A strict classification would distinguish the flood plain of erosion from that of deposition. Practically the two processes are intimately blended. On the steeper slopes the flood plain is almost always due to erosion in times of flood; on the gentler slopes it is composed wholly or in part of matter deposited by the flood waters. It is often difficult to determine which of the two processes has been more active. In field use, the term "flood plain" implies the lowest river terrace which is now overflowed by the river in time of flood, without regard to the origin of the terrace.

Below the highest postglacial level of the sea (230 feet), we find the larger streams bordered by a rather narrow flood plain, above which rise one or more erosion terraces in the marine beds, or in the glacial sands and gravels, or sometimes in till. Soon after we rise above 230 feet we find one or more river terraces in the so-called valley drift. In addition to the marginal terraces, several of the valleys show large ridges lying along the axis of the valley. The largest and longest of these that I have observed were found in the Kennebec Valley above Solon, in the valley of the Little Androscoggin above South Paris, and in the Piscataquis Valley above Abbott. The number of marginal terraces varies. In general, the top of the central ridge has nearly the same elevation as the higher marginal terraces. Both Jackson and Hitchcock report terraces in the upper Kennebec Valley at elevations such that they must be higher than the central ridges. These highest terraces are so obscure that I hesitate to call them terraces.

RECENT EROSION OF THE VALLEY ALLUVIUM AND OF THE GLACIAL SANDS AND GRAVELS.

Before discussing the origin of the higher river terraces, it is necessary to inquire what sort of geological work is now going on in the river valleys. We can not declare that the higher terraces above the flood plain are due

to erosion (the common theory) until it is proved that erosion is now going on at such a rate as to justify the induction that the terraces could have been eroded within the time that has elapsed since the Valley Drift period. Thus, for instance, the Kennebec and Sandy rivers are bordered for many miles by bluffs or terraces 50 to 80 feet high, and between these bluffs lies a valley one-fourth to three-fourths of a mile wide. On the erosion theory, there is a very large amount of denudation and transportation to be accounted for. We have already noted that areas of the marine sands and clays from 1 to even 5 miles in diameter have been eroded by rains and streams to a depth of 10 to 70 feet or more.

According to a common theory of stream erosion, the terraces were eroded directly by the rivers as they wandered back and forth over their flood plains, or by their lateral branches. On this theory the base of every bluff or terrace was once washed by the river or its tributaries, at least in time of flood. This process of erosion by meandering can be seen in operation in many valleys, and is no doubt a common, and in greater or less degree a universal, process. But there is in operation in Maine a process which is often far more efficient in eroding wide valleys than meandering.

We have seen that the upper stratum of the valley drift is usually coarser than the lower. Hence the surface waters soak readily through the porous upper stratum until they reach the rather impervious underclay. They then seep laterally through the basal layers of the sand and gravel and along the top of the clay until they find exit in the form of boiling springs. The same thing happens at the plains of glacial sand and gravel, only in this case the water is generally arrested by the till. Thus, boiling springs often reveal the presence of glacial gravel hidden beneath marine clay. The reasoning is as follows: Large boiling springs are rare in the till, unless for a short time while the snow is thawing in the springtime. If such a spring issues from a suspected ridge, the ridge is more likely to be glacial gravel than till. The decisive test is furnished by the stones found in the boiling spring and its outlet, which will be well rounded if the spring issues from a mass of glacial gravel, and will not be the ordinary tillstones.

A fine instance of recent erosion by springs can be seen a short distance south of Solon Village. The plain of the valley drift which occupies the valley of the Kennebec River here extends for one-half mile or more east of the river. Back from the river at varying distances up to one-

fourth of a mile is a crooked bluff. At one place the bluff makes a very reentrant curve and borders a cirque, locally known as the "Hopper hole." There can be no doubt as to the origin of this bluff. Within a few years preceding 1878 (the date of my visit to the place), the subterranean waters had eroded a ravine 10 to 70 feet deep and had cut back into the plain for 300 feet. In spite of the most strenuous efforts to stop the washout in order to save the public road, it had been necessary to change the road twice. Large piles of brush, logs, bowlders, and various kinds of rubbish had been thrown into the ravine. The flow had at times been temporarily stopped, but the waters collected as behind a dam, and the porous sand and gravel over considerable areas became permeated by water under pressure until a considerable part of the gravel plain was in the semiliquid condition of quicksand. Finally either the dam was swept out of the ravine or the sand-and-gravel plain was washed away around the ends of the dam. When once the sand and gravel was in motion, it passed readily into the river, very little being dropped on the way. The work of the river consisted in carrying away the sediment furnished it by the springs. Here is an unmistakable case of steep cliffs or bluffs of erosion formed at a considerable distance from a river, not by the meandering of the river but by rains and boiling springs, the surface wash being small compared with the action of the subterranean waters.

The great amount of erosion effected by subterranean waters as they rapidly flow out of a porous mass of sand and gravel has recently been demonstrated at a point 5 or 6 miles northeast from Cherryfield. The site of the washout is at a boiling spring which had long been known to issue from the southern edge of the great glacial sand and gravel plains of Deblois and Columbia. The plain here ends in a steep bluff facing the south, and rises 50 feet above the plain of marine clay at its base. At the time of the washout a ravine 100 feet long, 25 feet wide at its base, and on the average 30 feet deep, had been cut back into the gravel plain, and the eroded matter had been spread over an area of 2 or 3 acres at varying depths up to 4 feet. No surface stream is to be found on the gravel plain near this place, and the cause of the eruption lay beneath the plain. During the winter of 1885–86 there was a thaw, during which a large amount of snow melted. Soon after there came a remarkable storm. The precipitation took the form of snow in the interior of the State, but over a

belt 20 to 40 miles wide next the coast there was a heavy fall of rain and sleet. It is known as the "ice storm," because thick ice gathered on the trees and broke down thousands of them, besides numberless branches. The next July after the washout the matter eroded from the plain could be seen overlying great numbers of limbs that had recently been broken off and the tops of several small trees recently bent to the ground. The washout, therefore, must have occurred during or soon after the ice storm. Evidently the unusual rush of subterranean water was due to the snow melted during the thaw, assisted by the rains of the subsequent ice storm. The water seeped down through the porous gravel until it was stopped by the till or solid rock, and it could then find exit only by flowing out from the side of the gravel plain, which it did so rapidly as to effect the large erosion above stated.

We thus have not only the ordinary and unceasing erosion of porous sediments by springs boiling up through them, but also from time to time these extraordinary outbursts. The most destructive outbursts take place in winter and spring. In Maine the ground ordinarily freezes in winter to a depth of 2 or 3 feet, and it must often happen that the smaller outlets by which the seeping waters escape will be frozen solid. The waters thus temporarily dammed will accumulate until considerable pressure is attained and will help to increase the velocity of the escaping water when at length the ground thaws and a passage is forced. The dams or gorges which often form in rivers when the ice breaks up in the spring must have the same effect on porous valley alluvium. The pressure of the water above the ice dam must sometimes cause a rapid seepage through coarse gravel and cobbles and the formation of erosive boiling springs at points below the dam. As noted elsewhere, the erosive power of a stream when flowing out of a mass of gravel is much greater than that of the same stream when sweeping past the base of a body of the gravel. The remarkable amount of erosion of osar-plains by even small streams is well illustrated near Knox, between Canton and Livermore, and between Rumford and North Woodstock, as described elsewhere. It is noticeable that moderately coarse gravel plains are eroded even more than fine sand.

Universally, so far as my observation goes, the narrow ridges of glacial gravel (kames and osars) have resisted erosion better than the large plains. This fact seemed unaccountable until I began to investigate the action of

subterranean waters. It then became evident that erosion is often more active from within than from without. Large boiling springs can form only where there is a large surface of porous matter, since the seepage of such matter varies with the surface exposed to the rains. It follows that this kind of erosion was formerly more rapid than at present, since there was then a larger surface exposed. In case of some of the osar-plains the amount of subterranean water must once have been two or more times the present supply. In this connection it should be noted that the rainfall of Maine is from 40 to 56 inches annually.

ORIGIN OF THE HIGHER RIVER TERRACES OF THE VALLEY DRIFT.

The following considerations bear on this disputed question:

1. The facts stated above, and elsewhere, prove that the larger plains of sand and gravel are now being rapidly eroded at considerable distances from streams by rains and subterranean waters. In many cases it can be proved that these agencies are more efficient in eroding high-level terraces than is the meandering stream.

2. Many of the river terraces which are situated above 230 feet extend continuously down their valleys until they end in terraces in the marine clays. But the latter are plainly due to erosion.

3. The marine beds have been eroded over areas 1 to 3 and even 5 miles broad. A less amount of erosion, though of coarser matter, will account for all the river terraces above the former sea level.

4. The upper portion of the valley drift is so generally coarser than the lower that the conditions for rapid erosion by subterranean waters are afforded by most of the larger valleys of New England.

5. The formation of terraces and bluffs of erosion not distinguishable in form from the ordinary river terrace has been observed in recent time.

Two theories as to the origin of the higher river terraces of valley drift demand examination: One is the erosion theory, according to which the steep bluffs are the result of the partial erosion of a sheet of sediment which once extended across the valley. The other is the theory suggested by Prof. J. D. Dana, to account for the terraces of the upper Connecticut Valley.[1]

According to the latter theory, the terraces were deposited at the

[1] The flood of the Connecticut Valley glacier, Am. Jour. Sci., 3d series, vol. 23, pp. 87, 179, 360, 1882.

margin of a river which then filled the whole valley to the height of the terraces. The water rose by successive stages, and the central parts of the valleys were never filled by a sheet of drift, as postulated by the erosion theory. The erosion theory postulates a water channel along the valley, and a pretty large one, but by no means so large as the whole space included between the terraces. Professor Dana's theory requires several or many times the amount of water required by the erosion theory, i. e., the stream must have been swift enough to keep its supposed channel (the space between the terraces) free of sediment.

The presence in several of the river valleys of a central ridge, so evidently an uneroded portion of a once continuous plain, strongly favors the erosion theory as to the formation of the broader terraces of valley drift up to the level of the central ridges. This includes most of the terraces. Perhaps I have not seen the terraces at very high level, noted by Jackson and Hitchcock in the Kennebec Valley, though I looked for them; but I have notes of a few narrow terraces above the erosion terraces which seemed to have been deposited in substantially their present shapes. Their material resembles that of the glacial gravels, but is not much rounded. These terraces were at first judged to be ordinary glacial gravels, but they preserve so nearly the same longitudinal slope as the valley drift proper as to give good ground for suspicion that they were formed at the margin of the valleys, as suggested by Professor Dana. But if so, it is not certain that they were formed at the margin of a great river filling the whole valley. During the final melting, the ice in the valleys—if we may follow the analogies of ordinary glaciers flowing in valleys—might sometimes melt fastest on the side next to the warmed hills. A stream would form in these marginal depressions, and the sediments deposited in them would now appear as terraces. These narrow high-level terraces may therefore be of semi-glacial origin, i. e., formed between the bare hills on the one side and the ice of the valley on the other.

SUMMARY.

The channels of the rivers of valley drift time have been greatly deepened and widened, partly by the direct action of the rivers upon the valley drift which then filled up the lower parts of the larger valleys, partly by the rains and by subterranean waters. In this process terraces

have been formed; and while most of the terraces are due to the carving and partial erosion of alluvium previously laid down, yet a residue remains where narrow terraces may have been deposited in substantially their present shapes, either at the sides of an ordinary river of great size or along the margins of a mass of ice filling the central parts of the valley. The question will be more fully discussed later (see Chapter VI).

CHAPTER IV.

GENERAL DESCRIPTION OF THE SYSTEMS OF GLACIAL GRAVEL.

According to the nomenclature here adopted, a system comprises the sediments deposited by a single glacial river with its tributary and delta branches.

VANCEBORO SYSTEM.

Two well-defined osars converge at Vanceboro station. One has been traced for about 1½ miles northwest of the station, as a low ridge, scarcely rising above a bog. The gravel is distinctly waterworn, and the ridge would naturally extend farther north, but such extension has not yet been traced. The railroad station is built on the gravel of this ridge. The other osar is a two-sided ridge, from 10 to 30 feet high, which follows the west shore of the Lower Chiputneticook Lake for somewhat more than a mile north of Vanceboro, when it seems to end in a bog near the lake. The shore of the lake here bends toward the northwest, and the northern extension of this system, if there is any, would naturally be found on the north side of the lake in New Brunswick. Numerous persons have reported to me that "horsebacks" of gravel are found in the valley of Palfrey Brook, but I can not be certain from the descriptions whether these are till or true glacial gravel. A horseback on Eel River, in York County, New Brunswick, has also been reported. Mr. R. Chalmers describes it[1] as a large ridge, probably beginning in Maine and thence extending southeastwardly along the valleys of Bull Creek and Eel River to First Eel Lake, where it disappears under the lake. Mr. Chalmers's description shows this to be an osar. So large a ridge implies a glacial river of considerable size. As it does not seem to end, according to Mr. Chalmers's description, in a delta-

[1] Report on the surface geology of western New Brunswick: Geological and Natural History Survey and Museum of Canada, Report of Progress for 1882–83–84, p. 25 GG, Montreal, 1885.

plain at First Eel Lake, the river would naturally have flowed farther south or southeast. If so, the Eel River osar may prove to be a continuation of one of the osars that unite at Vanceboro.

A short distance north of the railroad bridge at Vanceboro is a small and rather level-topped plain of sand and fine gravel which extends westward from the main osar ridge. It ends in a steep bank, and is quite regularly stratified, the strata dipping outward. The material is somewhat coarser near the main ridge than at the edges, and therefore the deposit presents the external appearance of a small delta ending in sand, showing that the currents were not wholly checked.

Just south of this plain the St. Croix River bends to the westward and crosses the line of the osar. There is a short gap in the ridge at this point, perhaps due in part to erosion by the river. A ridge begins a few rods south of the railroad station (near where the two glacial rivers united), and thence a well-defined ridge or series of ridges is formed along the St. Croix for about 5 miles, it being most of the way on the west side of the river. At the mouth of Trout Brook the river makes an abrupt bend westward, and the course of the gravel system is uncertain. Large sand-and-gravel plains are reported by Prof. G. F. Mathew,[1] near Lynnfield, Charlotte County, New Brunswick. I did not personally explore the valley of the St. Croix for several miles south of Vanceboro, and my marking of the probable course of this glacial river as extending from the mouth of Trout Brook southeastward past Mud Lake to Lynnfield, where it would naturally deposit delta-plains, is provisional. The Lynnfield plains appear to be considerably above the contour of 225 feet, and this glacial river may have deposited gravels south or southeast of them, perhaps down the valley of the Digdequash River.

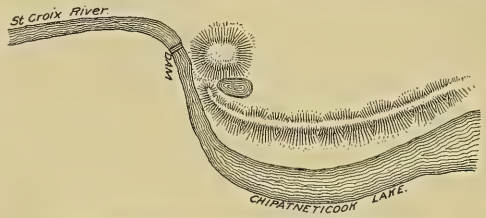


FIG. 9.—Osar and delta-plain inclosing lakelet, Vanceboro

[1] Report on the superficial geology of southern New Brunswick: Geological Survey of Canada, Report of Progress for 1877–78, pp. 13–14 EE, Montreal, 1879.

DYER PLANTATION SYSTEM.

An osar from 20 to 40 feet high extends from near the mouth of Big Simsquish Stream southward nearly parallel with the St. Croix River for about 3 miles, in Dyer Plantation, Washington County. It then takes the form of somewhat discontinuous low bars and terraces, which perhaps are a poorly defined osar-plain. This extends past the enlargement of the St. Croix River known as Loon Bay to the mouth of the Canoose Stream, where the system crosses into New Brunswick and sends out two tongues of sand and gravel for about 6 miles southeastward, one on each side of Basswood Ridge. I saw, in 1879, only a portion of these plains. They appeared to be rather level on the top, with the exception of a few two-sided ridges here and there rising above the rest of the plain. They present the external features of a delta-plain, either marine or deposited in a glacial lake.

For several miles above the mouth of Little Simsquish Stream I could find no glacial gravel on the west side of the St. Croix, but could see across the river on the Canadian side considerable gravel of some kind in the form of terraces. For about 1 mile above the mouth of Scotts Brook the gravel near the St. Croix was very nearly in shape that of tillstones. This makes it highly probable that the Vanceboro system does not continue in the St. Croix Valley below the mouth of Trout Brook so as to connect with the Dyer system. I could find no trace of this glacial river to the north or west of the mouth of Big Simsquish Stream, unless a small plain covered by a thin sheet of sand may have been deposited by it. This plain is overgrown with pines, and is situated not far from Scotts Brook, about halfway from Lambert Lake to the mouth of that stream. The country is a dense wilderness, and one might pass very near a large osar and not see it.

The osar in Dyer contains many rounded bowlderets and some bowlders. In many places the lateral slopes are very steep. According to Anson,[1] the elevation of the head of Canoose Rips is 211 feet; that of the foot of Rocky Rips, near the north end of the Dyer osar, as here described, is 227 feet. The plains of the Canoose Valley and those near Basswood Ridge are thus shown to be not far above the highest of the beaches.

[1] The Water Power of Maine, by Walter Wells, p. 115, Augusta, 1869.

BARING-PEMBROKE SYSTEM.

A ridge of glacial gravel comes from the north of the northern bank of the St. Croix River a short distance west of the bridge of the St. Croix and Penobscot Railroad Company, at Baring. Directly opposite, on the southern bank, the ridge begins again, and probably it was once continuous across the bed of the stream; but if so, it has been considerably washed away. A series of ridges separated by gaps extends from Baring southward over a low divide, and thence along the valley of Moosehorn Stream. Farther south the system takes the form of a rather continuous level-topped plain, which presents the external features of a marine delta-plain; but 1 or 2 miles north of Pennamaquan Lake, in Charlotte, the system changes to a series, nearly a mile wide, of broad reticulated ridges about 100 feet high, inclosing several deep kettleholes. The gravel passes into the northern end of Pennamaquan Lake as a long gently-sloping bar, and within 2 miles reappears on the western shore of the lake, and thence the series is found along the lake and Pennamaquan Stream to its mouth in Pembroke. Toward the south the ridges become shorter and the gaps somewhat longer—indeed, some of the ridges are so short as almost to be lenticular hummocks. Unless, perhaps, at Pennamaquan Lake and at the top of the col in the southern part of Baring, the gaps in this system seldom exceed one-fourth of a mile. The country traversed by this system is covered by marine clay. An excavation in this gravel ridge made a short distance south of Baring Village showed the ridge to be covered by 3 feet of clay containing marine fossils, and a number of bowlders having the ordinary till shapes rest on the clay directly above the gravel.

The northern connections of this system are obscure. D. F. Maxwell, a civil engineer of St. Stephen, New Brunswick, reports sand-and-gravel deposits in the valley of the Moannes Stream, extending about 4 miles north from Baring, and these are probably a part of this system. Gravels are reported at Chiputneticook Falls, St. Croix River. Possibly this system is a continuation of the Dyer system, but I mark them provisionally as independent systems.

HOULTON-DENNYSVILLE SYSTEM.

This important osar system appears to begin a few miles north of the divide between the waters flowing northward into the Aroostook River and

those flowing south and east, at an elevation of about 900 feet. In the eastern part of T. 9, R. 4, Aroostook County, a two-sided ridge extends for about 3 miles along the east side of the Alegwanus or Blackwater River, a stream which flows northwesterly into the Aroostook. The ridge has rather steep lateral slopes, and is from 10 to 30 feet high. On the surface it appears to be composed of till, but on digging down 2 or 3 feet, true water-washed gravel is revealed. The pebbles are only slightly rounded, yet the finest débris has been plainly removed by gentle currents, and therefore the deposit is seen to be, not unmodified till, but the residue after the action of water has removed the finest portion of the till and has rounded and polished the larger fragments a very little. The ridge is here composed of fragments of sedimentary rocks, which readily weather near the surface of the ground, so as to lose their waterworn surfaces and to resemble closely the stones of the upper layers of till. After an apparent gap in the system of more than a mile, another ridge is found, extending eastward, which is said to reach the northwest corner of Littleton, where the system takes a more southerly course to Carys Mills, a short distance west of Houlton Village. In this part of its course it several times crosses low divides, and thus passes from one valley into another; and there are several gaps in the system.

Prof. C. H. Hitchcock writes concerning this osar as follows:[1] "A short distance west of Houlton the same horseback reappears, being in one place 90 feet high. The material of the ridge is sand, gravel, and bowlders, indistinctly stratified. The sand of this horseback is black, and there is no similar sand anywhere else in the county south of Houlton."

On the same page is given a figure showing the internal structure of the "horsebacks." Occasionally I have observed sections such as that given in Professor Hitchcock's figure, but usually the osars have a more arched stratification in the cross section. Not far north of Carys Mills the osar extends into a broad ridge or plain, with some reticulated ridges as outlets. This great abundance of gravel is found at the southern end of a long slope, which, for 25 miles, has an average fall of about 20 feet per mile. The pebbles and cobbles are very well rounded at this point, and a much larger proportion of them are granitic than at the northern end of the system. From Carys Mills the osar continues as a large ridge for several miles,

[1] Preliminary report upon the natural history and geology of the State of Maine, p. 273, 1861.

through Hodgdon, following the south branch of the Meduxnikeag River. In Cary Plantation the system turns southeastward, crosses to the east of the Calais-Houlton road, and continues southward for several miles in a valley nearly parallel with that road. In this part of its course it crosses a divide at least 75 feet above Carys Mills, and for several miles in Hodgdon it consists of a series of low bars separated by short gaps, in part due to erosion. Near the north line of Orient the New Limerick branch unites with this series to form quite a large and broad ridge, which is continuous till it extends as a long sloping point out into the north end of Grand (St. Croix) Lake. The Calais-Houlton road is built for several miles on the top of this ridge. Excavations show much sand and gravel, with some coarser matter, rounded cobbles, bowlderets, and even a few water-polished bowlders. In several places the lines of stratification were observed to dip quite steeply toward the south. According to the testimony of numerous lumbermen and others, a two-sided ridge of gravel extends for long distances on the bottom of Grand Lake. In warping rafts of logs down the lake, the lumbermen are liable to drop anchor in the yielding gravel; they are then obliged to take up the anchor and drop it in the deeper water on each side of the ridge, where they report finding a firm "clay bottom." It is uncertain whether this is sedimentary clay or till. The osar appears on the land at several of the capes of Grand Lake, and disappears beneath the water while crossing the intervening bays. Thus at Birch Point, Weston, the osar runs out as a long bar for a considerable distance into the lake; and, according to report, the small islands, "Billy and Ann," are composed of rounded gravel. If so, they are parts of the osar which rise above the lake.

The outlet of Grand Lake is from the eastern side, about 5 miles from the south end of the lake. The portion of the lake south of the outlet is called the "Arm of Grand Lake," and is inclosed between two north-and-south ranges of hills. Going south we find these hills approaching each other, so that at the south end of the arm they are separated by a narrow V-shaped valley, whose sides rise steeply upward several hundred feet. One of these hills is called Spruce Mountain. The osar gravel is found for several miles along the west side of the Arm of the Lake. At the south end of the lake it forms a distinct two-sided ridge, which has been excavated for road gravel. It is thus revealed that near the axis of the ridge finely stratified sand and gravel dips 21 degrees in a nearly south direction,

and this over an exposure 40 feet long and 6 feet high. A small brook flows northward into the lake at this point, but it is only about 1 mile in length, and could never carry much sediment into the lake; still less could it give its sediments a southward dip. The gravel on the beach of the lake, as well as the small amount of gravel brought down by this brook, has very nearly the till shape, and is nowhere well rounded like the gravel of the two-sided ridge at the foot of the lake. It thus becomes evident that this ridge is the osar. A short distance south of the foot of the lake the ridge becomes low, and the stratified sand and gravel are almost covered from sight by a pellmell mass resembling a stony till containing numerous till bowlders. But for road excavations one would hardly suspect the existence of this hidden gravel.

This till-like mass might be accounted for in several ways. (1) It might be due to a landslide; but I could discover no place bare of till, or any other sign of a landslip, at least on the lower slopes of the hills. (2) It might be due to ice floes stranded at a time when the lake stood about 10 or 15 feet higher than at present. Nowhere else on the shore of the lake did I discover such proofs of the water having stood at a higher level. It must be admitted, however, that the shape of the Arm of the Lake is very well adapted to cause a convergence of floes to this place. (3) The till may have tumbled down upon the sediment of the glacial stream, either into a subglacial tunnel or from the sides into a superficial channel.

My brief visit did not permit me to explore the shore of the lake very far. The gravel ridge becomes less conspicuous as we go southward from the lake, and disappears within three-fourths of a mile, at an elevation of not more than 30 feet above the lake. The ground continues to rise very gently for somewhat more than a mile, and then slopes southward down the valley of the east branch of the Tomah Stream. The highest part of this divide is hardly more than 50 feet higher than the lake. It is certain that an osar stream flowed southward from the Arm of Grand Lake through this very low pass, where it was for 2 miles or more hemmed in by high hills on each side. But the gravel is rather fine and the ridge is not large. This indicates a stream of moderate velocity and size. The course of this stream must have been somewhere to the south or southeast. Its most natural route lay down the valley of the east branch of Tomah Stream,

which crosses the Maine Central Railroad a short distance east of Tomah station, but for 5 or more miles I have no note of any glacial gravels. The country is a wilderness difficult to traverse, and even large ridges might easily escape observation. The difficulty of the search is increased by the fact that near the lake the gravel is covered by considerable till, and this condition may continue for some miles southward. And if the ridge is not large at the south end of the Arm of the Lake, on an up slope, it should be expected that on a southward or down slope of 15 or more feet per mile the stream would sweep its channel clear of all except the coarsest matter. It is thus seen that although glacial gravels could not be found for a considerable distance, this fact does not, under the circumstances, prove that the glacial stream did not flow down this valley. Careful search and inquiry failed to show any line of gravels reaching from the foot of Grand Lake to Lambert Lake or other point southwestward.

A mile or two south of Tomah station the two branches of Tomah Stream unite, and from this point of junction an extensive series of reticulated ridges and broad plains of sand and gravel are found in the valley of the main stream, extending to near the mouth of Little Tomah Stream in Codyville. These large plains demand the assumption of large glacial streams. The Smyrna-Danforth osar river flowed down the valley of the west branch of Tomah Stream. This was a larger glacial river than that which flowed south from Grand Lake, and while it was competent to have brought down the large plains of the Tomah Valley, yet the probable history of these plains is as follows: The two glacial rivers, one from the direction of Houlton and Grand Lake, the other from Danforth, united near where the two branches of Tomah Stream now unite, and together produced the sand and gravel plains extending into Codyville. The elevation of Tomah station is 370 feet, and I estimate the elevation of the plains north of Codyville to be more than 200 feet. The southern part of these plains may therefore be a marine delta.

From near the mouth of Little Tomah Stream the ridge varies from 10 to 25 feet in height. Its lateral slopes are gentle, thus making it quite broad for its height. The ridge crosses the Schoodic River at an elevation of 165 feet, and continues southward near the line between Baileyville and Princeton. In the southern part of Baileyville and in Alexander the system becomes broken by several gaps while following a rather low pass,

and runs into the north end of Meddybemps Lake at an elevation of 150 feet.[1]

The southwestern angle of the broad part of this lake is bordered by a large peat-covered heath, in the midst of which is a rounded hummock, said to be composed of sand and gravel. It rises about 30 feet above the peat and is in the line of the gravels; it is probably a part of the system. From near the south end of this heath a plain of sand and gravel extends southward along the eastern base of a hill which lies parallel with the lake and outlet, and about 1 mile west of them. On the north this plain shows mounds and low ridges of gravel rising above the surrounding plains of gravel. It is here less than one-fourth of a mile in breadth. Going southward the material becomes finer, the top is more level, and it expands laterally, so as to be nearly a mile broad at the point where it is crossed by the road leading west from Meddybemps Post-Office. Both the east and west sides of the plain here rise steeply above the sedimentary clay and sandy clay which flank it, as a narrow border, toward the north at the angle of the lake, but toward the south it becomes broader, so as to cover the whole valley not far south of Meddybemps Village. Near there the gravel plain becomes finer by degrees and rises not so far above the clay, and soon they merge into each other and extend as a sheet of marine clay all the way to the sea. The plain lying west of the village is thus seen to have the gradations of sediments characteristic of the delta when examined lengthwise. Why, then, did it not spread outward across the whole valley? From the village northward the gravel plain lies about 40 feet above the outlet of the lake and the river. Had the ice melted over the whole valley, the gravel plain and its bordering clay would have spread across the valley and along the shores of the lake, whereas no clay to speak of appears at the lake. This can be accounted for only on the hypothesis that at the time the gravel plain west of the village was being deposited ice still covered the locality now occupied by the eastern part of the lake and the valley of Dennys River and as far south as where the gravel and sand delta merge into the marine clay. Here was the ice front, and to the south lay the open sea, where the finer sediments were spread far and wide. To the north lay a broad channel in the ice. The elevation of the place where the sea margin then stood was

[1] This lake is estimated at 250 feet in Walter Wells's Water Power of Maine, p. 129, Augusta, 1869. This was a typographical error. The estimate sent to Mr. Wells by P. E. Vose, esq., of Dennysville, was 150 feet.

140 to 150 feet. The elevation of the sea was certainly as much as this, and it may have stood higher, possibly up to its highest level, about 225 feet.

The local history was probably about as follows: The original narrow osar channel in the ice became broadened, and in this broad channel the gravel-and-sand delta was deposited. The channel broadened recessively northward, and thus the time came when the coarser sediments brought from the north were deposited at points considerably north of Meddybemps Village, perhaps as far as the north end of the lake or in the lake. The finer sediments were at this time brought down farther, and formed the clays bordering the sand plain opposite the village and southward. The time must have come when the ice all melted over the valley where the lake now is, but by this time the sea had advanced up the valleys of the St. Croix, the Schoodic, and the Tomah, so that this great glacial river poured into the sea near Codyville, many miles northward. The supply of sediment was thus cut off from the north, so that when the open sea at last prevailed over all the upper valley of Dennys River and Meddybemps Lake, but very little clay was deposited, except where the old river channel had been.

If, during any of the time the delta west of the village was being formed, the sea stood above the level of about 140 to 150 feet, the channel of the glacial river was in fact a bay within the ice, where the sea met the fresh water. During the time of the summer flood of the glacial river the muddy fresh water would fill all this broad channel or bay, but in winter, when the glacial waters were scanty, it would be a sort of estuary inclosed between walls of ice. As the high tides of that region prevailed, the salt water would naturally extend for some distance up the glacial channel, just as it does up the rivers of to-day. (This and all other descriptions should be read with the map in hand.)

Southward from Meddybemps the series extends along the west side of Dennys River, through Dennysville, and for a short distance into Edmunds. It is discontinuous all the way, and becomes more so toward the south, until in Edmunds the ridges are only one-third of a mile or less in length and not more than one-eighth of a mile in breadth.

In the southern part of Edmunds and in Trescott are numerous gravel beds, which are found on the slopes of hills having a southward or eastward exposure. I formerly supposed them to be connections of this gravel

system, but I have since examined several which proved to be beach gravel. I therefore provisionally mark the end of this system in the northern part of Edmunds. Length from Edmunds to T. 9, R. 4, 115 miles.[1]

NEW LIMERICK-AMITY BRANCH.

This branch extends from near the center of the town of New Limerick through Linneus, Cary Plantation, and Amity, and joins the Houlton branch near the north line of Orient. Toward the north this osar is quite continuous and prominent, with conspicuous meanderings. Southward it is somewhat interrupted by short gaps. It traverses a rolling plain, and several times passes from one valley to another over a low divide. South of where this and the Houlton branch unite, the ridge is larger and more continuous than is either branch for several miles north of their junction. The average size of this branch is about as large as the Houlton branch, though it does not expand to so great size as the latter at Carys Mills. Length, about 20 miles.

SMYRNA-DANFORTH BRANCH.

Measured by the amount of gravel which the Smyrna-Danforth glacial river deposited, it deserves to be classed as the main tributary and the Houlton River as a branch. According to this nomenclature, the system ought to be known as the Smyrna-Dennysville system. But, on the whole, there are such advantages in considering the longer tributary as the main river that the Houlton branch has been considered the main one, although it is by no means certain that a careful exploration will not show the Smyrna branch to be longer than that which passes near Houlton.

The other connections of the Smyrna series are uncertain. A ridge of gravel, probably glacial, is reported as being found a short distance south of St. Croix Lake. The divide between the Masardis River, flowing northward, and the east branch of the Mattawamkeag is so level that the waters of one stream have been diverted into the other by a ditch. The valleys of these two streams thus form a continuous valley with slopes favorable for a long osar system to extend from the vicinity of Masardis south and eastward to Smyrna. I crossed the Masardis River in the No. 9 townships and explored its valley for several miles, but no gravels were found near

[1] I am indebted to Mr. John C. Carpenter, of Houlton, for much valuable information relating to the gravels of Aroostook County.

the river. The forest is so dense, however, that one could easily miss a gravel system unless following it lengthwise. In T. 9, R. 5, several short ridges of true glacial gravel are found a few miles west of the Masardis River, and it is not impossible that they are part of a series extending past St. Croix Lake to Smyrna.

From near Smyrna Mills the gravel series takes the form of a nearly continuous and rather flat-topped plain of sand and gravel following the east branch of the Mattawamkeag to Haynesville. In places the plain, before being eroded by the stream, extended across the whole of the rather narrow valley. The river sometimes flows at one side of the gravel plain, but more often it has eroded the central part, thus being bordered on each side by terraces of erosion. Sometimes it has cut out two channels, leaving a central ridge uneroded. It will thus be seen that the alluvium contained in the narrower parts of the valley presents the external features of ordinary valley drift. The material of this alluvial plain is in general composed of sand and fine gravel, but with a mixture of larger pebbles, cobbles, and some bowlderets. The stones are much rounder than those found in the beds of the other streams of this region, and must have been subjected to much greater attrition. In some places the valley broadens considerably. Here the gravel plain does not widen correspondingly, so as to fill the whole valley, but sometimes is bordered on the side away from the river by a steep bank downward, which, so far as I could determine, is not due to erosion. The alluvial plain of highly rounded matter is thus shown to be of glacial origin, and not a plain of ordinary river drift. Its breadth varies from a few rods to about one-fourth of a mile. This plain is a good instance of what I have elsewhere named the osar-plain, or broad osar.

Not far north of Haynesville this series is joined by another series, from Island Falls. At Haynesville the gravel forms a single plain about one-eighth of a mile broad, which shows that the two tributary glacial rivers here flowed as one. The two branches of the Mattawamkeag River also unite not far north of Haynesville to form the main river. The river here flows in a broad and quite level valley. For 4 miles southeast of Haynesville an osar-plain of sand and gravel extends along the axis of the valley, bordered by a plain of horizontally stratified sand and silt, one-half mile or more wide. In many places this sand has blown into low dunes.

Excavations not in the dunes show the sand overlying the till and till bowlders. This bordering sand plain has the external features of valley drift. At the great bend, or "oxbow," of the Mattawamkeag the river makes an abrupt turn from a southeast to a southwest course. The osar-plain here leaves the river valley and goes on southward through Weston to Danforth. The character of the alluvium of the Mattawamkeag Valley here changes. Below this point the river shows an alternation of long reaches of dead water separated by short rapids or falls. Along the level parts of the valley the river drift consists of clay and silt, with sand, subangular coarse gravel, and even bowlderets and bowlders at the rapids. The rapids are found at places where the ice-sheet left deep masses of till spread across the valley. The only gravel found in the valley below the oxbow is the result of the river's eroding the till, and the shapes of the stones are very different from those of the osar-plain in Haynesville. True, some rounded stones can be found in the bed of the river, or as a part of the lowest terrace, for some miles below the oxbow, but they were probably washed down from the osar-plain, although I could not prove them to be contemporaneous with it or with any of the higher terraces. The till ridges left across the valley of the Mattawamkeag must originally have caused a series of lakes to form in the valley directly after the melting of the ice. The broad sand plain found bordering the osar-plain proper in Haynesville might thus be a lake delta if a till barrier high enough to form a lake at that level existed. Thus far I have found no barrier high enough for the purpose. Concerning the broad plains of the Mattawamkeag Valley extending from Haynesville to the oxbow, it is safe to conclude, first, that the sand-and-gravel plain near the center of the valley is a true osar-plain; second, that the bordering plain of sand was probably deposited in a still broader channel within the ice, making it in fact a glacial lake; yet there is nothing in its form to disprove the hypothesis that it was formed in an ordinary lake if a till barrier (now cut through by the river) of sufficient height can be found; or it may possibly be an overwash or frontal plain deposited when the ice had retreated a little north of Haynesville.

A plain of sand and fine gravel extends from the great bend of the Mattawamkeag southward through Weston. It is one-eighth of a mile or more wide, and ascends the valley of a small brook which flows northward. The stream has excavated numerous terraces of erosion in the osar-plain.

The plain is quite continuous on the northern slope until it reaches a height of 75 or 100 feet above the Mattawamkeag River. It then is somewhat discontinuous while passing over a divide, and then it takes the form of an osar-ridge from 15 to 40 feet high, containing much coarse matter, very round cobbles, and some bowlderets. The ridge continues southward for several miles, and then, making a beautiful curve to the left, it turns southeastward and crosses the Baskahegan Stream about 1 mile north from Danforth Village. It follows the western bank of this stream through Danforth Village, and then, leaving the Baskahegan Valley, which lay directly before it, it turns more to the eastward along the valley of Crooked Brook. It goes up this valley and over a divide near Forest station, and thence follows the valley of the west branch of Tomah Stream to its junction with the Houlton osar, not far south of Tomah station. Between Danforth and Tomah stations of the Maine Central Railroad, this great gravel system follows the same valley or pass as that followed by the railway. About one-fourth of a mile northeast of Danforth Village there is a small hillside kame at nearly right angles to the main osar. It slopes rather steeply down a hill for nearly one-eighth of a mile and disappears. It was evidently deposited by a small lateral tributary of the main glacial river. The gravel comes to an end within one-fourth of a mile from the main osar. Near Danforth the gravel is fine enough to serve as railroad ballast. Going eastward up the slope, we find the material becoming coarser, and at the top of the divide at Forest station the ridge consists almost wholly of large pebbles, cobbles, and bowlderets. East of this point the valley of the west branch of the Tomah Stream has a fall of about 30 feet per mile southeastward, and for about 3 miles east of the col the gravels are very scanty and difficult to trace. Apparently on this steep down slope the force of the glacial river was such as to sweep before it all but the larger bowlderets and bowlders. The valley is one of the dreariest bowlder fields in the State. The rounded gravel becomes easily traceable at a point about west of Tomah station, and so continues down the valley, soon expanding into the plains north of Codyville, as before described. To these plains this tributary probably contributed much more material than the Houlton branch.

The most noteworthy features of this important gravel series are the following: For a considerable part of its course it takes the form of a plain

with rather level top in the cross section. When traversing narrow valleys, this plain appears like valley drift, but is distinguishable from it by the very round shape of the pebbles, by its greater size than the valley drift of the region, by the larger size of its stones, by the fact that it does not always spread laterally to fill the valleys in which it is situated, and, still more conclusively, by its going up and over hills. While crossing the lower ground the material is rather fine, approaching the top of hills it becomes coarser, and on a steep down slope it is scanty or absent for a mile or more. In Haynesville the osar-plain proper is flanked by sand plains. Apparently the osar was first deposited in a channel one-eighth to one-fourth of a mile wide. This was situated north of a hill 75 or 100 feet high, and the water must have been at least of that depth in order to flow southward over the hill. Subsequently this channel was widened by lateral melting of the ice, until it became one-half mile or more wide and approximated the condition of a lake 75 or more feet deep. In this a plain of fine sand was deposited at the flanks of the central plain of gravel. This plain has subsequently been somewhat modified by the winds and by the floods of the Mattawamkeag River, and to that extent is valley drift. No 30 miles of any other osar of eastern Maine at such a distance from the coast has so great a cubic content as this series for the 30 miles north of Danforth.

Length, about 45 miles.

ISLAND FALLS BRANCH.

A nearly continuous osar extends from Merrill Plantation southward near the line between Dyer Brook and Hersey to the village of Island Falls, and thence southeastward along the western shore of Mattawamkeag Lake and the west branch of the Mattawamkeag River, and joins the Smyrna branch a short distance north of Haynesville. In some places, especially toward the south, the gravel widens so as to approach the form of the flat-topped osar-plain, but for most of the distance it takes the form of a two-sided ridge with arched cross section.

Since the Smyrna and the Island Falls tributaries are near each other and are at equal distances from the sea, and penetrate regions having similar rocks and topography, they throw light on each other's origin. The pebbles are no rounder in the osar than in the osar-plain. The stones in both are

largely made up of granite, slates, and the harder sedimentary rocks, and in both are much rounder than the stones of the streams of this region not in the lines here indicated for the glacial gravels. These points had to be carefully studied before it became evident that the plain of rounded gravel situated in the valley of the east branch of the Mattawamkeag between Smyrna and Haynesville, where the slope of the river coincided with that of the glacial stream, was really an osar-plain and not ordinary valley drift.

LOCAL KAMES IN MARION.

A short kame is situated on the east side of Rocky Brook in the northern part of Marion. Another is found near the southeast angle of the northern division of Gardners Lake. It is a narrow ridge rising 15 to 20 feet above the marine clay, and is about half a mile long from east to west. It has the direction of a terminal moraine, but appears to consist wholly of water-washed gravel.

On the western side of the long point of land which projects from the eastern shore of Gardners Lake, so far as almost to divide the lake into two separate lakes, is a broad ridge or plain of rounded gravel and cobbles. It has been eroded by the waves on its western side so as to form a prominent beach cliff.

These gravel deposits of Marion do not appear to have been formed by a single glacial stream, and therefore they are not classed as a system. There are many old beaches in Marion on hills that would be exposed to the surf while the sea stood at higher level than now.

EAST MACHIAS SYSTEM.

This system begins abruptly in T. 18 near where the road from East Machias to Crawford is intersected by the road leading west from Dennysville. The gravel here takes the form of a single two-sided ridge 10 to 30 feet high. Going southward we here and there find two or more ridges inclosing kettleholes, and then the gravel soon becomes discontinuous. Still farther south the gaps become longer and the gravel ridges shorter, until the system ends as a series of small rounded hummocks or cones, separated by intervals of from one-eighth to one-half a mile. The last of the gravel hillocks which I could find was a short distance south of East Machias Village. South of this point were a low pass and a plain covered by marine clay. Although the system ends several miles north of the open

sea, yet the end is only a few feet above tide water. Toward the north the ridges of this system are broad and massive, with gentle side slopes. The stones are well rounded throughout the whole length of the system, and among them are a multitude of bowlderets and bowlders, up to 3 feet in diameter. It lies on a southern slope favorable to the flow of the water until the ice was nearly all melted. Its course is quite free from meanders. The elevation of the northern end is not precisely known, but the glacial stream, at the time the sea stood at 230 feet, would flow into it not far from the north end of the system. This is where the broad, almost plain-like, ridges, inclosing kettleholes, are found. The large size of the bowlders in this system makes it quite probable that this was the work of a subglacial river.

Length, about 10 miles.

CRAWFORD SYSTEM.

A short deposit of glacial gravel is found about 2 miles north of Crawford Church, in a low valley leading south from Crawford Lake. This valley contains a small brook which flows northward and has partially eroded the kame, though the brook is but little more than half a mile long. A valley leads over a low divide from this point southward, but no gravels have been found near the height of the pass. Directly in front of this pass, toward the south, is a plain of sand and gravel about one-fourth of a mile in diameter. It is situated near the northwestern angle of Love Lake, in the southern part of Crawford. The plain is rather level on the top, and the material is finer toward the south. It rises steeply above the surrounding till to a height of from 6 to 15 feet. It thus has every appearance of a delta. Its elevation above the sea is probably from 250 to 300 feet. No marine clay appears below this point, and I regard the plain as having been deposited in a small glacial lake. Near the southwestern angle of Love Lake there is another and longer gravel plain, and from that point a somewhat discontinuous two-sided ridge extends southward into Ts. 19 and 20. It is for several miles nearly parallel with the outlet of Love Lake. At the road from Crawford to East Machias it leaves this valley, and the road is made upon it for about 1 mile south, when the system bends southwestward. It is said to end in a level sand-and-gravel plain near the East Machias River, not far south of Round Lake.

The map shows that this gravel series is nearly in the direction of the East Machias system prolonged northward. Several small ridges of subangular glacial gravel are found intermediate between the two systems. They are in T. 18, near the road from Crawford to East Machias. They are found on the western slopes of the rather high hills which border the valley of the East Machias River on the east. Their course is westward down the hills, and I regard them as short hillside kames deposited by small glacial streams which were either lateral tributaries of a large glacial stream in the valley or flowed into the sea at the time it extended far north in the valley of the East Machias River. This valley is very inaccessible, and my exploration was confined to the region lying near the road from East Machias to Crawford.

According to my present information, it would appear that the glacial and postglacial history of the broad and plain-like valley of the East Machias River is about as follows:

None of the longer glacial rivers flowed through this valley, the drainage of the glacier to the north being either carried off eastward by the Dennysville system or westward down the valley of the Machias River. The East Machias system of glacial gravels was wholly deposited before the melting of the ice, unless the enlargement of the system before described as being found about 2 miles from its northern extremity prove to be a marine delta. At the time the ocean stood at the contour of 225 feet, an arm of the sea 3 to 5 miles broad extended northward up this valley to Crawford, and probably was continuous with the bay of salt water which at that time extended up the valleys of the St. Croix and Schoodic rivers to Princeton. The Crawford-Love Lake system was deposited later than the East Machias system, at a time when the ice had receded so far northward that all the valley from Round Lake southward was covered by the sea. Occasional gravel deposits have been reported in the valley near the river, but the descriptions make it uncertain whether they are glacial gravel or till. A ridge of true glacial gravel crosses the Air Line road from Calais to Bangor in the southwestern part of Crawford. It is near the East Machias River, and is about a mile long. Another short and rather broad ridge is found not far to the south of it. This series ought to end at the south in a delta, but I have not been able to find one, unless it be the shorter ridge just mentioned. This short series is evidently an incident in

the retreat of the ice northward, and the glacial stream which deposited it was soon terminated by flowing into the sea.

WILDERNESS REGION NORTH OF COLUMBIA, COLUMBIA FALLS, AND JONESBORO.

We now approach a region very difficult to investigate. The gravel deposits situated in it are vast, being equaled only by the great plains of the southwestern part of the State. The western part of Washington County and the eastern part of Hancock County are mostly wooded. There are many swamps impassable in summer or penetrated with difficulty. There are only four continuous east-and-west roads crossing the great region lying south of the railroad from Mattawamkeag to Vanceboro. These roads I have traversed, and have penetrated the wilderness in several other directions. In addition, I have derived much information from lumbermen and explorers and from three experienced land surveyors—Mr. F. I. Campbell, of Cherryfield; Mr. J. R. Buckman, of Columbia Falls, and Mr. H. R. Taylor, of Machias. I am indebted to Mr. Taylor for quite an elaborate map of this region. As a result of my observations and inquiries, it is hoped that the map (Pl. LI) contains all the larger systems of glacial gravel, but as to the details of their courses much remains to be done.

The sea at one time extended northward up the Machias Valley to the Air Line road from Calais to Bangor, in Wesley, and probably a few miles farther. Machias Bay was then a pretty broad body of water, in places 10 or more miles broad. This gave great force to the waves, and sea beaches are found as far north as Wesley. The necessity of distinguishing these beach gravels from the glacial gravels in this wooded country, where the whole is often disguised by marine clays and the peats of swamps, complicates considerably the problem of the drift of this valley. The till is very heterogeneous in its composition, fragments of slates, schists, and granite being rather indiscriminately mixed. The granite is partly derived from local bosses of that rock which rise in the midst of the slates and schists, but chiefly from the great area of granite which extends from Orland to Aurora and thence northeastward past the region of the great Schoodic Lakes. Heaps and trains of granite bowlders abound. Many of the granite stones of the till are so rounded by the glacial attrition that it often requires close study to distinguish the till from a slightly water-washed

glacial gravel. I have in the past been obliged to change my views concerning some of these formations, yet, in spite of all the difficulties, enough is known to mark the region as a very interesting one. The map shows several of the longer osar systems of the State converging toward an area 10 or 15 miles broad (from east to west) lying in Columbia, Columbia Falls, and Jonesboro. Over a very large area there is a convergence of the glacial striæ toward a north-and-south line passing through the same place. At several other places on the coast there are converging striæ, but they are shown in small areas where only the scratches last made converge. It thus appears that in these cases the convergence took place only during the final retreat of the ice. But in the Columbia-Jonesboro region all the scratches converge, the later ones more than the earlier ones. It is thus shown that, like the Greenland glaciers of to-day, the ice-sheet did not advance with an equal rate of flow in all parts, but that the snow fields of the interior parts of the State were discharged more rapidly along certain belts, which made them practically glaciers of limited breadth, confluent, however, with more slowly moving ice. A stream of ice about 10 miles wide here served as the outlet of an area which broadened toward the north to 30 and perhaps 50 miles, and doubtless its rate of flow was correspondingly rapid. An observer off the coast during the Ice period would have seen a greater number of icebergs from opposite this place than elsewhere. It is difficult to account for the convergence to so narrow limits by the surface features of the land. The area between the Big Tunk range of hills lying west of Cherryfield and the hills of Marshfield is a gently rolling plain, with only here and there a hill rising more than 100 feet. It would be very natural for the ice to be wedged in between these ranges of hills, a distance of 25 miles. Instead, the ice abandoned the level valley of the Narraguagus River, which extends for 15 miles east of the Big Tunk Mountain, and crowded eastward toward Columbia. So also the deflection westward extended as far east as Marion, 10 miles east of the Marshfield Hills. The central line toward which the striæ converge passes near Jonesboro Village, and the lines of striation, if prolonged, would meet at a point in the sea several miles south of the most projecting point of the coast. I have not been able to determine whether there is any deep channel of the sea south of Jonesboro or other features causing this remarkable convergence of glacial flow. It was certainly determined by causes to a

considerable extent independent of the surface features of the present land, perhaps by the outline of the ice front in the sea off the coast.

WESLEY-NORTHFIELD SYSTEM.

Wesley Post-Office is situated on a range of hills about 200 feet high. Along the western base of this hill is a rather low north-and-south valley, in which lies a series of ridges of glacial gravel. The system may have connections northward toward Chain Lake, but I have traced it unmistakably only to a point about half a mile southwest of Wesley Post-Office. Beds of apparently water-washed gravel are found about 2 miles west of Wesley, but it is uncertain how much of them is glacial gravel and how much is beach gravel. In view of the doubt, I omit them from the map. The series above described as beginning near Wesley extends southward in a nearly straight line to Lower Seavey Lake, where it turns southwestward and soon spreads into a series of reticulated ridges inclosing kettleholes. Going southwestward the ridges become broader and the kettleholes more shallow, and it soon appears to be a marine delta-plain. This series is said to connect with the Old Stream series in Centerville and Whitneyville.

Length, about 15 miles.

TOPSFIELD-OLD STREAM SYSTEM.

This important osar system appears to begin not far north of Musquash Lake, in Topsfield. At the road from Topsfield west to Springfield the gravel takes the form of a low terrace on the west side of the outlet of the lake. It consists of well-rounded gravel, and is distinguished from valley drift partly by the shape of the stones and partly by appearing on one side of the valley with no corresponding terrace on the other side; and often it takes the form of a two-sided ridge while following the valley of Musquash Stream. It is somewhat discontinuous, and for part of its course takes the form of an osar-plain that once extended across the valley, but is now deeply eroded into terraces by the stream. The material is rather fine, and the size of the deposit is in general not very large. In the southern part of the valley of Musquash Stream it becomes a ridge 20 to 40 feet high, with moderately steep lateral slopes. For several miles in the midst of a low level region it rises above the swamps like a railroad grading. The matter here is coarser, and many cobbles and large pebbles appear, all well rounded. A short distance west of where Musquash Stream empties

into Big Lake, there is a thin sheet of gravel on a gentle slope rising but a few feet above the lake. This gravel lies a full half mile south of the osar. The stones are distinctly water-polished, though differing little from tillstones in shape. This deposit is an old beach, either marine or lacustral.

The osar leaves the Musquash Valley about a mile north of Big Lake and takes a nearly straight course southwestward. It is easily traceable for several miles along the northwestern shore of Big Lake, often forming the beach. The gravel reappears on the southwestern shore of the lake, between Little River and Little Musquash Stream, and continues its southwestward course for several miles along the valley of Little River. It then crosses a low divide and extends for many miles southward along Old Stream, expanding into extensive plains of reticulated ridges near the Old Stream Lakes. The sand and gravel plains extend to the junction of this stream with the Machias River, and toward the south are quite level on the top and present the appearance of a marine delta-plain.

A series of discontinuous and rather flat-topped plains or broad ridges extends from near Masons Bay, Jonesboro, northward into Centerville. They appear to be marine delta-plains, deposited not in the open sea but in bays receding backward into the ice. They are probably a continuation of the Topsfield-Old Stream system.

The extensive marsh region penetrated by this gravel system is underlain in considerable part by sedimentary clay. Big Lake is 189 feet above high tide. Hence, when the sea stood at 225 feet, a sheet of salt water must have extended up the valley of Schoodic (also called Kennebasis) River to a point a short distance west of Big Lake, and at an elevation of about 36 feet above the present level of the lake. The region around the lake, especially toward the south and southwest, is so low that a body of water of that elevation would be very much larger than the present lake. The divide between Little River and Old Stream is low, but probably not low enough for an arm of the sea to have extended from Big Lake down the Old Stream and Machias valleys. The region overgrown with pine near Clifford Lake, which I formerly supposed was covered with glacial gravel, now appears to owe its sand and gravel to the action of the waves; they are probably beaches of that period. There is an enlargement of the osar near the northwestern angle of Big Lake. Part of this appears to be a small delta. If so, the history of the Topsfield-Old Stream glacial river

appears to be as follows: First, the main glacial river flowed on to the sea near Jonesboro. As the ice retreated, a series of small deltas were formed in bays or lakes within the ice. The great delta-plain in T. 25 and in Wesley was formed when the ice had retreated so far up the Machias Valley that the glacial river carried its sediments beyond the ice front into the open sea. Finally, when the sea stood at about 230 feet, the ice had melted so far to the northward that a bay of salt water occupied the basin of Big Lake. The glacial river, now greatly reduced in size, poured into the sea near the northwestern angle of Big Lake, and perhaps subsequently at another point a few miles northward in the Musquash Valley. These apparent deltas near Big Lake may have been deposited in purely glacial lakes, yet they bear a suggestive relation to the old sea-level in the basin of the lake.

GRAND LAKE OSAR.

At the foot of the outlet of Grand (Schoodic) Lake a well-defined osar extends northward into the lake and can be seen for some distance on the floor of the lake. The stones are so well rounded that it seems probable the series extends north or northwest of this point, perhaps to Oxbrook Lake. The ridge extends southward from Grand Lake Stream and joins the main system in the valley of Little River. Not far from the lake the ridge consists of very coarse matter. The large size of the bowlderets and bowlders makes it probable that the ridge was deposited by a subglacial stream. The upper Schoodic Lakes lie in the midst of a granite region which has contributed a great number of stones and bowlders to the drift. The vast quantities of granitic drift contained in the great gravel plains of Hancock and Washington counties came chiefly from the long outcrop of granite which extends from Orland on Penobscot Bay with but few interruptions through New Brunswick to Chaleur Bay.

FARM COVE GRAVELS.

Farm Cove is a deeply reentering bay on the south shore of Grand Lake. From the head of the cove a low pass extends southeastward, bordered by high hills. The highest point of the pass rises but a few feet above Grand Lake, and within less than a mile from the lake a branch of Little River takes its origin and flows southeastward. Water-washed gravel is reported in this valley. The present outlet of Grand Lake is cut through

a mass of till, and it is possible that before the barrier was eroded the lake stood at a high enough level for the waters to discharge from Farm Cove southeastward. If so, these gravels are partly, perhaps wholly, valley drift. I have not personally explored this series. It is provisionally included among the glacial gravels.

BANCROFT-GRAND LAKE SYSTEM.

An osar crosses the Maine Central Railroad about a mile west of Bancroft station. The gravel is somewhat rounded, but not enough to indicate that the ridge extends very far to the north. It has not been explored in that direction, and probably extends only a few miles. With numerous gaps the gravel takes a southeast course across the valley of the Mattawamkeag River, thence over a low divide and obliquely across the valley of Hawkins Brook, then over another low pass into the valley of Hot Brook. It then turns more nearly southward, and near the Hot Brook Lakes it expands into a plain about one-third of a mile wide. Part of this plain has the external appearance of a delta, and was probably deposited in a small glacial lake, such as would naturally form on a north slope. Thence the gravel system goes south along the valley of the eastern branch of Hot Brook. At the road from Danforth to Prentiss the gravel takes the form of a low osar-plain in the bottom of the valley. This has been eroded by the stream into terraces, so as to appear like valley drift, but the stones are much more rounded than the till gravel which appears in the beds of small brooks in that part of the State. Crossing a divide said to be much less than 200 feet above the Hot Brook Lakes, the gravels turn southeastward over a rolling region to near the northwestern angle of Baskahegan Lake. In this part of its course the gravel is somewhat interrupted. It next turns southwestward through Kossuth to Pleasant Lake, crossing the valleys of several streams and as many low divides. In this section it is a two-sided ridge, and is not quite continuous. It would be contrary to general analogy for this long osar stream to have ended so far from the sea as Junior Lake. Rounded gravel, in the form of ridges and terraces, is reported along Junior and Scraggly lakes, which I infer are part of this system. They appear only at intervals, and probably a large part of the gravel is beneath the water. The gravels are well developed along the western shore of Grand Lake, and thence they

continue southward along Pocumpus and Wabos (or Wabosses) lakes, to near the south end of Machias Third Lake. The accounts as to its course from this point south are conflicting. According to some accounts the gravel continues southeastward and unites with the Topsfield system near the head of Old Stream; according to others the gravel is nearly continuous down the Machias Valley, part of the way keeping back from the river. On general grounds the latter appears to be the more probable course of this large glacial river, since the great "Mont Eagle plains" and the "Raceground" demand a large and long river as their origin. But whatever doubts attach to the course of this system in the vicinity of Machias Second Lake, there is no doubt that a system of gravels extends from Machias First Lake southward along the west side of the Machias River, expanding into a broad series of plains in T. 30, known to the deer hunters as the "Raceground." The part of these plains near the Air Line road (Calais to Bangor) is very level and is a delta-plain. Sedimentary clays cover the valley of the Machias River all the way from this point to the sea, which makes it probable that the southern portion of the Raceground is a marine delta. The glacial gravels continue southward over a gently rolling plain and cross the Mopang River, where they expand into an extensive series of sand and gravel plains, known as the "Mont Eagle plains." These plains are reported to contain in places kettleholes and ridges, while in general they are quite level on the top. This indicates that in part at least the Mont Eagle plains are a marine delta. In regard to the section extending from this point to the road from Columbia Falls to Jonesboro my information is quite conflicting. The map shows the system as extending past Libby Lake and becoming discontinuous toward the south, ending near Masons Bay, Jonesboro. The plains in Columbia Falls and Jonesboro are in general quite flat on the top, and show much coarser matter on the north and west than farther south and east. This indicates that in part, if not wholly, they are delta-plains, deposited in reentering bays in the ice or in glacial lakes.

Length from Bancroft to Masons Bay about 85 miles.

SISLADOBSIS-PLEASANT RIVER SYSTEM.

All my informants are agreed that a ridge or horseback of gravel extends from Sand Cove at the south end of Sisladobsis Lake nearly south

to Machias Fourth Lake. From this point southward I have followed in great part the information given by H. R. Taylor, C. E., of Machias, and the late Hon. S. F. Perley, of Naples. As mapped, the system runs near the town lines east of Sabao Lake and the large Mopang Lake, and appears to end near Pleasant River Lake. I crossed this system on the Air Line road in 1878, but could not at that time distinguish the plains as a delta. My information concerning the Pleasant River Valley south of the lake of that name is meager and conflicting. As seen from Columbia, the valley appears to have a gentle slope and to be covered with marine clay for a long distance northward. It seems probable, therefore, that the plains near Pleasant River Lake end at the south in a marine delta—at least that would account for the system's ending so far from the sea.

As to the region between Sisladobsis and Nickatous lakes, I have received much information from Messrs. James Belmore and S. W. Haycock, of Calais; also from D. F. Maxwell, C. E., of St. Stephen, New Brunswick; A. J. Darling, of Enfield; John Gardner, of Robbinston, and many others. All agree that in that region there are large tracts of sand and gravel overgrown with "Norway pine." These are probably glacial gravels, but my informants locate them with reference to streams and lakes not on the existing maps, and therefore it is impossible for me to map them even approximately.

Within 30 miles from Machias are perhaps the most noted grounds for the hunting of deer to be found in the older portion of the United States. The "Raceground" is so called because favorable to the chase. These great plains are due to the large glacial rivers which poured into the sea, at a time when the Machias Valley as far north as the Air Line road was covered by a broad sheet of salt water.

SEBOOIS-KINGMAN-COLUMBIA SYSTEM.

A short ridge of glacial gravel is found in Oxbow Township, Aroostook County, and several similar ridges are reported along the upper Seboois Lakes. It is as yet uncertain whether they have any connection with the remarkable system now to be described. An osar of unknown length comes southward out of the woods to the north shore of Seboois Second Lake in T. 7, R. 7, Penobscot County. It enters the water on the north side of the lake and reappears on the south shore, and thence

extends south for several miles along the west side of the Seboois River to the road leading from Patten northwestward to Seboois farm and Chamberlin Lake. It is here in a valley of natural drainage continuous (by the Seboois and Penobscot rivers) all the way to the sea. But the osar leaves this open valley and turns abruptly eastward. The road just mentioned is made on top of the osar for a half mile or more, when the road turns southward while the ridge keeps on eastward, up the valley of Hot Brook, then over a low divide, and down the valley of Hay Brook, to Upper Shin Pond. Here it rejected another slope of natural drainage, crossed the pond, and then went over a low divide into the valley of Peasley Brook. It then turns south and follows the valley of this brook to its junction with Fish Stream, about 1 mile west of Patten. In this valley the gravel takes the form of an osar-plain, extending across the valley or forming a flattish-topped terrace on one side. From near the junction of Peasley Brook and Fish Stream a low valley extends for several miles southward, cut off on the south by hills about 200 feet high. Rejecting this valley, the osar river turned nearly a right angle eastward, and for several miles follows the valley of Fish Stream. Its course lay through Patten Village, but there is a short gap in the gravel deposits at that place, so that a traveler on the north-and-south road sees no signs of the system. About 4 miles east of Patten, in Crystal, the gravel (here in the form of a two-sided ridge) turns another right angle quite abruptly and goes south and southwest across the 1,000-acre bog. This bog lies near the top of the low and level divide between the waters of Fish Stream, flowing north and east into the west branch of the Mattawamkeag at Island Falls, and those of the Molunkus River, flowing south. Here the gravel takes the form of low bars and narrow osar-plains, flanked and often nearly covered by peat and water. The drift of the upper Molunkus Valley merits study. No two-sided ridges appeared at the places examined by me, but the river is bordered by low terraces which have the form of erosion terraces of ordinary valley drift. An inspection shows that the stones of this gravel are all well rounded, much more so than the ordinary stream gravel in that part of the State. We know, too, that a large glacial river flowed into the upper end of this valley, and it is also certain that such a river flowed in the southern part of the valley. The river therefore must have flowed the whole length of the valley. But the only water-washed gravel

found in the upper part of the valley is that plain near the stream having the form of a sheet of valley drift extending across the whole of the valley. From these considerations and the very round shape of the stones it appears that the gravel along the Molunkus for several miles south of Sherman is an osar-plain and not ordinary valley drift. The gravel follows the Molunkus through Sherman, Benedicta, and Golden Ridge. Approaching Macwahoc, it takes the form of two-sided reticulated ridges inclosing several kettleholes. The ridges here are higher and steeper than they are farther north, and are composed largely of pebbles, cobbles, and bowlderets. The Molunkus Stream empties into the Mattawamkeag River a short distance west of Kingman. For 12 miles north of its mouth the Molunkus flows with a very sluggish current, and in time of flood overflows its broad alluvial plain of silty sand and clay. The reticulated ridges at Macwahoc were deposited at the foot of the steeper slope of the valley. From near the north line of Macwahoc to Kingman the gravel is found on the east side of the Molunkus and at a distance of from one-eighth to near one-half a mile from it. The lateral slopes of the valley are gently inclined toward the west, and the gravel is seldom found more than 30 feet above the river. In respect to its material and stratification, this plain, situated on the side of the hills above the river, is exactly like the low plain of gravel which fills the bottom of the valley farther to the north and which has the external form of a plain of valley drift. But the plain or terrace on the side of the hill above the river is plainly of glacial origin, and this shows the origin of the plain in the bottom of the valley farther north. They differ in no respect except situation with respect to the river.

South of Macwahoc the gravel becomes finer, and then comes an interesting study. For 2 miles north of Kingman we find a north-and-south line of ridges of fine sand. The large alluvial plain of the Molunkus lying to the west could have furnished sand which the west winds might drift up the hill. The question arises, Are these ridges and terraces of sand really the osar or are they blown sand? I have seen great numbers of sand dunes in various parts of the State, but never any north-and-south ridges showing such steep lateral slopes as these or forming a narrow and nearly continuous ridge for 2 or more miles. I therefore conclude that this sand is the osar. The ridge is well developed at the cemetery in the northwestern part of Kingman Village, where the railroad has cut through it to a depth of about

15 feet. South of this point the glacial river crossed the valley of the Mattawamkeag River. No sand or gravel is visible in the valley for half a mile or more; such deposits may perhaps have been laid down and have been washed away by the river or covered out of sight by its alluvium.

At Kingman there is an excellent opportunity to compare the shapes of the stones of the glacial gravels with those of ordinary stream gravels. The Mattawamkeag River at this place has cut down through a broad ridge or sheet of till to a depth of 30 or 40 feet, and has deposited the stones of the eroded till as a narrow plain of valley drift extending down the valley for about one-fourth of a mile. A series of rapids existed at this point before the building of the dam; and directly after the melting of the ice-sheet, when the fall must have been 30 or more feet higher than at present, the rapids and waterfalls must have formed quite a cataract. While the deep cut was being eroded the stones of the till must have been subjected to much more abrasion than is common except in case of the steeper mountain valleys, yet they preserve their till shapes very well. Their surfaces are polished, and the apices of the angles are more rounded than those found in the beds of the rivers and streams of Maine, except near the White Mountains and in the valleys followed by the glacial rivers. Their shapes are far nearer the angular and subangular shapes of the tillstones than those of the glacial gravel. As one sees how much more rounded the stones of the osars are than this stream gravel at a place favorable to attrition, he can not fail to be impressed with the great amount of attrition and frequent changes of position to which the stones of the osars owe their shapes. The alluvium of the Mattawamkeag River consists of fine sand and clay, except for short distances near the rapids and waterfalls.

The dam at Kingman originally extended from a bank of solid till on the north to the terrace of rolled gravel, cobbles, bowlderets, and bowlders before described. Twice in time of high water this loose gravel on the south side of the river has been undermined and eroded by the water falling over the dam until the water escaped around the south end of the dam. It thus happens that the dam is now twice as long as it was originally and the channel is much broader at the dam than it is a short distance below. At the time of my visit the water was flowing through three chutes near the bottom of the dam, situated at intervals of about 12 feet. Between these swift streams two ridges of coarse gravel had collected beneath the water.

The ridges were thus flanked on each side by a stream. About 30 feet below the dam these two ridges were connected by a transverse ridge, thus inclosing a kettlehole about 10 feet deep. Here is well illustrated one of the ways in which reticulated kame ridges inclosing basins and depressions are deposited by glacial streams as they shoot swiftly out of their narrow channels or tunnels into a broader channel or into a lake or the sea.

Not far south of the Mattawamkeag the osar begins again and continues somewhat interruptedly through Webster to the Mattagordus Stream, in Prentiss. It then follows the valley of this stream for several miles southward, expanding into a series of reticulated ridges inclosing kettleholes The gravel here is very coarse, and cobbles, bowlderets, and bowlders abound. Near the northwest corner of Springfield the system turns southwest. It crosses the road from Springfield to Lee about midway between those villages, consisting at that point of a low plain of well-rounded gravel which incloses a small lake, the source of one branch of Mattakeunk Stream. Just north of the road is a broad dome or hummock of morainal aspect, since it is strewn with many bowlders 2 to 4 feet in diameter. Examination of these bowlders on faces not weathered shows that they have been polished by water. These bowlders are granitic, like the far-traveled bowlders of the surrounding district, while the osar-plain near it is composed largely of slate and schists, like the local rock. The lower parts of the till of that region are mostly derived from local schists and calcareous and argillaceous slates. In the region east and northeast of Mount Chase and Patten numerous granite outcrops have contributed a great number of granite bowlders, and they are found covering the slaty till for many miles to the south. The granite bowlders in Springfield and Lee are unusually numerous, and there may possibly be an outcrop of granite somewhere to the south of the Mattawamkeag, but careful inquiry has failed to find it.

The situation may be summed up as follows: The osar-plain at this point is composed chiefly of the same material as the lower part of the till, while the outlying hummock resembles in composition the upper till. The osar-plain shows few or no bowlders, while the hummock is largely composed of them. The base of the outlying ridge is but little higher than the osar-plain. Evidently the conditions under which these deposits were formed were different in the two cases. There are numerous swells and ridges of till near this place. During the final melting of the glacier the

ice might for a time continue to flow across the valley until checked by the hills of Springfield and Lee, and the remarkable mounds of till may partake of the nature of a terminal moraine. The mound of glacial gravel lying near the osar-plain may date from this period. I could find no signs of a glacial stream, a lateral tributary of the main river, reaching farther north than this mound. The very large size of the bowlders of the mound indicates that it was formed subglacially and makes it probable that the deposit is partly or wholly a water-washed terminal moraine. The region deserves more careful study than I have been able to give it. Apparently the upper ice-bearing granite bowlders from the north continued to flow over the lower ice after the latter was partially embayed. The osar-plain soon crosses a low divide at an elevation near 200 feet above Kingman, and then follows the valley of the Passadumkeag River to Nickatous Stream, where it turns from its southwestward course to south. It here takes the form of a two-sided ridge 80 feet high (at an elevation above the sea of 380 feet, as determined by spirit level by D. F. Maxwell, C. E.), and continues as a prominent ridge for several miles southward. It then turns more nearly southeastward and follows the Narraguagus Valley for many miles, most of the way lying one-fourth of a mile or more to the west of the river. Part of the way it takes the form of a single two-sided ridge; at other places it is an osar-plain one-eighth of a mile or more in breadth, and occasionally it expands into narrow plains of reticulated ridges. North of Lead Mountain, in Beddington, an osar-ridge composed almost wholly of bowlderets and bowlders is found on the eastern border of the gravel, while to the west extends a plain of sand and gravel 1 to 3 miles wide. The western portion of these plains shows some low sand dunes. But for the wind, the plains would probably now be quite level on top. The material plainly becomes finer as we go westward. The plain was a delta deposited in a glacial lake or in the sea. Its elevation, by aneroid, is more than 300 feet above sea level.

Just south of Lead Mountain there is another gravel plain of rounded shape, about three-fourths of a mile in diameter. It ends in a steep bank downward both on the west and south, beyond which is till, not a plain of clay. It is gently rolling on the top, yet shows finer sediments on the west and south, and must have been deposited in an open body of water. The

following considerations make it probable that both this plain and the one north of Lead Mountain were deposited in glacial lakes rather than in the sea: First, the contour of 240 feet lies several miles south of here, not more than 3 or 4 miles north of Deblois Village; second, no marine sands or clays are found in the valley of the Narraguagus far to the north of Deblois, whereas the basin of Beddington Lake ought certainly to be covered with marine clay if the sea formerly extended north of Lead Mountain; third, the fact that the plain south of Lead Mountain ends in a rather steep bank on the west and south is most easily explained on the hypothesis that a glacial lake was there bordered by walls of ice. At Upper Beddington the osar-plain once filled the whole valley of the Narraguagus to a height of 50 feet and a breadth of about one-eighth of a mile, though the river has now deeply eroded the gravel along the axis of the valley. Going northward a short distance, we find the glacial gravel leaving the valley and keeping off to the west on ground 30 to 75 feet above the river. Above this point there is but little gravel of any kind in the bed of the Narraguagus. The valley drift is scanty, and the stones it contains are plainly tillstones, which have lost but little of their till shapes, a great contrast to the very round stones of the osar-plain that fills the valley at Upper Beddington. Now, if at the time the delta-plain north of Lead Mountain was being deposited the sea occupied the valley of the Narraguagus as far north as that place, then no reason can be given why the glacial gravel should not spread across the open valley as it did at Upper Beddington, instead of being deposited so abundantly to the west of the river and on land considerably higher. These appearances are just as if, during the final melting of the ice, a tongue of ice or a local glacier continued to flow down the unobstructed north-and-south valley of the Narraguagus, while to the west, in the lee of hills that obstructed the ice flow, the ice had already melted, not being replenished from the north, like the glacier in the open valley. On this theory the ridge of bowlderets and bowlders lying on the east side of the plain north of Lead Mountain may in part be a water-washed lateral moraine of the hypothetical valley glacier.

The gravels of this series appear on the shores and islands of Beddington Lake and then expand into broad, rather level-topped plains that are continuous with the great Deblois-Columbia plains, which will be described

in connection with the Katahdin system. It has not been possible thus far to distinguish in these plains the gravels brought down by the respective glacial rivers.

The amount of sediment transported by this long osar river is very great. The more noticeable features of this gravel system are the following: For most of its course the gravel takes the form of a two-sided ridge (osar proper) with arched cross section. At intervals are found several reaches of a low, broad ridge or plain, rather flat on top in cross section, but in longitudinal section, both up and down, parallel with the surfaces passed over by the system. The stratification of this plain is rather horizontal or slightly arched in cross section. To this plain-like enlargement of the osar I have given the name broad osar, or osar-plain. In places this plain enters a valley, and it then for some miles fills the bottom of the valley from side to side, like a plain of valley drift, and is often eroded into terraces. The broad osar in such situations is readily distinguished from valley alluvium by the more rounded shape of the pebbles and by the fact that the plain soon leaves the valley and is found on the hillsides where no ordinary stream could have deposited it, the pebbles and all other features exactly resembling that portion of the plain found in the valley. On the north it originates about 700 feet above the sea, and it ends in Columbia but a few feet above high tide. Five times it leaves large valleys of natural drainage and crosses hills into other valleys, besides crossing many minor elevations. Its remarkable meanderings are in general determined by the relief forms of the land, since it does not cross hills more than about 200 feet high, measured on the north, but it does not always follow the lowest passes. Reaches of fine matter alternate with coarse, and where the coarsest matter appears the system generally takes the form of reticulated ridges inclosing basins. The most abundant deposits of large stones and bowlders are in the granitic region of the lower Narraguagus Valley. North of Springfield there are only two places where the stones are very large: One in Prentiss, at the middle of a long slope of 15 miles northward, and one at Macwahoc, near the middle of a southward slope of more than 20 miles. Intermediate between these two points (near Kingman, at the bottom of the deepest valley which the system crosses) the material is unusually fine, i. e., fine sand. The gaps in this gravel system are less numerous and shorter than in any other of the long systems.

"Norway pine" plains.—In western Maine a growth of the various yellow pines known locally as "Norway pine" is a proof of the presence of reticulated kame ridges. In eastern Maine such pines are often found on delta-plains of nearly horizontally stratified sand and gravel, some of which are special sediments deposited in the sea. The presence of a yellow-pine growth is indicative of water-washed matter, and that is about all that I am yet able to affirm of eastern Maine.

Length of the Seboois-Kingman-Columbia system, about 125 miles.

WINN-LEE GRAVELS.

A line of glacial gravels extends nearly north and south along the valley of the west branch of the Mattakeunk Stream. It passes through the eastern part of Winn into Lee. Most of the way these gravels take the form of an osar-plain. At Lee Village this plain, which is there nearly one-fourth of a mile wide and rises 10 to 30 feet above the surrounding till, becomes somewhat reticulated and incloses a lakelet and trotting track. Southeast of Lee Village the gravels become somewhat discontinuous, yet the gravel can readily be traced over the southwestern spur of a high hill and thence more nearly east along a low valley to join the main system not far from the Passadumkeag River, east of No. 3 Pond. It is uncertain whether this series has any northern connections. A well-defined osar extends from the Penobscot River for 3 or more miles northward along the valley of the Mattakeunk Stream. The glacial stream which deposited it probably flowed farther than this place. Its probable course was from the mouth of the Mattakeunk southeastward along the Penobscot Valley to Mattawamkeag, thence up the valley of the Mattawamkeag River to the Mattakeunk Stream, and thence along this valley to Lee. Yet it is somewhat difficult to make out the connection with certainty. Mattawamkeag Village stands upon a terrace of well-rounded gravel at an elevation of about 190 feet. At the time the sea stood at 230 feet, the Penobscot Bay of that time would extend beyond Mattawamkeag up both the Penobscot and Mattawamkeag valleys. If a plain of glacial gravel were deposited in these valleys, the tidal currents would subsequently have modified and more or less reclassified the surface portion, and these marine sediments would afterwards have been more or less acted upon by the rivers after the sea receded. At Mattawamkeag we have to distinguish glacial, marine,

and fluviatile drift. The details are complex, and space does not permit a full discussion of the problem The most probable interpretation of the facts is that we have all three forms of drift represented in the Mattawamkeag terraces and that the glacial river followed the route above indicated.

Length from Mattakeunk to No. 3 Pond, about 15 miles.

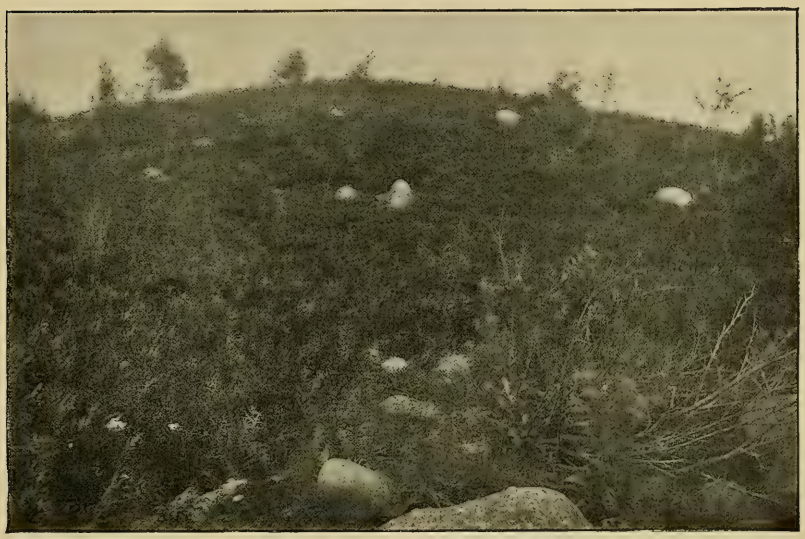
Several narrow terraces of water-washed gravel are found at intervals in the valley of the Penobscot in Winn and Lincoln. They are found at least 50 feet above the Penobscot River, and are probably sea beaches.

KATAHDIN SYSTEM.

This is an extensive osar system, deposited by a very large glacial river which drained the region about Mount Katahdin and which was remarkable for the number of its tributary branches. It is uncertain which is the longest tributary of this rather inaccessible system.

A horseback, or two-sided ridge, passes the Seboois farm, near the west branch of the Seboois River in T. 6, R. 7, Penobscot County. It is known to extend 3 miles northward into the forest. It passes only a few rods from the farmhouse and has been cut through at this point by a road to the depth of 12 feet. The stones are so angular that at first sight the ridge appears to be a meandering lateral moraine. A more careful examination shows that the finer detritus has been washed out of the mass and that the stones have been slightly water polished. It is thus proved to be a form of glacial gravel, the residue left after the till had been washed by gentle currents. The osar can be traced for several miles southward nearly parallel with the west branch of the Seboois River, but it disappears near where this stream enters the remarkable canyon by which the Seboois penetrates the Katahdin highlands. This gorge extends from near the junction of the two branches of the Seboois River almost to the junction of this river with the East Branch of the Penobscot. For several miles at the north end of this wild gorge the rocky hills slope steeply down to the river, and there is a constant succession of rapids; naturally there is but little water drift in this part of the valley. Southward the valley widens here and there and contains a plain of sand, gravel, cobbles, and bowlderets. In places the plain is about one-fourth of a mile wide and rides 30 or 40 feet above the present bed of the river. From one to three terraces of erosion border the river. The stones have been much more water rounded than those found in the

A. LAKELET SURROUNDED BY GLACIAL GRAVEL; LEE.



B. DOME OF COARSE GRAVEL; SPRINGFIELD.

beds of the present streams of that part of the State, and are more rounded than those found in the midst of the rapids of this stream to the north of the plains in question. The valley is not valley drift, but is an osar-plain. The hills bordering the canyon on each side are from 400 to 1,000 feet high. It is certain that a glacial river flowed into the north end of the gorge, and the height of the lateral hills is such that it could not escape except along the valley. The Seboois Valley broadens for several miles north of its junction with the East Branch of the Penobscot. This wide valley is bordered by plains of clay, sand, and gravel, and so also is the valley of the East Branch of the Penobscot from this point to Medway. Whether any part of this is an osar-plain I can not now be certain. At the time of my exploration in 1879 I had not diagnosed the level-topped osar-plains, and regarded them as valley drift. The sedimentary plain of these valleys is from near half a mile to a mile or more in breadth. My notes refer to certain coarser gravels on one side of the plain, which perhaps are a broad osar. A well-defined osar begins about 14 miles north of Medway and extends continuously southward to that place. While passing along the river in a canoe I saw no osar ridges farther north from Medway than this. This ridge is bordered on the east by the river and then by a broad sedimentary plain extending for many miles southward. It is composed of clay overlain by sand and gravel, all very nearly horizontally stratified. The ridge has steep lateral slopes on both east and west sides. It is usually densely covered by vegetation and from the river does not appear very different from the steep bluff of erosion in the alluvium on the east bank of the river. None of the geologists who passed up this valley appear to have noticed the ridge, but Thoreau must have seen it and recognized its nature. He writes (Maine Woods, p. 294): "We stopped early and dined on the east side of an expansion of the river [East Branch of the Penobscot] just above what are probably called Whetstone Falls, about a dozen miles below Hunt's. * * * There were singular long ridges hereabouts, called horsebacks, covered with ferns."

In a few places the osar expands into oval or elongated plains, not very broad, but rather flat on top, sometimes inclosing kettleholes.

A comparison of the alluvial drift of the valleys of the East Branch of the Penobscot and Seboois River above Medway with that of the valleys of Pleasant River, the Piscataquis, the upper Kennebec, the Carrabassett, and

the Sandy, shows that the sedimentary deposits are very nearly the same in all of them. These valleys are all at about the same distance from the sea and the sediments may well be interpreted by comparison. In some of these valleys, as the Pleasant and Carrabassett, the sediments are plainly overwash or frontal plains, composed of matter that was brought down by glacial streams to the extremity of the ice and then spread out over the bottoms of the open valleys. They mark a stage in the retreat of the ice when it still lingered in the upper parts of these valleys and practically formed local valley glaciers. Since a true osar river flowed from the north into the gorge of the Seboois River and also in the lower part of the valley of the East Branch, the history of these valleys is probably this: A long osar river at one time flowed through the valleys. Later the osar expanded to an osar-plain in the gorge of the Seboois and for some miles down the East Branch. Finally, on the retreat of the ice the lower portion of these valleys was covered by a frontal plain of sediments derived from the glacial streams of the glacier that still lingered near the head waters of the Seboois Valley.

At Medway this osar crosses the West Branch of the Penobscot, and, except an island in the river, has been washed away by it. The osar then follows the south bank of the river for about 3 miles, being washed away in some places. Just west of the mouth of Pattagumpus Stream there is, on the south side of the river, a plain of high reticulated ridges, forming a jumble of hummocks and hollows. The gravel here is coarser than the average of the ridge. The osar for 3 miles has been taking a nearly east course, and directly before it lay the broad Penobscot Valley. The osar river, leaving this valley of natural drainage, turned to the right through a deflection angle of nearly 135° and took a southwest course up the Pattagumpus Valley, then over a low divide and down a branch of Maddunkeunk Stream into Chester. Near the Penobscot River it turns southwestward and follows the west side of that river for several miles, and then at the north end of Hocamoc Island it crosses to the east side (Pl. IV, *A*). The north end of this island is composed in part of the osar gravel. South of this point the gravel takes the form of a series of massive ridges or plains, separated by short gaps. These ridges are 20 to 50 feet high, and are rather level on the top, in places gently rolling and containing shallow hollows. The system

A. OSAR CROSSING PENOBSCOT RIVER; HOCAMOC ISLAND, LINCOLN. LOOKING NORTH.

The bluff at the left center and the plain at the right are composed of glacial gravel. The osar here forms a broad and massive table.

B. OSAR EXPANDED TO A PLAIN; SOUTH LINCOLN. LOOKING NORTHWEST.

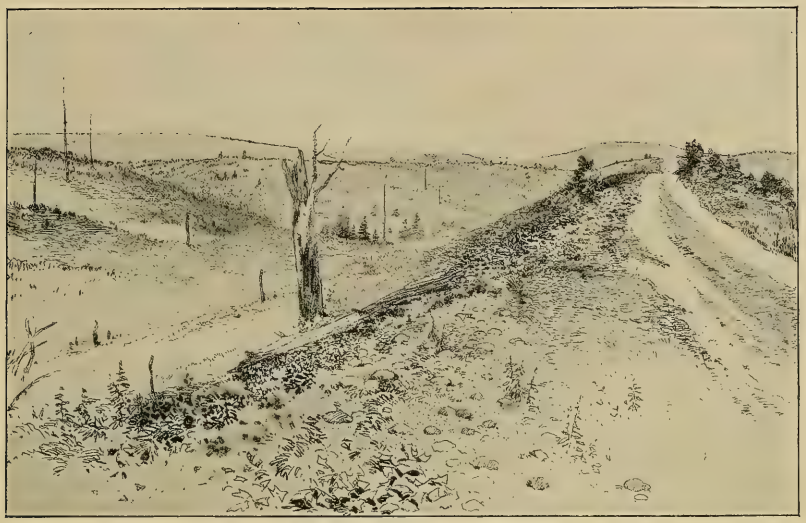
The hill at the right, on which are the house and the trees, is the extension of the level-topped ridge at the left. The gravel mesa here shows the steep lateral slopes characteristic of sediments deposited between ice walls.

passes a short distance east of South Lincoln, and soon takes the form of a single two-sided ridge, which takes a southeastward course and crosses the Maine Central Railroad a short distance north of Enfield station (Pl. V, *B*). North of Lincoln the osar is chiefly composed of small fragments of slate, but in Enfield it passes through a granitic area and contains many bowlderets and bowlders of granite, up to 2½ feet in diameter. I formerly regarded the numerous bowlders on the surface as having been dropped by ice floes. The proof is abundant that ice floes often did this, but recent excavations in the osar in the northern part of Enfield show that water-polished bowlders are scattered through the gravel to the depth of at least 8 feet. The latter are, therefore, a true part of the osar, though there are some bowlders on the surface that are not water-polished on what seem to be unweathered faces, and these may be floe bowlders. The ridge here is 30 to 50 feet high and of arched cross section. The osar passes a short distance east of Enfield station and then traverses a great clay-covered plain in the towns of Passadumkeag, Greenbush, and Greenfield. Much of this plain is as level as the prairies of the West, and formed part of the expanded Penobscot Bay. The flanks of the osar are here covered, often deeply, with clays containing clams and other marine fossils. Both the clay and the osar are sprinkled with occasional bowlders having the shapes of till bowlders. There is nothing like a sheet of till overlying the clay, and the bowlders indicate the work of ice floes rather than a readvance of the glacier after the deposition of the clay. It is noticeable that more bowlders were stranded on the hillsides than on the lowlands, and they are most numerous on the north sides of hills, where the ice floes drifted as they made their way down the bay. The Penobscot Bay at the time the sea stood at 230 feet was 15 or more miles wide from east to west at this point. In one place near the north line of Greenbush so many bowlders were piled on the top of the osar that no attempt has been made to plow the surface. A road is made on the top of the osar for many miles, the ridge forming a natural roadway through the level and sometimes swampy region. The osar here seldom rises more than 20 or 30 feet above the plain of marine clay, but in three places in Greenbush it expands into a series of broad and plain-like ridges, inclosing some kettleholes. The ridges here rise above the level plain to a height of 100 feet. Rising so abruptly out of the plain,

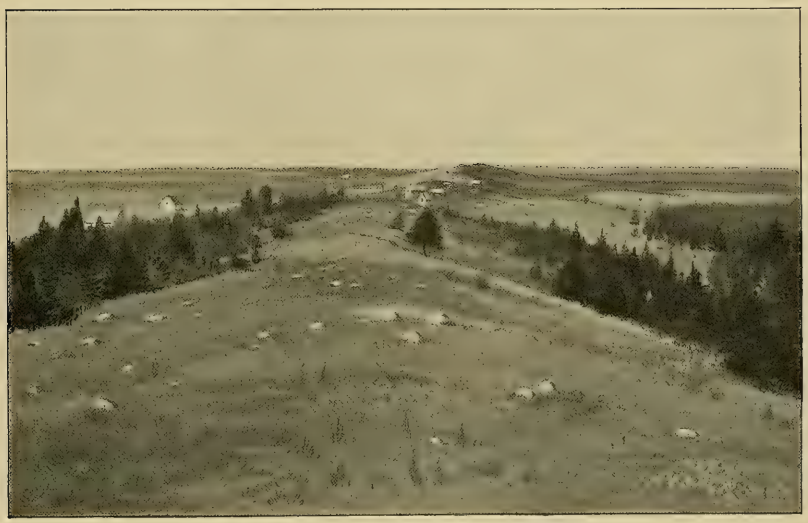
they are very prominent landmarks from every direction, and are locally known as "mountains." Their material is rather coarser than the average of the osar, and shows the usual sprinkling of stranded bowlders.

In Greenfield this osar unites with the Howland tributary. Near their junction are extensive sand-and-gravel plains having a gently rolling surface. I once supposed that the sea had washed down the original ridges as deposited by glacial streams and had redeposited them with a nearly horizontal stratification. As shown elsewhere, the power of the sea to erode till and glacial gravel was very limited except on the most exposed coasts. These plains in Greenfield were deltas deposited by the glacial waters near where they poured into the sea, or possibly into a large glacial lake.

The gravel plain continues on southward along a branch of the Sunkhaze Stream. Soon the plains are left behind and we find an osar of ordinary type, often of very large size. This is a treacherous wilderness, and the explorer must not let the osar get out of his sight if he can help it. Just as he approaches the head of the Sunk-haze, he reaches a particularly aggravating swamp. With many misgivings, he concludes to trust the osar for just a few minutes and flank the swamp. Arrived at the other side of the swamp, it is just as he had a right to expect. The osar has vanished. Before him is the top of the divide, dreary with bare ledges and an endless array of roches moutonnées sprinkled with large bowlders. But really we are dealing with rivers, and the gravel is only a symbol. A mighty osar river certainly came from the north to this place. What became of it? It must have swept over that divide with velocity sufficient to enable it to carry all loose matter before it except the large bowlders. Still we must seek field evidence that it passed over this divide. Going east, we soon descend to the Morrison Pond, a long narrow body of water situated between two high granite hills which slope steeply down to the pond from each side. Within a half mile the osar reappears. Round cobbles and bowlderets soon appear, and in the jaws of the pass take the form of a large windrow of polished bowlderets and bowlders situated on the south side of the pond. Then for a mile or two on a steep down slope there is but little sediment to represent the osar. The osar river crossed the west branch of the Union River, and immediately we find a broad series of sand and gravel plains in Aurora known as the Silsby Plains. These are about 5 miles long and from 1 to 3 miles wide. They extend about 1 mile north of the outlet of



A. OSAR FORKING INTO A DOUBLE RIDGE.



B. KATAHDIN OSAR, ENFIELD. LOOKING NORTH.

The bowlders on and within the ridge are of granite with waterworn surfaces where unweathered. This view shows the characteristic development of an osar within an area of granitic rock.

Morrison Pond. This broad plain consists of nearly horizontally stratified sand and gravel, the material becoming finer as we go away from the mouth of the outlet of Morrison Pond. This proves that it is a delta deposited in some body of water. These plains are about 120 feet above the sea, and at the south the sand passes into marine clay, which covers the valley of Union River from this point all the way to the coast. It is therefore evident that the great Katahdin glacial river here emptied into an arm of the sea which extended up the valley of Union River to a point several miles above these plains. But the history does not here come to an end. From near the Morrison Pond outlet a ridge or series of ridges of coarse gravel, cobbles, and even bowlderets, extends southeastward across the Silsby Plains. These ridges rise above the surrounding plain. They are of arched cross section and are clearly of different origin from the plain of nearly horizontally stratified gravel and sand which surrounds them. Near the Union River, on the west side of the plain, this ridge of coarse matter is intersected by several lower transverse ridges which are parallel with the trend of the valley, and it is also deeply cut through by furrows having the same direction. Apparently the swift tidal currents as they swept up and down the valley cut furrows through the ridge, which crossed the valley obliquely, and built up the matter as transverse ridges.

The facts, so far as known, indicate that the history of this interesting locality is as follows: While the ice was still deep, the glacial river flowed through the Morrison Pond Pass and so on obliquely across the level valley of the west branch of Union River, where the Silsby Plains now are, and deposited the ridge of coarse matter. But during the final melting of the ice the sea advanced, and finally covered all the valley to a depth of about 100 feet. But the ice to the north in the Penobscot Valley was not yet melted, and the glacial river continued for a time to pour its freight of sediment into the bay, and the tide carried the finer matter far and near in nearly horizontal stratification. The delta thus formed extended about 1 mile north of the mouth of the glacial river and 4 miles south and southeast. While this was going on, the tides, sweeping up and down the valley, partially washed away the ridge which had been laid down before the melting of the ice, cut transverse channels through it, and reclassified the matter. According to this hypothesis, the Silsby Plains consist of an older osar which was deposited between the ice walls and afterwards bordered

and overlain by a delta-plain deposited by the glacial waters in an open arm of the sea.

A series of high granite hills borders the valley of the west branch of Union River on the east, and the osar, having crossed the Silsby Plains, ends right in front of a very low and level pass between two of the hills. For near a mile in this pass no glacial gravel could be found, but at the east end of the pass the gravel begins again as an osar-plain one-eighth of a mile or more wide. The system is soon cut through by the middle branch of Union River and then takes the osar form of a two-sided ridge (Pl. V, *A*). This ridge rapidly enlarges toward the southeast and becomes known as the Whalesback. It is one of the largest ridges of glacial gravel in Maine, varying in height from 50 to 100 feet above the plain of marine clay which deeply covers its base. For several miles a parallel smaller ridge lies a short distance west of the main ridge, and the two are connected by numerous cross ridges. Thus are inclosed numerous large kettle-holes and swamps containing several acres. Among the local legends, I find one to the effect that Agassiz was greatly interested in this huge ridge, speaking of it to my informant as a moraine. The Air Line road from Calais to Bangor is made on the top of this ridge for about 3 miles. The ridge becomes lower toward the south, and the Whalesback is considered to end at this low place, near where the Air Line road leaves it and turns east.. The gravel does not end here, however, but continues on southeastward along the valley of Leighton Brook, a tributary of the middle branch of Union River flowing northwest, most of the way as a prominent two-sided ridge. In the eastern part of T. 21 it escapes from the hilly country into the great plain of the Narraguagus, which extends for many miles to the sea. It at once expands into a series of low and broad reticulated ridges, showing a gentle rolling and hummocky surface. Soon the gravels become more level and horizontally stratified. They extend almost continuously through Ts. 22, 16, and Deblois, into Columbia. Here and there, rising above the horizontally stratified sediments, are ridges of arched cross section that were evidently deposited within the ice walls. Most of these plains from Rocky Pond and southeastward must be considered as a marine delta. From Columbia to Deblois, and perhaps still farther northwest, the southern edge of the gravel plain ends in a steep bluff and shows so many cobbles and bowlderets that it seems quite certain

that the plains were bordered by ice at the time they were being deposited. Not far west of Deblois the plain ends on the south in sand, which passes by degrees into clay, and there are several areas of sedimentary clay on the north side of the sand plain, and partly inclosed by it. A minute examination may show that some of them were laid down in glacial lakes. In the absence of direct proof to the contrary, I provisionally assign to them all marine origin. According to my present information, the most probable interpretation of the facts is this: The plains southeast of Deblois were deltas deposited within ice walls, i. e., in a broad channel or fiord inclosed by ice at the sides, but open to the ocean in front. Subsequently, when the ice had all melted over the lower part of the Narraguagus Valley, the Katahdin glacial river flowed into the open sea not far from Rocky Pond in T. 22, and at this time were formed the large delta-plains situated west and northwest of Deblois. The situation is further complicated by the fact that the great Seboois-Kingman osar river was at the same time forming a marine delta in the Narraguagus Valley north and northeast of Deblois.

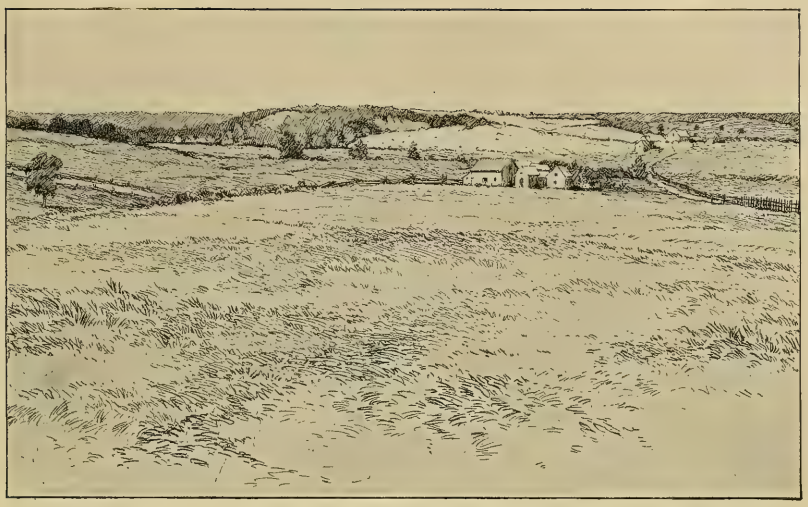
The eastern end of the United States Coast Survey base line is situated just at the top of the bluff which borders the Deblois-Columbia Plains on the south. Toward the east the plain becomes narrower and the material coarser. Near Epping Corner, in Columbia, the gravel forms a plain near one-half mile wide, rising from 40 to more than 100 feet above the marine clays which border it on the north, east, and south. The plains extending from here northwestward toward Deblois are widely known in all this part of the State as the Epping Plains. Near Epping the plain is rolling and ridged on the top and contains numbers of shallow kettleholes. From it proceed several tongues. On the north three of these tongues project out one-fourth of a mile or more toward the Pleasant River. The valley of this river is here a broad and very level clay plain, and the ridges rising steeply 100 feet or more above the plain form a very prominent line of bluffs. An examination of the map shows that the Seboois-Kingman and the Katahdin osar rivers together drained near one-fifth of the southern slope of Maine, and that all this vast rush of glacial waters converged at Epping—a sufficient cause for the great plains of Columbia, Deblois, and the Narraguagus Valley.

A tongue of glacial gravel extends from Epping Church southward on the road to Addison. This soon becomes discontinuous and the gravel

hummocks grow smaller, and the series ends within about 2 miles. To the south of this point lies a low clay plain all the way to the sea in Addison. In this I could find no glacial gravel rising above the clay. The only eastward or southward connections of the Epping Plains which I have been able to find are certain broad plains which extend through Columbia Falls eastward toward Masons Bay, Jonesboro. In the midst of the Deblois-Columbia Plains are several areas of till rising above the gravel plains.

Near Epping Church, Columbia, is an excavation showing an interesting section. On the top is a thin layer of well-rounded, medium-sized gravel. Beneath this is a stratum 2 to 4 feet thick containing unpolished stones and bowlders having the shapes of tillstones. This plain, being below the contour of 230 feet, would project from the west far out into the expanded bay of that time occupying the valley of Pleasant River, and would be much exposed to stranding ice floes. I do not see how in general the scattered and isolated bowlders having till shapes found upon and in the marine clays can have been brought to their present positions except by ice floes or small bergs. But this till-like stratum is so continuous that I see no objection, so far as the mass itself is concerned, to considering it a sheet of till. The till-like mass is found on the eastern end of the high plain, and does not extend far west of Epping Corner. This is where the ice floes would be most liable to run aground, and it is a point in favor of the ice-floe theory. I saw no bowlders distinctly glaciated, but this is not fatal to the theory of a readvance of the ice after the deposition of the plain of gravel. On either theory the surf would subsequently beat on top of the plain and wash down some of the highest gravel onto the adjacent till-like mass, though in many places there is no overlying beach gravel. As one goes over much of the plain near Epping the angular or unpolished bowlders make it look so much like a field covered by ordinary till that it needed the testimony of those who have fruitlessly dug wells to a great depth to convince me that the plain is underlain by 100 feet of coarse glacial gravel. A more careful exploration of the whole region is needed in order to decide the question of the origin of the till-like stratum. At present I incline to favor the ice-floe theory.

Comparing the gravel of the Katahdin osar with the till, also with the country rock of the regions through which it passes, we find that both the till and the osar are made up chiefly of fragments of local rocks or of rocks



A. BROAD PLAINS, EXTENDING FROM COLUMBIA FALLS TO JONESBORO, LOOKING EAST.

The hill in center is a mesa or massive plain of glacial gravel 100 feet high. The foreground is covered with marine sediments.

B PLAIN OF GLACIAL GRAVEL CONTAINING TILL-SHAPED BOWLDERS; NEAR EPPING CHURCH, COLUMBIA

found not far to the north. Yet there has plainly been a transportation southward along the line of the osar greater than the distance traveled by the till. Thus, north of Enfield the osar consists chiefly of slate. It there crosses a small granite area. The granite immediately appears in the ridge, and continues to be largely represented in it for 10 or 15 miles after reentering the slate region, more abundant apparently than in the till over the slate area. Near Morrison Pond the osar again leaves the slate area and enters the great granite area extending northeast from Orland on the Penobscot Bay nearly all the way to Bay Chaleur. For several miles after entering the granite the osar contains more slate than the till. As a rough estimate, I compute that the stones of the osar traveled from 5 to 10 miles farther than those of the till.

For most of its course the Katahdin osar is closely guarded by the wilderness. Whoever loves the large, generous works of nature, unspoiled by the hand of man, will find much to his taste in following this osar. A casual crossing of the system is insufficient for adequate appreciation. One needs to follow it for 100 miles or more in order to see what a grand geological construction it is. As the mighty rampart stretches away before him day after day, the explorer becomes intensely interested in watching its varying developments. Railway embankments become insignificant in comparison with it. It is perhaps most beautiful in the midst of the dark, silent wilderness, gray with lichens. Its vegetation is interesting all the way from Thoreau's horseback, covered with ferns; past days and days of white birch and poplar growth; past the hemlock thickets of the high pinnacles or so-called "mountains" of Greenbush, where Linnæa and Chiogenes vie with pipsissewa and Epigæa in decorating the huge piles of gravel; past the checkerberry plains and mosses of Greenfield and the kame-inclosed sphagnous swamps of the Sunk-haze wilderness, lovely with calopogon, Pogonia, and Arethusa; and the interest keeps up even to the great blueberry plains of Deblois and Columbia, and to the drosera-shining spruce swamps which cover the unsightliness of the cobbles, bowlderets, and rounded bowlders of the great plains near Rocky Pond.

Not less interesting are its topographical relations. By the time one has seen the osar crossing transversely the Penobscot River twice and the valleys of three streams to their source, then crossing divides and descending the valleys of the same number of streams flowing in the opposite

direction, and in so doing taking its way in all directions from southwest around to south, southeast, and even east, by this time one will see how irresistible is the proof that such a river must have been confined between ice walls to flow so independently of the surface forms of the land. Yet it did not flow wholly independently of them. It nowhere crosses hills more than 200 feet higher than the ground to the north of them, and thus it penetrates the high ranges only along low passes. Traveling southward, for two days before reaching the Morrison Pond Pass I had observed that remarkable gap through them, and at a venture assigned it as the gateway of the osar river. For a day and a half after the idea came to me the osar continued a nearly south course, and it often seemed impossible it could go so far to the east. But at last in the Sunk-haze wilderness it described a long and regular curve to the left and shot straight for its natural outlet between the hills.

This osar affords interesting points as to the retreat of the ice northward before the advancing sea. To say nothing of the delta-plains deposited in reentering bays or broad channels within the ice up which the sea extended, we have at least two and perhaps three series of delta-plains deposited in the open sea. First, the ice over the Narraguagus Valley melted, so that the delta-plains west and northwest of Deblois were formed. Subsequently the ice disappeared over the valley of Union River, which then became covered by the sea. This arrested the further flow of the glacial river southeastward. For a time it continued to flow into the bay of the Union River Valley, and the Silsby Plains in Aurora were thus deposited. Still later, the ice receded up the valley of the Penobscot until the osar river probably poured into the broad Penobscot Bay of that period in Greenfield. The broad, plain-like ridges near the Penobscot River at South Lincoln, though deposited between ice walls, may have been in part due to the checking of the glacial water at that point by the advance of the sea. The same thing may have happened at the mouth of the Pattagumpus, and the apparent plains of valley drift near the junction of the Seboois and the East Branch of the Penobscot may be either fluviatile or estuarine drift, brought down from above by glacial streams while the country to the north was still covered by ice. The pinnacles of Greenbush and several other enlargements of the gravel deposits were probably deposited in glacial

lakes or in a plexus of sediment-clogged ice channels which were practically equivalent.

Length, about 125 miles.

STACEYVILLE-MEDWAY BRANCH.

A nearly continuous ridge begins in the southern part of Staceyville and traverses a very level region for about 15 miles, when it approaches the Salmon Stream. Its course then lies along the west side of that stream for several miles, and not far north of the Penobscot River it expands into plains of sand and gravel, which are rather level on the top, so much so as to make it probable that they are a delta deposit, either in a glacial lake which then extended across the Penobscot Valley and for a short distance up the valley of the Pattagumpus Stream, in an estuary, or in the sea. The sea certainly extended for several miles up the Penobscot above Mattawamkeag, but how far I am as yet unable to determine.

Length, about 20 miles. Much information as to the region about Medway has been received from Col. J. F. Twitchell.

SALMON STREAM BRANCH.

This has been traced northward along the valley of Salmon Stream to Salmon Stream Lake. It joins the Staceyville branch about 2 miles north of the Penobscot River.

Length, about 10 miles.

SAM AYERS STREAM BRANCH.

This osar is said to extend as a two-sided ridge 6 or more miles along Sam Ayers Stream, above its junction with the Mattamiscontis Stream. The connections of this series are uncertain. The Champlain sea extended up the valley of the Mattamiscontis for several miles above South Lincoln, and if this short glacial stream emptied into the sea at some place in that valley, the series would end at that point in a marine delta. If so, this may be an independent system. But I found several domes of glacial gravel in that valley of the Mattamiscontis nearly opposite South Lincoln. These may be either an extension of the Sam Ayers Stream series or simply outlying ridges of the main Katahdin system, which lies less than a half mile away across the Penobscot. My own exploration did not extend far up

the Mattamiscontis Valley. I provisionally include this short osar among the tributary branches of the Katahdin system.

MILINOKET LAKE-HOWLAND BRANCH.

This, perhaps, ought to be considered as the main branch of the Katahdin system.

A series of gravel ridges is reported by J. W. Sewall, C. E., of Oldtown, as beginning near the West Branch of the Penobscot River at the mouth of Katahdin Stream and extending eastward along the valley of Aybol Stream for several miles. My information is conflicting and rather indefinite as to the region from the head of Aybol Stream eastward to Milinoket Lake. On a down slope the glacial stream must have continued its flow through that region, but if it left any gravels in its channel they seem to have been scanty and discontinuous, just as happens on most steep down slopes in the State, and not to have attracted the attention of my informants. South of Milinoket Lake a nearly continuous osar extends along the valley of Milinoket Stream to the West Branch of the Penobscot River, at the east end of the enlargement of the river known as Shad Pond. At this point the ridge contains numerous highly rounded pebbles and cobbles, showing that it must extend for a long distance northward. It is not a large ridge, and numerous hummocks rise above the rest of the low ridge. The course of the osar lies obliquely across Shad Pond for about a mile, as is proved by islands of gravel rising above the water. It soon leaves the valley of the Penobscot and follows the Nollesemic Stream past the lake of that name, and then, penetrating a low pass, it extends southward near the Seboois River for many miles. The ridge is well developed almost all the way. Near the Piscataquis River it does not show above the marine sediments and valley drift, and it has been either washed away or covered out of sight by the clays, or the gravel may never have been deposited in this part of the channel of the glacial river. This glacial river certainly crossed the Piscataquis Valley, for the gravel ridge begins again a short distance south of that river and continues southward through Edinburg and Argyle as a low ridge rising only 10 to 30 feet above the marine clays. It then turns southeastward, crosses the Penobscot River at Olamon Island, and soon spreads out into broad, rather level, plains as it approaches Greenfield.

This glacial stream is pretty long, but, judging from the amount of sedi-

ment it deposited, it was probably not so large as the Seboois-Medway-Enfield branch. It drained the region directly south of Mount Katahdin, and it is an open question whether it ought not to be known as the Katahdin osar. It is even more inaccessible than the Enfield branch.

Length, 50 or more miles from Greenbush northward.

SOPER BROOK GRAVELS.

A ridge, probably of glacial gravel, is found along Soper Brook, north of Ripogenus Lake, in T. 4, R. 11, Piscataquis County. It is about 2 miles long, and is possibly a branch of the Katahdin system.

NOTE ON THE UPPER PENOBSCOT VALLEY.

I have not had opportunity to explore this valley above the Twin Lakes. On comparing the map of the upper Penobscot region with the country lying east and west of it, symmetry is seen to demand that the glacial gravels should extend farther north and west than is shown on the map. Probably the osars are there, but have not been discovered and reported. The hilly region about Katahdin can not be judged by the analogy of the level areas, but to the west a more level country is found, where glacial gravels may be expected.

EASTBROOK-SULLIVAN SYSTEM.

This rather short system extends from the south end of Webbs Pond, Eastbrook, southeastward through Franklin and Sullivan. It traverses a rolling plain along valleys or over low hills, and lies wholly within the area that was beneath the sea. It crosses the Shore or Telegraph road, and then continues southward as a high, broad ridge of coarse gravel, cobbles, and bowlderets. At the east end of Hog Bay it turns abruptly eastward and goes up a narrow valley. It is said to continue for several miles in this direction and to end near Flanders Pond, in the northeast part of Sullivan.

MINOR GRAVEL SERIES.

These were probably deposited by different glacial streams.

Amherst delta.—A small, rather level-topped plain of sand and gravel is found on the Air Line road, about 3 miles west of Amherst Post-Office, at the southern base of a high range of granitic hills. Going south of the road the sediments become finer. The gravel passes by degrees into sand, and this

into clay, within one-fourth of a mile. This clay is continuous with that which extends down the valley of Union River to the sea, and is of marine origin, as shown by fossils found about 1 mile east of this place. North of the road we find two tributary branches. One ridge extends for about one-eighth of a mile northwestward, up the valley of a small stream; the other starts from a point a few rods east of this ridge and ascends another valley northward for one-half mile or more. This gravel plain is small, but interesting. The horizontal transition from gravel and cobbles on the north to sand and finally clay on the south is shown with unusual regularity and within a short distance. It is an instructive instance of a delta deposited by two small glacial streams, whose mouths were so near each other that they formed a single delta-plain.

NORTH MARIAVILLE SYSTEM.

This is a discontinuous series of short ridges and hummocks separated by numerous short gaps, or apparent gaps. On the north the series begins about 1 mile north of North Mariaville and takes a south course along the west side of Union River for several miles. Near the road from Otis to Waltham it crosses to the east side of the river, where the gravel takes the form of a low terrace, while no corresponding terrace is found on the west side of the river and no similar gravel is in the bed of the stream. This is thus proved to be glacial gravel and not valley drift. South of this point the valley of Union River is a very level, clay-covered plain, and no ridges can be seen rising above the clay. Probably the series ends near this place.

WEST MARIAVILLE MASSIVE.

About 1 mile from Union River, on the road from North Mariaville southwestward to Tilden Post-Office, is a flattish-topped plain of well-rounded glacial gravel and cobbles. It is about one-fourth of a mile wide from east to west and three-fourths of a mile long. The plain becomes somewhat finer in composition toward the south, but the change is not so marked as it is in the case of most fan-shaped deltas. The plain is but little, if any, broader toward the south. It must have been deposited either in a glacial lake or within a bay of the sea bordered by ice walls that prevented the sediment from spreading. If so, the outlet channel toward the sea was probably narrow.

PEAKED MOUNTAIN ESKERS.

A series of ridges somewhat like an interrupted osar extends along the valley of a small stream that flows northward past the western base of Peaked Mountain, in the eastern part of Clifton. The series seems to end in front of a rather low pass leading southeastward through the high granitic hills. According to general analogy, this small stream must have flowed southeast through the pass, although it has not deposited much, if any, gravel on the steep slopes. It is possible that its course lay past Hopkins Pond to the plain in the western part of Mariaville, above described. I have not explored the indicated route, which is quite inaccessible.

CLIFTON-LAMOINE SYSTEM.

This series appears to begin as an osar ridge about one-fourth of a mile northwest of Clifton Post-Office. From thence it extends for about 1 mile southeastward, when it turns nearly east and crosses the granite hills by a pass about 80 feet above Clifton (Pl. VII, *A*). This is the lowest place in the granite range to be found in this vicinity. The gravel is scanty at the top of the pass, but on the down slope soon becomes very abundant and expands into a series of two or more large ridges inclosing kettleholes. It soon turns nearly south along the valley of a brook past Floods and Spectacle ponds, and then in Otis spreads out into broad plains from 1 to 1½ miles wide. These extend several miles southeastward into the northern part of Mariaville. These plains are rather level on the top, and the sediment passes from coarse gravel and cobbles on the north to horizontally stratified sand on the south, which in turn ends in the marine clays. This proves that the plains of Otis are a delta deposited in the open sea. South of these plains the system becomes discontinuous. After a gap of somewhat more than a mile, a rather broad ridge of very round gravel, cobbles, and bowlderets begins a short distance northwest of the tannery in Mariaville and extends nearly south for 3 miles. Another ridge lies about 1 mile west of this, situated in the southeast part of Otis, and it extends farther south than the first, so that they are arrayed en échelon. These ridges are several hundred feet broad, with very gentle side slopes. Two or three miles south of the last-named ridge is Beach Hill, a nearly round mound or massive plain of glacial gravel, more than one-fourth of a mile in diameter, and rising steeply about

75 feet above the marine clay that covers its base. The top of the plain is diversified with low ridges and some not very deep kettleholes, but the top is so level, as seen from a distance, as to resemble one of the buttes of the Rocky Mountains. After a gap of nearly 2 miles a plain begins on the east side of Union River, near the road from Ellsworth to Waltham. This plain is from one-fourth to three-fourths of a mile wide, and, with two short gaps, extends to the cemetery, a short distance east of Ellsworth, where it ends in a rather steep bluff on all sides except the north. The central parts of the plain, measured east and west, contain cobbles and bowlderets; to the very south end of the plain, but on the east and west margins pass into fine gravel and finally into sand. This plain thus is seen to differ much from the typical delta, yet shows some horizontal assortment of sediments, as if the channel within the ice was by degrees enlarged so much toward the east and west that the velocity of the current was checked in it—indeed, it practically formed a lake within the ice. South of this point there is another gap of a mile or more, and then a broad ridge or plain, interrupted by a few short gaps, extends southward through Hancock, past North Lamoine, and ends not far above sea level near East Lamoine, right opposite Mount Desert Island. Toward the south the gravel becomes finer and soon passes into sand, which is good for building purposes, and large quantities of it are shipped to Bar Harbor and along the coast. The plain does not become fan-shaped, but remains only from one-eighth to one-fourth of a mile wide. While, then, we see the horizontal classification of sediments characteristic of the delta, yet this is not the radiating shape of a plain deposited in the open sea, when it was free to spread in all directions under the action of winds and tides, as it would have been on the rather level plains of Lamoine. These facts warrant the interpretation that the glacial waters were flowing in a broad channel which opened on the sea and formed a sort of bay or estuary, bordered by ice walls at the sides.

Some of the gaps in this system are pretty long, yet the linear arrangement of the several deposits is such that there can be little doubt they were all deposited by a single glacial river, with perhaps one or two tributary branches. The largest marine delta of the system is situated in Otis, above 175 feet elevation and below the contour of 230 feet.

The length of the system is about 27 miles.

A. OSAR PENETRATING A LOW PASS, CLIFTON. LOOKING SOUTHEAST.

The osar is a low ridge on which the road is made.

B. BROAD OSAR TERRACE; BUCKSPORT. LOOKING NORTH.

The road follows the terrace of glacial gravel, which is much obscured by the marine clay that covers all the lower slopes of the hills.

LOCAL ESKERS NORTHWEST OF ELLSWORTH.

Some short ridges of glacial gravel are found about 1½ miles northwest of Ellsworth Falls; another is situated on the line of the Maine Central Railroad about 5 miles northwest of Ellsworth; and still another near Reeds Pond station, Maine Central Railroad.

A short ridge, ending in an enlargement at the south which resembles a small delta, is found a short distance southeast of East Eddington. This is near the foot of the northern slopes of the high granite hills extending northeast from Orland. The whole deposit is small, but I could find no connections. A short glacial stream probably here flowed into a small lake, perhaps late in the time of final melting, when the ice next the hills was melted, but some yet remained over the open plain to the north.

HOLDEN-ORLAND SYSTEM.

This is a well-defined series of rather short plains, ridges, and domes or mounds of glacial gravel, separated by gaps.

It appears to begin near Holden Village, and extends southwest through Dedham and Bucksport and appears to end not far north of Orland Village. Toward the north the gaps, though frequent, are not more than one-eighth to one-sixth of a mile in length. Going south, we find the gaps increasing to one-half a mile, and the ridges at the same time becoming shorter and smaller, till they are reduced to mere hummocks or elongated domes, 10 to 15 feet high.

The course of this system is southwest, while the other systems of this part of Maine trend south or southeast. The topographical relations of the system seem to afford a satisfactory explanation of this anomaly. The system lies along the western base of the range of high granitic hills before referred to as extending from Orland northeastward across Maine and New Brunswick. The schists which border the granite on the west weather readily, and it was not possible without excavation to find glacial striæ in the region penetrated by the gravel system. It is therefore uncertain whether there was a local deflection of the ice, caused by the hills, which corresponded to the direction of the kame system. This is a fine example of the discontinuous systems of lenticular or dome-like kames, at least toward the southern end of the system. Toward the north the ridges

become longer and approach the short osar type, and are sometimes broad, like osar-plains. It should be noted that in the discontinuous systems as here defined the gaps are not due to erosion subsequent to the deposition of the gravel, and they are as constant and noticeable a feature as the gravels themselves. As a class they are quite nearly parallel with the movements of the ice during the last of the Glacial period. This makes it probable that there was a movement of the ice southwest into Penobscot Bay about 12 miles along the western bases of the granite hills; but thus far it is not proved by evidence of the scratches.

MOOSEHEAD LAKE SYSTEM.

The principal branches of this important system were remarkable for being very widely separated at the north. They drained the glacial waters of a large part of the Penobscot Valley and its tributaries, and poured them into the Penobscot Bay by a single channel. Estimating the amount of water by the area drained, only three or four of the osar rivers of the State probably equaled this river in volume, yet a dozen or more of them exceed this in the quantity of sediment they have deposited. With insignificant exceptions, the system traverses a region of slates and schists, and it is the universal law that when an osar river passed through a granite region its gravels are many times as abundant as those of rivers in slate regions having the same length. The tributaries of this system are all easily traced; they left ridges nearly as large as those of the main river. The longest one of these is the Medford-Hampden osar.

MEDFORD-HAMPDEN OSAR.

On the north it appears to begin as a series of ridges on the south shore of South Twin Lake. It passes southward as a single two-sided ridge. In crossing Seboois Lake it is said to appear at certain places as "horseback islands," and farther south it crosses the valley of Schotaza Creek obliquely. The above statements are made on the authority of Mr. Eber Ames, of Medford, and are confirmed by many others. From near Schotaza Creek I have followed the system all the way to Hampden. For several miles north of the Piscataquis River it is a ridge 20 to 40 feet high, with arched cross section and broad base. The gravel contained many cobbles and some bowlderets, all well rounded, which proves that the ridge

extends a considerable distance north of Schotaza Creek. It reaches the Piscataquis River at the mouth of Schoodic Stream in Medford. The general course of the Piscataquis is east, but in Medford it bends sharply to the north for more than a mile and then resumes its eastward course. The osar reaches the river just where it makes this last bend eastward and follows the western bank for about 1 mile, and then crosses the river. The river in its eastward course impinges against the base of the osar and is deflected by it nearly one-fourth of a mile northward before cutting through

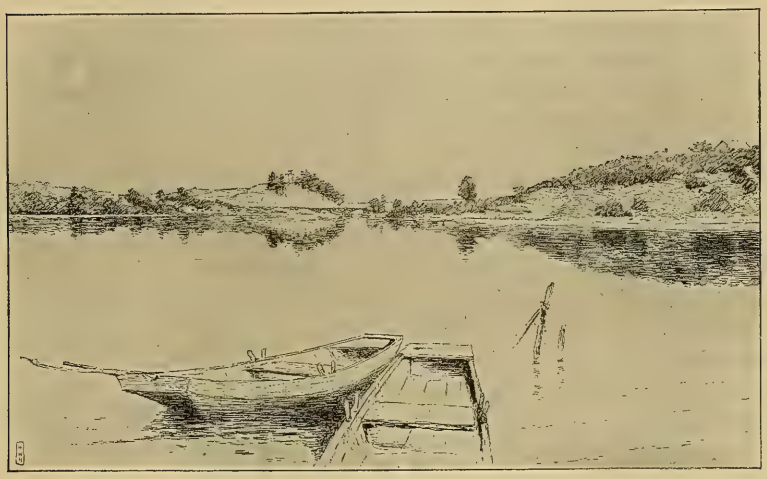


FIG. 10.—Osar cut by the Piscataquis River at Medford Ferry.

it. The ridge is here from 20 to 30 feet high, and is in part covered by the sedimentary sand and clay which constitute the valley alluvium. This place is not far from the upper limit of the sea. Medford Ferry is situated just at the point where the Piscataquis breaks through the osar (see fig. 10). From this point southward the road to Medford Center follows the ridge for a short distance and then passes east of it. The osar extends about one-fourth of a mile west of Medford Center and, still rising above the Piscataquis River, it penetrates a low pass in Medford and Lagrange. It is here somewhat discontinuous, and in places takes the form of the osar-plain,

especially for some miles south of the divide. In an excavation between Medford and Lagrange, bowlderets and bowlders 2 to 3 feet in diameter, all well rounded and polished, were abundant as far down as the excavation reached—6 to 8 feet. The osar passes about half a mile east of Lagrange station. A short distance south of this point the Bangor and Aroostook Railroad comes near the ridge, and for several miles in Lagrange and Alton it is constructed along the base of the osar. A wagon road is laid out on the top of the osar for many miles. In this part of its course it is a broad ridge or narrow plain with gentle lateral slopes and arched cross section, rising 10 to 30 feet above a very level plain of marine clay. Both the clay and the ridge are sprinkled with floe bowlders. At Pea Cove, Alton, the ridge becomes narrower, and has steeper lateral slopes from this point southward through Oldtown and Orono, on the west side of the Penobscot. In Veazie the ridge begins to be interrupted by short gaps. These gaps are especially noticeable south of Mount Hope Cemetery, situated not far north of Bangor. Mount Hope itself is a part of this gravel system. The next gravel of the series is on the east side of the Penobscot River in Brewer, just above the railroad bridge, Bangor. The next gravel is the ridge at what is known as High Cut, where the Maine Central Railroad cuts through an elongated dome of this series in the southeastern part of Bangor. In like manner, a series of short and broad ridges, separated by intervals of one-fourth mile to more than 1 mile, extends along the west side of the Penobscot River through Hampden and joins the main system not far west of Ball Hill Cove, near the north line of Winterport.

A study of the glacial gravel and of the drift of the Penobscot Valley will show the great difference between glacial and river gravels in Maine.

The course of this osar is wholly within a gently rolling plain, much of which is as level as the prairies. The base of the ridge is more or less covered with clay containing marine fossils as far north as Alton, and perhaps farther. Sedimentary clay is found in places along the top of the pass in the northern part of Lagrange. If this were marine clay we might expect a marine delta in the valley of the Piscataquis a few miles northward. There is no such delta, and the history of the Medford-Lagrange pass seems to be this: First, in a rather broad channel within the ice, an osar-plain was deposited. Subsequently the channel, by lateral melting, became still broader, and the supply of water was no longer able to main-

tain a swift current in the broader channel. Clay was then laid down on the flanks of the previously formed osar-plain—osar border clay.

In places the sea waves have washed down some of the top of the osar and strewn the gravel over the adjoining clay. This osar is nowhere very high, and it does not spread out into broad plains, like many of the systems, yet it is so continuous north of Veazie that it contains a large amount of gravel. The meanderings of this osar do not in general depend on any very evident surface features of the land.

Its length is about 60 miles, from Hampden north.

MOOSEHEAD LAKE OSAR.

This appears to be the longest tributary of the system. It is uncertain how far a ridge of glacial gravel extends in the floor of Moosehead Lake. Gravel, probably glacial, appears on Hogback and Sandbar islands in the midst of the lake. An osar appears on the western shore about 3 miles north of the so-called Southwest Cove of the lake. It follows the west shore to the foot of the lake in Greenville, and thence runs southward in a nearly straight course over a low divide in Shirley. From Shirley northward the ridge is quite continuous, but while following the Piscataquis Valley in Blanchard and Abbott on a down slope of about 50 feet per mile the gravel is much interrupted for several miles, partly by recent erosion. Near the north line of Abbott a plain of sand and gravel, now much eroded, appears in the midst of the valley. A two-sided ridge extends for some distance near Upper Abbott, but its summit has nearly the same level as terraces which border both sides of the valley. This appears to be a ridge of erosion, though it may have along its axis a core of coarser matter than is contained in most of the plain. The stones of the ridge and terraces are well rounded, like those of the glacial gravels, but, on the other hand, the gravel extends from side to side of the valley, like river alluvium. This condition prevails for several miles in Abbott. Much of this sand and gravel is glacial, but the broad alluvial ridges and terraces of the Piscataquis Valley in Abbott present a complex problem. Part of it seems to be an osar-plain, part is a frontal delta, part of it may have been deposited in a glacial lake, and in part it is composed of river drift. The very round shapes of the stones of what appears to be valley drift may best be accounted for as an incident in the final melting and retreat of the ice. If

the ice still remained over the Moosehead region to the north, the glacial streams would bring down well-polished sediment, while, when the ice had melted over the Piscataquis Valley, this rounded sediment, as it was poured out by the glacial streams on the steep slopes in Blanchard, would be transported by the swift Piscataquis River and deposited on the more gentle slopes in Abbott. In this way we may account for valley drift containing stones having the shapes of the glacial gravels. Of course the stones would be somewhat rounded while being transported by the river, but these stones are rounder than I find in the beds of even the swift streams that come down from Mount Katahdin. With respect to the ice they were frontal matter.

From Abbott a line of ridges and terraces of unmistakable glacial gravel, interrupted by several short gaps, is found on the south side of the Piscataquis River, extending eastward through Guilford and Sangerville. It then turns southeastward and follows the valley of Black Brook (a stream flowing northwest into the Piscataquis River) past Dover South Mills to the "Notch" in the northeastern part of Garland. All the way from Abbott to the Notch the ridges are in general broad and plain-like, some of them 50 and even 70 feet high, and are separated by frequent gaps. Near Dover South Mills there are two parallel ridges for nearly a half mile, which inclose a deep elongated basin. This enlargement of the system about two-thirds of the distance up the slope closely corresponds to the plexus of reticulated ridges in Prentiss, also on a northward slope.

The Notch is a remarkably low pass which forms a natural gateway through the range of rather high hills which border the Piscataquis Valley on the south. The top of the pass is less than 100 feet above the Piscataquis River at the mouth of Black Brook. Approaching the Notch from the northwest, many ridges and irregular terraces and mounds of glacial sand and gravel are seen along the south flanks of the main ridge. Part, if not all, of these are due to irregular erosion, by springs and streams, of a plain of rather fine sand and gravel which was laid down at the side of the main ridge of coarse gravel and cobbles. As a whole, this plain appears to correspond to what I have termed the broad osar. In this case an osar was first formed. Subsequently the channel became enlarged, not on both sides, as usually happens, but almost wholly at the south side—the side away from the glacial flow. In this broad channel was deposited a plain of

finer sediment which was more nearly horizontally stratified than the coarse gravel of the ridge formed in the narrow channel.

There is much silt and clay covering the upper part of the valley of Black Brook. I have no accurate data as to the difference of level between the Notch and the Piscataquis River. By measurements with the aneroid, taken at several hours' interval, the difference is but little short of 100 feet. If so, the clay of the valley of Black Brook near the Notch is not due to the floods of the Piscataquis, being higher than the terraces of that river. Besides, these clays are so abundant that it seems improbable that so large an amount of sediment could be carried several miles along a backwater lake. A much more probable theory is that the clays were deposited late in the Ice period, when the broad channel of the osar-plain had become still further broadened and the ice next the hills had melted, so that the valley of Black Brook formed a lake between the hills on the southeast and the ice which still covered the valleys of Black Brook and the Piscataquis River to the northwest. This lake would for a time overflow southward through the Notch, and would cease to be a lake when the ice over the Piscataquis Valley had melted so that the waters could escape along the present lines of drainage. Into this lake considerable mud would for a time be brought by glacial streams.

Just at the north end of the Notch the gravel system is joined by a tributary branch. It appeared to be short. I traced it for one-fourth of a mile, when it seemed to end. I afterwards regretted that I did not explore the country to the north, as it is possible a discontinuous series of kames may extend in that direction. The osar-plain is fully one-eighth of a mile broad at the north end of the Notch, and extends southward about one-half mile. Then for another half mile, where the steep hillsides almost meet at the bottom so as to form a V-shaped valley, a few very round cobbles and bowlderets are found here and there and testify that the osar river flowed through the Notch. The force of current must have been very great in order to leave so little gravel in the valley. Bare ledges abound, yet here and there considerable areas of till have escaped denudation. The till was the fine clayey till characteristic of the slate regions. The rounded osar stones distinctly overlie the till, and therefore must have been deposited at a later stage. I made no excavations, and do not know with certainty that there are no rounded osar stones mixed with the till, but in the banks of a

small brook no such stones appeared as part of the till. There is here no proof of a landslide of till from the hillsides, and no proof that till dropped down into a subglacial tunnel from above subsequent to the deposition of the glacial gravel. The evidence strongly favors the following conclusions: (1) The till was first (in order of time) deposited beneath the ice as a ground moraine. (2) Subsequently part of this till was washed away by the glacial river. (3) The fact that a considerable part of the till escaped denudation, notwithstanding the large size of this glacial river, proves that it must have presented considerable resistance to erosion; and this conclusion follows whether we consider that the osar river flowed in a subglacial tunnel or in an ice canyon open to the air. (4) The fact, then, that the glacial gravels often overlie uneroded till is not fatal to the theory that the kames and osars were deposited in subglacial tunnels. The fact is, the ground moraine was a very tough, compact mass, and not easily eroded even by a rapid glacial stream. Besides, it is not proved that in all cases subglacial streams would erode the till while those flowing in superficial channels would not. (5) The absence of till overlying the osar leaves us without direct proof that the osar river here flowed in a subglacial tunnel.

At the south end of the Notch the gravel and cobbles spread out into a fan-shaped plain about one-half mile long and half as broad. The plain has been eroded by a small stream which flows southward through its center, so that the plain of original deposition has been cut into two parallel terraces separated by a valley of erosion. The lateral terraces are also intersected by several transverse valleys of erosion, so that what must have been originally a continuous plain is now a series of detached terraces and mounds. The gravel is coarse at the north end of the plain and grows much finer toward the south. It was a small delta, deposited either in a glacial lake or in the sea. The plain is bordered by clay, and a sheet of clay extends from this point all the way to the sea. I found marine fossils in this clay at Kenduskeag Village, a few miles south of this place. It is certain that the sea extended nearly to the Notch, but exactly how far I have not been able to determine. If the clays that border the osar all the way from the Notch southward are not wholly marine, then we must regard them as osar border clays toward the north, i. e., deposited in the broadened osar channel at the sides of the previously deposited glacial gravel.

South of the gravel plain at the south end of the Notch there is an

apparent gap in the gravels of somewhat more than a mile. In Charleston, not far north of the Corinth line, a ridge rises above the clay. It is low and has gentle side slopes. It extends southeastward for several miles, passing about one-half mile west of East Corinth, here becoming higher and narrower and with steeper sides. Near here many boiling springs issue from the base of the ridge. The ridge is bordered on each side and partly covered to a height of 10 or more feet by sedimentary clay. The gravel is readily permeated by the rains, but the water can not readily escape from the sides of the ridge on account of the rather impervious clay. In this natural channel it runs lengthwise of the ridge. Coming to the lower grounds, it fills up the gravel to the top of the clay and boils over the top or escapes through the clay near the gravel. In the lowlands wells dug in the gravel ridge reach water, but the uplands are so dry that the winds circulate freely through the gravel and cobbles. The cellars of houses built on the gravel in such situations are exposed to rapid currents of air in time of high winds, and have to be cemented tight before the houses are habitable. In various parts of the State great numbers of wells have been dug in the glacial gravels in such situations that it was inevitable that all the surface water would be at once conducted away to lower levels, and where it would be impossible to get water without penetrating the gravel into the underlying till, and the loose gravel generally caved in before this depth could be reached.

In Corinth the osar and the neighboring clay are in a few places sprinkled with bowlders having till shapes, probably dropped by ice floes. The ridge is for several miles parallel with the Kenduskeag River. Near the south line of Corinth the osar crosses the Kenduskeag as a shallow bar extending across the stream. The water plunging over the bar has eroded a deep hole directly below it, known as the "Salmon hole." In general, if the explorer of glacial gravel hears of a salmon hole on an east-and-west stream, he may at once suspect it is formed where a stream flows over a submerged osar. The osar now turns southwesterly and soon disappears on the surface, yet can be readily traced for about a mile beneath the marine clay. By inquiries concerning the nature of the soil found in digging wells, it is often possible to trace an osar which is deeply hidden beneath the clay, or perhaps may show as a low mound covered by clay. As a typical instance, and in order to fully explain the methods employed

in this investigation, I give a single observation made about a half mile south of where the osar crosses the Kenduskeag River.

The surface was wholly covered by clay and silty clay. A well had been dug 200 feet or more in front of a house. This was an unusual position and required investigation. Inquiry showed that two or three wells had been dug near the house, all penetrating 3 or 4 feet of clay, and, deeper, dry gravel and cobbles, until the wells caved in. One of these wells was 80 feet in depth. Afterwards a well was dug a few rods back of the house, reaching water at the depth of 15 feet *in clay*, and the same experience was had when the well in front of the house was dug. The house was situated right on the line of the buried osar prolonged. Hence it was evident that the osar had disappeared simply because it had been flanked and covered by 80 or more feet of clay.

With a few short gaps, where it may exist, but, if so, is covered by the marine clay, the osar continues southwestward over a rolling country. Two miles north of Hermon Pond it spreads out into a hill or table-like plain, varying from one-fourth to one-half mile wide and more than 1 mile long, rising 50 feet above the marine clay that covers its base. The surface is rolling and incloses shallow basins. Although not large as compared with the plains of many of the gravel systems, unless we except the plains in Abbott, these are probably the largest plains in the whole line of the system. They are not true delta-plains, ending in sand and clay. After a short apparent gap the ridge begins again and extends past Hermon Pond station to the north shore of Hermon Pond. The ridge is cut through by the Maine Central Railroad just at the station, being there covered by marine clay, and a short distance south of that point the gravel has been extensively excavated by the railroad company. The gravel reappears on the south shore of Hermon Pond and passes a short distance east of West Hampden. From this point southward the gaps become a constant and essential feature of the system. South of here the ridges are nowhere more than 1 or 2 miles long, and often they are so short and broad that they may be called plains or domes rather than ridges. These discontinuous gravels extend in nearly a straight line from West Hampden to Winterport Village, passing nearly 1 mile west of Ball Hill Cove, near which point it unites with the Medford-Hampden branch. The gravel appears at the cemetery, Winterport, and at various gravel pits in the southern part of that village

OSAR ENDING AT THE SHORE OF PENOBSCOT BAY; SANDY POINT, STOCKTON.

it is overlain by clay. Within a mile south of the village the system comes obliquely down to the shore of the Penobscot River, and its course lies within a broad bay of the Penobscot River from this point to Frankfort Village. It then follows the valley of Marsh River past the bases of the high granitic hills which cluster about Mosquito Mountain. From this point southward the gravel contains a large proportion of granite and the ridges become more nearly continuous. Numerous bowlderets appear, and bowlders up to 4 feet in diameter. These in part have till shapes and are floe-bowlders, but many of them are water-rounded and polished on their unweathered surfaces, and are therefore an integral part of the osar. The great size and number of these large rounded bowlders favor the hypothesis that they were deposited in a subglacial channel. The system passes through Prospect Post-Office, and then soon turns southeast along the northern slopes of a range of hills. It comes nearly to Gondola Cove, and then turns southward parallel with the Penobscot Bay. As a broad ridge it comes down to the shore of the bay at Sandy Point, Stockton, where it ends in a cliff of erosion at the beach. The bluff here is near 25 feet high. Gravel is reported at Fort Point, in the line of this ridge prolonged. I have examined the deposit and am in doubt whether it is glacial gravel or a raised beach.

Its length from Moosehead Lake to Penobscot Bay is about 80 miles.

KENDUSKEAG-HAMPDEN BRANCH.

This begins not far north of the south line of Charleston and extends southward through the eastern part of Corinth, then southeasterly to Kenduskeag Village, where it abruptly turns southwest to Levant Village. It here turns south, and is interrupted by numerous gaps from this point on. It crosses a low col, and at the southern end of the pass it makes a sharp meander almost west for one-fourth of a mile, and then as abruptly turns southward again. The system crosses Hermon Bog and the Maine Central Railroad a short distance east of Hermon station. A continuous ridge extends from the railroad for about 2 miles, where the system becomes interrupted by rather long gaps again. This glacial river may have joined the Medford branch near Hampden Upper Corner, but my most recent information makes it more probable that it joined the main osar river near the south line of Hampden, and that its course lies a mile or more west from the Penobscot. I have not personally explored this series in Hampden.

This osar is a ridge from 10 to 50 feet high, and north of Levant it has rather steep lateral slopes (see fig. 11). It nowhere expands into broad plains, though it is somewhat plain-like south of the railroad in Hermon. It begins a few miles south of the high hills bordering the Piscataquis Valley on the south. Except near its north end the series lies wholly in a region that was under the sea. At Kenduskeag Village the lines of stratification of the ridge are much distorted, as shown in figs. 12 and 13.

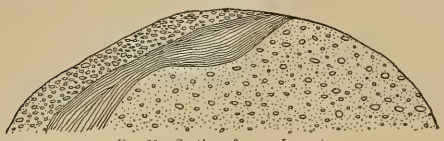


FIG. 11.—Section of osar; Levant.

Its length is about 25 miles.

EXETER MILLS-CARMEL BRANCH.

This branch appears to begin near the northern brow of a hill about 1 mile south of Exeter Mills and at an elevation of about 100 feet above that place. The series for several miles is interrupted by numerous short gaps, yet is easily traceable to South Levant and thence through the eastern part of Carmel to join the Moosehead Lake osar somewhat more than a mile north of Hermon Pond station (see fig. 14). It is nowhere a very large ridge, being 10 to 30 feet high. In Carmel it shows several remarkable zigzags (see fig. 15). It has been under the sea for most of its course, and is often nearly covered on its flanks by marine clay.

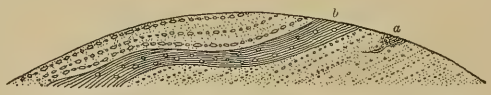


FIG. 12.—Crumpled strata near surface of osar; Kenduskeag. At *a* layers are crumpled as shown in fig. 13; the layer *b* contains much clay and fine sand.

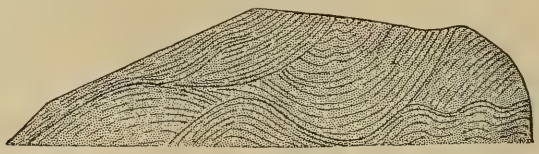


FIG. 13.—Crumpled strata near surface of osar; Kenduskeag. Enlarged view of strata at *a* in fig. 12.

In several places it develops into cones considerably higher than the rest of the ridge. In one place it expands laterally and incloses a deep kettle-hole, and right south of this point is a cone of unusual height. It nowhere expands in broad plains. On the north it begins on the south side of the

valley of the Kenduskeag and several miles south of the high hills lying south of the Piscataquis River. It traverses a gently rolling plain. Its length is about 12 miles from Hermon Pond north.

FIG. 14.—Section across Exeter Mills-Hermon osar, in Carmel.

The following-named osars are situated between the two principal branches of the Moosehead Lake-Penobscot Bay system. The streams which drained this portion of the ice-sheet would naturally flow into the system, but it may have been at a time before the deposition of these glacial gravels. I have not yet been able to make out any connection between these and the Penobscot Bay sys-

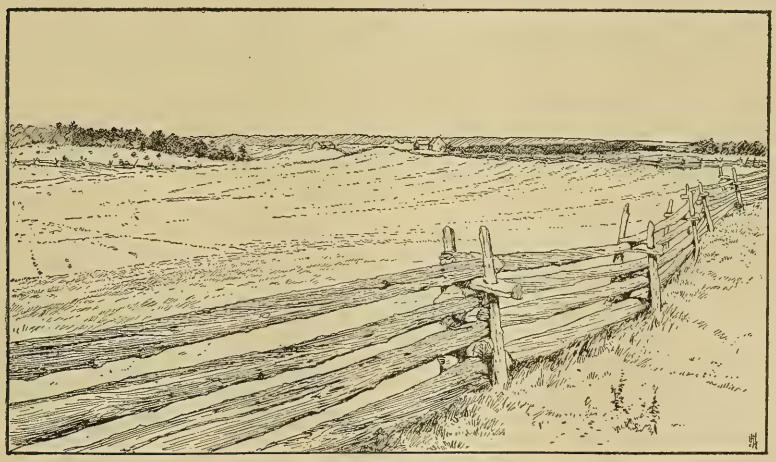


FIG. 15.—Meandering of osar; Carmel. The fence is built along the top of the ridge.

tem. It is probable that the osars next to be named were deposited at a time when the ice had receded to the north of the Piscataquis River, and that therefore they are independent systems deposited late in the Ice period.

JO MERRY OSAR.

This osar is said to extend through the wilderness for about 10 miles along Pratt Brook, a stream which flows nearly east into the middle of Jo Merry (or Jo Mary) Lake. Its course prolonged would lead it near South Twin Lake, and it may be an extension of the Medford-Hampden osar.

ROACH RIVER OSAR.

Roach River flows westward into Moosehead Lake. An osar follows the valley of this stream quite continuously for about 12 miles. Large pebbles and cobbles, with some bowlderets, make up the larger part of the ridge. The stones are not much rounded at the angles, though they plainly have polished surfaces, an indication that the system does not extend much farther to the north or west. From the head waters of Roach River low passes lead down the valleys of both the east and the middle branches of Pleasant River. These two branches unite near the north line of Brownville, and from near their junction a plain of sand and gravel containing many very round pebbles and cobbles extends up both valleys for about 3 miles northward. Here my exploration ended, and my information as to the valleys above this point is indefinite and conflicting. The preponderance of evidence favors the hypothesis that the principal glacial streams flowed down the valley of the east branch of Pleasant River. It length is about 25 miles.

KATAHDIN IRON WORKS OSAR.

A two-sided ridge from 15 to 30 feet high extends along the valley of the west branch of Pleasant River for several miles above the Katahdin Iron Works. Much well-rounded gravel is found along the valley below this place in Williamsburg which resembles a delta in composition and structure. The most probable theory as to its origin, according to my present information, is that glacial rivers flowed down the valleys of all three branches of the Pleasant River at a time when the valley of the main river to the south was bare of ice. The well-rounded gravel was thus brought down to the extremity of the ice and then spread as valley drift over the open valleys. This is an interesting region and deserves further study.

A plain of well-rounded gravel more than 2 miles long and from one-

fourth to one-half mile wide is found on the west side of Pleasant River a short distance east of Milo Village. A line of clay covers the Piscataquis Valley from Howland to Milo, and then silty clay extends up the Piscataquis to Dover and up the Pleasant River to Brownville. The gravel of the plain east of Milo Village is so much coarser than the drift of the Pleasant River Valley north of the plain for several miles, and the slopes of the valley are so gentle, that it is quite certain this plain is glacial gravel. The plain shows several of the characteristics of the delta. The Pleasant River glacial gravels do not seem to have connections south, a fact which strongly supports the conclusion that they were terminated by delta-plains at the ice front during the final melting and recession of the great glacier.

LILLY BAY-WILLIMANTIC OSAR.

A medium-sized ridge leaves Moosehead Lake at Lilly Bay. The gravel is here not much rounded. The ridge is described as following a rather crooked line of low passes southward, and then down the valley of Wilson Stream, expanding into broad plains in Willimantic, west of Sebec Lake. No glacial gravel extends along Sebec Lake and Stream, and I can not trace any extension of this system south into Guilford or Dover. This makes it highly probable that the broad sedimentary plain of Wilson Stream above Sebec Lake is really a frontal plain composed of matter poured out by glacial streams into the valley in front of the ice, at a time when the ice had retreated to this place. There is very little alluvium of any kind along Sebec Stream, the outlet of Sebec Lake, until we come east to within 2 miles of Milo Village, when the valley widens and is covered with silty clay continuous with that of the Piscataquis and Pleasant River valleys. This clay is just such a deposit as would be formed in the valley by the Gletschermilch of glaciers still existing 20 miles or more to the north.

We now pass beyond the region included between the two principal branches of the long Moosehead Lake-Penobscot Valley system.

ETNA-MONROE SYSTEM.

We now reach a part of the State where those parts of the gravel systems which contain gaps as a constant and conspicuous feature are as long as or longer than those parts where the ridge is continuous.

A series of ridges separated by intervals of various lengths up to 1½ miles begins in the south part of Stetson near the top of a rather low east-and-west hill. The series passes around the west and south sides of Etna Pond and then southeastward. It passes a few rods south of Carmel station of the Maine Central Railroad, and within 2 miles turns rather abruptly southward along the main tributary of the Soudabscook River. In this part of its course it is nearly continuous. For several miles in the northern part of Newburg it takes the form of an osar-plain, i. e., a level plain of well-rounded gravel filling the bottom of the valley, being bordered on each side by a sheet of sedimentary clay which extends back to the hills. The clay-and-gravel deposits have substantially the same upper level or surface. The osar does not follow the axis of the valley exactly, but is often nearer to one side. In the central part of Newburg the gravels leave the valley of the Soudabscook and go south up and over a hill fully 150 feet high. Above this point the valley of this stream contains only a scanty valley drift reaching scarcely 5 feet above the stream, a great contrast to the broad and deep sheets of gravel and clay which fill the part of the valley where the osar river flowed. This clay bordering the central gravel plain is a good example of what I have named the osar border clay. The gravel itself was deposited in a rather broad channel in the ice. This channel subsequently broadened so as to extend across the whole valley and the clay was deposited at the flanks of the older gravel plain. A lake 150 feet deep would naturally gather here on the north side of the hill, but it was inclosed by ice walls on the sides (at least most of the time of its existence), otherwise it would have extended up the valley for some miles and the upper part of the valley would be covered by lacustrine sediments.

On the hill above referred to the gravel is much interrupted. At the southern base of the hill it spreads out into a broad deposit nearly one-half mile across. This is in the valley of another branch of the Soudabscook, which flows northeastward, past South Newburg, into Stetsons Pond at West Hampden. The gravels take an unusual form. There are several gently sloping terraces, rising one above the other, each separated from the adjoining ones by rather steep bluffs which are nearly parallel with the strike of the hillside. The higher terraces on the north are narrower and composed of coarser material than those on the south. The deposit as a

whole has some of the characteristics of a fan-shaped delta. A plain of marine clays extends from this point eastward to the Penobscot River. Between this gravel plain and South Newburg, 2 miles distant, there are several small low ridges or plains of rather fine gravel, which fact favors the conclusion that during the final melting there was a limited overflow from the larger plain (then a glacial lake) eastward into the arm of the sea which then occupied the valley where now is South Newburg. South of the delta-plain above mentioned lies a region of valleys and low hills. The glacial gravels cross these as a series of broad ridges, separated by gaps, which soon expand into a pretty large plain, about 2 miles long and three-fourths of a mile wide. Along one part of the plain is a ridge rising above the rest of the plain. This ridge expands in places into reticulated ridges inclosing deep kettleholes. Bordering this ridge, which is composed chiefly of large pebbles, cobbles, and bowlderets, is the rather level plain of finer sand and gravel. Evidently the central ridge was deposited in a channel between ice walls. The bordering plain is a delta, deposited either between ice walls in a glacial lake or in the sea. This plain is situated east and northeast of Monroe Village, and the Monroe Fair-ground is situated on it. Marine clays widely cover the valley of Marsh Stream to a point far west of Monroe. South of Monroe Village the gravel takes the form of lenticular ridges or elongated domes. From this point south the gaps are a very regular and constant part of the system, and they do not seem to depend on the surface features of the land for their distribution; at least if there be such a dependence it is not easily detected. The system extends southward through Monroe, crosses a low divide in Swanville, skirts the western side of Goose Pond, and then takes a nearly straight course to Belfast Bay, near the line between Belfast and Searsport. South of Goose Pond the system for some miles takes the form of a low plain one-eighth to one-fourth of a mile broad. The material becomes finer on the south, and is a delta-plain, laid down probably in a bay of the sea inclosed at the sides by glacial ice.

The gaps between these separated gravel deposits are not due to erosion, unless locally here and there at the crossing of streams, but the gravel was deposited discontinuously in this way. Between the separate deposits lie undisturbed till or marine clay.

The length of the system, from Stetson to Belfast Bay, is about 35 miles.

LOCAL ESKERS IN JACKSON.

A ridge of subangular glacial gravel extends about one-fourth of a mile north from Jackson Village. About 2 miles east of the village is a plain nearly 1 mile long and one-fourth mile wide. It is near Fletchers Mill, on Marsh Stream. Another similar plain is found near Marsh Stream at the mouth of Emery Brook, about 2 miles west of Monroe Village. The gravel of these small plains is coarser on the north and west; they are probably deltas deposited in the arm of the Penobscot Bay which once extended for many miles up both branches of Marsh Stream.

The till in Jackson shows a great variety of heaps and ridges, probably owing to the fact that Jackson lies just south of the high hills of Troy and Dixmont.

WALDO-BELFAST BAY SYSTEM.

This is a short series, consisting of short and broad ridges or plains, also of domes or mounds of glacial gravel. The system begins in the northeastern part of Waldo and extends southward along the valley of Westcott Stream to City Point, at the head of Belfast Bay. Toward the south the deposits continue to grow smaller, and the last of them that is now above the sea is only a small hummock, not more than 75 or 100 feet in diameter at the base. The system is discontinuous throughout its whole course.

It is 5 miles long.

BROOKS-BELFAST SYSTEM.

This is a discontinuous series. It appears to begin in the northeastern part of Brooks, perhaps extending into Jackson. It crosses the valley of the south branch of Marsh Stream about 1 mile east of Brooks, here being joined by a short branch from the northwest. It then goes up and over the hills by the same pass in which the Maine Central Railroad is constructed, and its course lies near the railroad in the valley of Westcott Stream to Waldo station. The railroad here turns eastward and follows the lower valley of Westcott Stream, while the gravel takes a straight course southward past Evans Corner to near the Head of the Tide, Belfast. Near Waldo station the series takes the form of broad ridges and rather level-topped plains bordered by marine clay. These are apparently delta-plains, but since they do not spread out in fan shape, as they could easily have done if the glacial river flowed into the open sea, they must

have been deposited in a glacial lake or in a broad channel inclosed between ice walls and opening into the sea. South of the delta-plains the lenticular mounds grow smaller, and the last known deposit of the series is only a small hummock, which was once wholly covered by marine clay and laid bare by excavations.

The system is about 15 miles long.

LOCAL ESKERS IN DEXTER.

About 2 miles east of Dexter on the road to Garland are two small ridges or hillside eskers. They begin on the south side of a long sloping hill, not far above its base, and extend out into the rather level valley a short distance. They enlarge somewhat at their south ends, but not into a well-developed delta, such as ends in sand and finally clay. These ridges are less than one-fourth of a mile in length.

A short ridge of glacial gravel is found near the railroad station in Dexter Village. The valley of Dexter Stream is covered by very abundant alluvium of uncertain origin. It is more abundant than usual in a valley of this size. It is possible some of this rather fine sediment is an osar-plain connecting with the system next to be described. I have not explored the valley north of Dexter Village, but have recently heard of bogs without visible outlets being found not far north of Dexter. If this is so, there probably is a system of glacial gravels along this stream, and the fine silt and clay in the valley below Dexter may be frontal matter derived from this stream at a time when the ice had retreated to some point near or north of Dexter. This interpretation would well accord with the finding of the hillside eskers east of the village.

CORINNA-DIXMONT SYSTEM.

As above noted, this system may extend to Dexter or farther north, but I was not able to determine the limit with certainty. A well-defined series of glacial gravels is found in the valley of Alder Stream for 3 miles north of Corinna, and thence southward to the junction of this stream with Dexter Stream. The gravel takes the form of level plains in several places, and there are a number of gaps. Its course crosses Newport Pond. It appears as an osar ridge on the south side of this pond, and takes a quite straight general course southward past East Newport station, on the Maine Central

Railroad, to Plymouth Village. The road from East Newport to Plymouth is made on top of the ridge for several miles. Just north of Plymouth Village the road crosses a hill about 125 feet high. The gravel system here bends to the east of the road for a short distance and crosses the hill at an elevation about 50 feet lower than the road. At the northern base of this hill there is a plain of gravel with much sand. The plain is near one-fourth of a mile wide, and indicates a checking of the glacial streams north of the hill. From East Newport to this point the osar traverses a plain that is covered by sedimentary clay—border clay. We have seen that the osar river turned east in order to cross the hill north of Plymouth at a low part of the hill; but by bending about the same distance west the stream could have flowed around the hill along a valley of natural drainage. The gravel is scanty on top of the hill, but becomes abundant near its southern base in the outskirts of Plymouth Village. The ridge next crosses Plymouth Pond, plainly showing as a natural roadway extending across the valley, but it is submerged for a short distance. The road is made on top of this natural embankment while crossing the pond and bordering swamp. The system now begins to ascend a hill 100 feet high, and at once expands into a plexus of broad, rather parallel ridges inclosing several kettleholes. Approaching the top of the hill, the several ridges coalesce into a flat-topped plain near one-eighth mile wide. It is composed chiefly of sand, and is a fair type of the broad osar. No gravel is found on the top of the hill for a short distance; then it begins again and continues down the hill to North Dixmont. It here takes the form of a narrow ridge 50 to 75 feet high, having steep lateral slopes. In several exposures the strata, as shown in cross section of the ridge, dip monoclinally eastward, as if the channel in the ice enlarged on the east side toward the open valley. The ground rises to the west, and this makes it a possible hypothesis that the ice flowed eastward enough to compensate for the natural enlargement of the channel westward.

Going southward, we find the ridge growing broader and lower, and it finally spreads out into a rather level plain one-eighth of a mile wide. This becomes finer in composition toward the south, and finally becomes sand. It is bordered at the sides and south end by a rather steep bluff, which overlooks the valley of Martin Stream. This is a small stream which rises in Troy, then flows northeastward through Dixmont, when it turns north-

west past Plymouth Village and empties into the Sebasticook River a few miles below Newport Village. In Dixmont the valley of this stream is very level and a half mile or more broad. A continuous plain of clay and silty clay overlying fine sand (the reverse order of the ordinary valley alluvium) is found in this valley all the way from Troy, through Dixmont and Plymouth and thence along the Sebasticook and Kennebec valleys, to the sea. This clay is proved by its fossils to be marine as far east as Pittsfield, and perhaps as far as Newport. I have often suspected that a narrow arm of the sea connected the Kennebec and Penobscot bays of that time, along the low ground where Etna Bog is. Now the gravel-and-sand plain which seems to terminate the Corinna-Dixmont system has the general character of a delta deposited where rapid streams flowed into a body of still water and are rapidly checked. At once our attention is called to the large plain of fine sediment in the valley of Martin Stream, in which this delta lies. This stream is only a small brook, and ordinarily streams of that size would deposit only a very little alluvium. Evidently, at the time this delta-plain 2 miles southwest of North Dixmont was being formed the valley of Martin Stream in Dixmont and Troy was in large part bare of ice, and was either occupied by a lake contained between the ice on the north and the hills over which the ice had melted at the south, or was filled by an arm of the sea. But the Kennebec Bay of that period could reach this place only along the valley of Martin Stream through Plymouth, and if the sea extended from that direction the delta would have been formed in the valley of Martin Stream at Plymouth Village instead of several miles south of that place. It is evident that when the delta southwest of North Dixmont was being deposited, the ice must still have remained at Plymouth Village, and this would prevent any communication with the sea in the Kennebec Valley. Was there an arm of the sea in the valley of Martin Stream which connected with the Penobscot Bay? I have traced the marine clay from the Penobscot River as far west as Etna Pond, but between that point and Plymouth is an area not explored. According to Col. A. W. Wilder, quoted in Wells's Water Power of Maine,[1] the elevation of Plymouth Bog is 256 feet, and that of Plymouth Village 275 feet. As elsewhere suggested, the sea may have stood at a higher elevation in the interior than on the coast, but in the absence of direct proof to that effect,

[1] The Water Power of Maine, by Walter Wells, p. 89, Augusta, 1869.

the clays of the valley of Martin Stream in Plymouth and Dixmont must be considered as probably having been deposited above the highest level of the sea, and therefore in a lake contained between the ice which was still unmelted toward the north and the high east-and-west hills of Troy and Dixmont on the south. If so, where did the supposed lake overflow? There are two low passes by which the water of such a lake could have escaped southwestward into the Sandy Stream Valley in Thorndike, after the waters had accumulated to a depth of about 100 feet, provided no barrier of ice then existed in that direction. But no clays analogous in any way to those of the Martin Stream in Dixmont are found along these valleys, and hence there is no proof of an overflow this way; neither do I find proof of such overflow westward into Troy. The order of events here is probably about as follows: The Corinna-Dixmont glacial river emptied for a time into an enlarging glacial lake, inclosed between the ice and the high hills on the east and south. The outlet of this lake was toward the Penobscot Bay or in some unknown direction. During the retreat of the ice the glacial water may have escaped into the open valley of Martin Stream at or near Plymouth Village, but if so it could have been for only a short time. The gravel plain at the north base of the hill situated just north of Plymouth Village may point to another glacial lake, formed north of that hill, and the clay bordering the osar northward to East Newport may have been deposited by a broad channel which practically formed an enlargement of this lake. There are plains of sedimentary clay in Plymouth extending an unknown distance northeastward toward Etna Bog, and these may mark an overflow to the Penobscot Bay. How far this is marine remains to be determined by future investigation.

The length is about 20 miles.[1]

EAST TROY KAMES.

About 3 miles southwest from the delta-plain in which the Corinna-Dixmont system ends, a discontinuous series of short ridges and cones of glacial gravel begins on the hills north of Martin Stream, crosses the valley of that stream near East Troy, and then ascends the hills lying to the south to a height of about 100 feet. It appears to end in a thin gravel plain a little north of a low pass leading into Jackson. Not far north of where the

[1] The clays extending from Dixmont eastward are now (1893) considered by me to be marine.

gravel disappears is a cone of gravel and cobbles 80 feet high. The Brooks-Belfast and Troy-Belfast systems are both so situated that this short glacial river might connect with either of them, but I have not been able to trace any connection with them. The clay in the valley of Martin Stream overlies these gravels; hence the flow of this glacial stream dates previous to the time when the terminal delta of the Corinna-Dixmont system was deposited in a body of water then filling this valley.

This short series does not have a wholly satisfactory beginning or end, but I have not been able to trace any connections with other gravels. It may at one time have been part of the Corinna-Dixmont system.

The length is about 3 miles.

TROY-BELFAST SYSTEM.

This system appears to begin about one-half mile south of the road from West Troy to Troy Post-Office (Troy Corner), as a low, north-and-south ridge, which shows numerous meanderings. It lies in a region of rather low hills, forming a rolling plain lying north of the much higher hills of southern Troy and of Thorndike. At the northern base of these high hills this ridge is joined in the southern part of Troy by a rather level gravel plain from the west. It is nearly one-fourth mile in length and perhaps half as wide. This appears to be a delta, either of a lake wholly glacial or of a lake confined between the ice on the north and the hills on the south. The gravel system then crosses a low divide in a narrow pass and follows the valley of Parsons or Halls Brook for 2 miles southwestward. It then abandons this valley and follows a low pass into the valley of Higgins's Stream. It follows this valley southward for several miles, passing about one-half mile west of the Friends' Meeting House in Thorndike. It leaves this valley not far from Thorndike Corner, and by a crooked route penetrates the hilly region of eastern Knox and the northwestern part of Brooks, crossing several pretty high hills. It then follows the valley of Marsh Stream, parallel with the railroad, to a point about 1 mile west of Brooks Village, when it turns southward along a low valley. It soon goes up and over a hill 100 or more feet high and descends to Passagassawawkeag Pond. From this point south its course lies in a rather level region in Brooks and Waldo. In Waldo it expands into a rather level plain several miles long and one-eighth of a mile or more in breadth. The material

becomes finer toward the south, and gradually passes into the marine clay at an elevation of 200 feet or a little more. The plain is probably a delta deposited in a bay of the sea between ice walls. South of this plain are a few small gravel deposits, forming a discontinuous series, with long gaps. The system seems to end in the northern part of Belfast. The way in which most of the longer gravel systems reach their maximum development at about the contour of 230 feet and then become less and less till they end at or not far above the sea, is well expressed by the Western phrase, "peter out."

This glacial river brought down a large amount of sediment for so short a stream. Its course is circuitous, and for most of the distance is in a very hilly country. Five times it left drainage valleys and crossed hills into other valleys, none of the hills being more than 200 nor less than 100 feet high. Its larger deflections occurred invariably in order that it might cross the hills by the lower passes. The system is an instructive example of the power of the higher hills to deflect the glacial rivers. When it crosses hills, the gravel is usually abundant near the southern base of the hills or in the level plains, while it is scanty near the tops of the cols.

It is about 20 miles in length.

MORRILL-BELFAST BAY SYSTEM.

This is a discontinuous system of short ridges, small plains, and lenticular mounds or domes of glacial gravel separated by intervals varying in length from one-eighth to one-half of a mile.

The series begins in the northern part of Morrill and takes a southeast course over a level plain past Morrill Village to Poors Mill, in the northwestern part of Belfast. It then goes up and over a hill about 100 feet high and descends the valley of Little River, ending in a beach cliff of glacial gravel on the shore of Belfast Bay, a few rods south of the mouth of Little River.

Near Poors Mill the system expands into a somewhat level plain, suggesting a small marine delta. The whole region traversed by the system has been under the sea, and the gravels are more or less covered by the marine clay.

An interesting formation is found in the valley of Little River at the road from Belfast to Belmont. The axis of one of the ridges of this sys-

tem is shown by the deep cut at the road to consist of till. A central ridge of till was covered on both slopes by 10 or more feet of glacial sand and gravel, some of it reaching the top of the ridge, and subsequently the whole was buried beneath several feet of marine clay. This suggests the question whether a core of till may not often occupy the central and basal portions of the low rounded ridges of the discontinuous systems of glacial gravel. I have examined a large number of the lenticular masses characteristic of this type of gravels, and this is the only case where they could be proved to contain unmodified till. Yet these excavations seldom went to the bottom of the deposit, and their number is small as compared with the whole number of similar bodies. It is possible a till nucleus may be somewhat common in these mammillary kames.

The length of the system is about 11 miles.

GENERAL NOTE ON THE BELFAST REGION.

It will be seen that five gravel systems converge to Belfast Bay. The glacial scratches last made converge to the same place, while the earlier scratches were more nearly parallel. The discontinuous systems of gravel are, therefore, nearly parallel with the scratches last made, and they appear to date from the last part of the Glacial period. Most, perhaps all, of the discontinuous systems expand at some point into delta-plains, the largest of which are situated at or not far below the contour of 230 feet. Toward the south the gravel deposits become smaller and the intervals between them longer.

The large island of Isleboro lies in the midst of Penobscot Bay, to the south and east of Belfast, and in the line of these systems prolonged. The island shows a limited amount of beach gravel, but no glacial gravel that I could find. Three of the Belfast Bay gravel systems come down to the shore, but their diminishing size toward the sea indicates that there was probably no large development of glacial gravel over what is now the sea.

LOCAL ESKERS IN TROY AND PLYMOUTH.

A broad, level region covered by marine clay extends from Unity Pond northeastward through Troy. It is continuous with a line of sedimentary clay extending northward through Plymouth and Detroit to the

Sebasticook River. Part, perhaps all, of these clays are marine, but the estuarine, fluviatile, and lacustrine drift are all present in that region and difficult to distinguish. On the slopes of rather low hills that border this clay-covered plain on the south and east are several local kames. One of these is situated in the southwestern part of Plymouth, at the southern end of a hill bordered on each side by a low north-and-south valley. It ends near the upper limit of the sedimentary clays. Two other deposits of glacial gravel are found in the north-and-south valley of a small brook flowing north into Carlton Stream. They are situated a short distance north of Troy Center. Still another is found on the east side of a north-and-south valley near Cooks Corner, about three-fourths of a mile west of Troy Center. It is a short terrace, only a few rods long, about 40 feet above the bottom of the valley and about midway up the slope. It has been cut through by the road to a depth of several feet. On the south side of the road the terrace is plainly stratified, the strata dipping down the hill and transversely to the ridge. The different layers vary much in composition, some being fine sand, others coarse gravel and cobbles, slightly polished and rounded. Near the surface the mass is pellmell in structure. On the north side of the road, and only about 25 feet away, the whole section exposed shows the pellmell structure. The separate pebbles and cobbles are like those at the south side of the road in form, and the two sections differ in structure only. Both have plainly been water-assorted and the finer parts of the till have been washed away. It will be noted that the pellmell layer at the south overlies the stratified portion. Apparently a small kame was first deposited with a stratified structure, and subsequently the advance of the ice pushed the sediments forward sufficiently to mix up the several layers near the surface and destroy the stratification.

The hills extending from Palermo to Dixmont and Newburg rise 300 to 600 feet above the broad plain-like valleys of the Sebasticook and Soudabscook, situated to the north of them. These hills would stop the flow of ice southward during the final melting of the great glacier long before the ice had disappeared in the lowlands to the north. As the ice gradually retreated northward, it would often happen that lakes would be inclosed between the ice and the hills to the south of them. Within the limited time these lakes were in existence no very large amount of sedi-

MEANDERING OF OSAR; DETROIT.

The road and fence follow the osar ridge, which is nearly covered by marine clays.

ment could have been deposited, except where the larger glacial rivers flowed into them. It is possible that some of these lakes left too scanty sediment to be now recognizable. The glacial lakes of central Dixmont, as well as others to be hereafter named, also the short kames of Plymouth and Troy, seem to be connected phenomena, all pointing to the time when the ice front had retreated a short distance north of the hills. There was probably but little motion of the ice at this time.

1. A still higher range of east-and-west hills lies only about 30 miles to the north of the Palermo-Dixmont Hills—those lying south of the Piscataquis River. These would cut off the southward flow of the ice nearly as soon as the lower hills to the south. Thenceforth there would be no pressure and supply of ice adequate to cause much advance of the ice even over so level a plain as the Sebasticook Valley.

2. I have been able to find no very noticeable terminal moraines on the northern slopes of the Palermo-Dixmont Hills at the places where I have crossed them, though there are many irregular heaps of till, and these may yet be explained as the best approach to a terminal moraine which can be made by a mass of rather slow ice that is not receiving its moraine stuff on its surface, but from below, and is gradually retreating.

3. But that there was some motion is probably proved by the observations at Cooks Corner, Troy, where we seem to have an instance of the ice advancing and obliterating the stratification of the surface portion of a kame.[1]

GEORGES RIVER SYSTEM.

This is a discontinuous system of short ridges and lenticular hummocks. It begins about 3 miles south of North Searsmont. The gravel here is plainly water assorted, but the stones are only a little polished, retaining their till shapes except at the angles. This indicates that we are near the north end of the system. About 1½ miles south of this is another short ridge; the next one is in the southwest part of Searsmont Village, and from this point the series lies near Georges River all the way to Thomaston. The gravels take the form of ridges one-third of a mile or less in length, and they are more often mere elongated domes or mounds. The intervals are several times as long as the ridges, and are a constant feature of the

[1] For the facts near South Albion, see pages 165 to 167.

system from end to end. They vary from one-fourth mile to 1½ miles in length. The system seems to end in a cone or dome of glacial gravel situated on the east side of Georges River, just above the railroad bridge at Thomaston. The gravel lies for most of the way on the west side of the river, and not far above it. The system lies in the towns of Searsmont, Appleton, Union, Warren, and Thomaston.

Near Union Village a small mound of this series shows contorted and folded strata overlying stratified material. The dome lies so low in the narrow valley that it is very improbable an ice floe came from the north with sufficient force to distort the stratification. More probably the gravel was deposited beneath the glacier and the distortion was due to the pressure of the moving ice. This system is in a region once wholly covered by the sea, unless on the extreme north.

The length is about 8 miles.

HARTLAND-MONTVILLE SYSTEM.

A series of rather short ridges begins near the top of a high range of hills in the northern part of St. Albans. It extends southward past Indian Pond and through St. Albans Village, and thence southwestward along a branch of the Sebasticook River. A short distance south of Hartland Village this series unites with another, which takes the form of a large ridge beginning at the south shore of Moose Pond and thence taking a southern course through Hartland Village. The gravel of the latter series is much rounder than that of the St. Albans series, which is but little worn. This indicates that the Moose Pond system probably has a northward extension. The Cambridge-Harmony eskers hereafter to be described would naturally be a part of this system, but thus far I can not prove a connection. From Hartland the united series continues south as a quite continuous osar ridge for several miles. In the southern part of Pittsfield the system is interrupted at several places. About one-half mile north of Pittsfield it rises into a rather high cone called the "Pinnacle." From this point southward through Pittsfield, Burnham, and Unity the gravel takes the form of a nearly continuous osar with very gentle lateral slopes. It rises 10 to 30 feet above the marine clay which borders and partly covers it. In places the ridge is nearly one-eighth of a mile broad, yet it is rounded on

the top, so that its cross section is almost always arched. At Peltoma Point the ridge crosses the Sebasticook River. The river can be forded on the top of the ridge, but the water is much deeper on each side. It also rises nearly to the surface while crossing Unity Pond. The ridge broadens south of Unity Pond, and from near Unity Village a plain of complicated structure extends south along the valley of Sandy Stream almost to Thorndike station. The plain fills the valley from side to side, and is from one-fourth to one-half of a mile wide. It shows some arched ridges of gravel, bordered and often covered by a more nearly horizontally stratified stra-

FIG. 16.—Osar; Pittsfield.

tum of fine gravel, sand, and clay. Originally there were kettleholes, but most of them have been filled or nearly filled by the later sediments. The sea certainly extended to Unity, as is proved by marine fossils. How far it extended up the valley of Sandy Stream is uncertain. The contour of 230 feet would be found 1 or 2 miles south of Unity Village. The origin of this plain will be discussed more fully later.

Not far from the junction of Sandy Stream with Half Moon Stream the gravel comes up out of the valley. For a half mile southward it takes the form of a broad osar, or perhaps delta-plain. Then for several miles it

is a two-sided ridge, or often a terrace on the hillside west of Half Moon Stream and 50 feet or more above the stream. It skirts the eastern slopes of a high hill in Unity and Knox, and near Chandlers Corner crosses the north branch of Half Moon Stream, and within one-eighth of a mile disappears as a two-sided ridge. Here it required careful observation to determine the course of the glacial river, and the result was quite unexpected. The ridge seems to be lost at the northern base of a range of hills 300 to 500 feet high. This range is several miles in length and has a northeast-and-southwest direction. Along its northern base is a depression, or valley, occupied by the south branch of Half Moon Stream, which flows northeastward. It is from 100 to 400 feet wide and from 20 to 40 feet deep. In places nothing but till can be seen in the steep banks inclosing it, and it looks like a large canal cut in a deep sheet of till. In other places there is a steep wall or cliff of solid rock 10 to 30 feet high, glaciated on the top, bordering the valley on the north, and it is thus proved to be, in part at least, a valley of preglacial weathering and erosion. It is parallel with the strike of the upturned pyritiferous and other easily weathered slates and schists characteristic of this region. The depression, being transverse to the direction of general glacial movement, became more or less filled with till. The bottom of this valley is covered by a level-topped plain of sand and well-rounded gravel 10 to 20 or more feet in thickness and 1 to 400 feet wide. The south branch of the Half Moon Stream flows in this valley for about 2 miles, but it is a small brook, such as ordinarily has in that region a flood plain containing only 1 to 3 feet of gravel, the stones of which have the till shapes almost unchanged. Plainly it is incompetent to deposit any such plain of sand and rounded gravel as that found in its valley. At one place the brook soaks into the gravel and disappears except in time of flood, when it can not seep into the gravel as fast as the flow from above, and the surplus water then for a time escapes by an overflow channel over a rough and crooked bed evidently recently eroded in the till and gravel. As this channel is dry most of the time, it is locally known as the "Dry Stream." The water which disappears in the gravel, as above described, comes out again about one-fourth of a mile below in the form of boiling springs, which are eroding the gravel more rapidly, working from beneath, than both the main stream and the overflow stream combined are eroding it above where the water disappears in the gravel. In this way the gravel plain has been eroded for more than one-fourth of a

mile from where we lost the osar as a two-sided ridge. It is evident that the valley is filled by a rather narrow osar-plain. It extends continuously

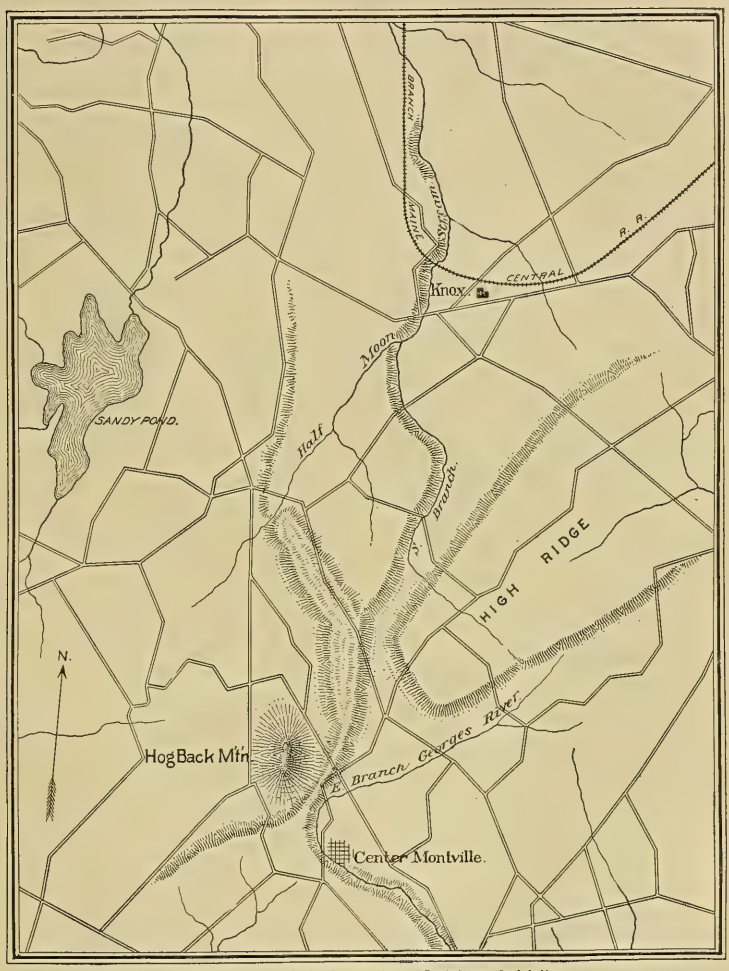


FIG. 17.—Map of Hogback Mountain; Montville and vicinity.

for about 1 mile and then is interrupted by two or three gaps of one-third mile each or thereabout. In places the erosion has revealed arched ridges

of coarser gravel, which were afterwards covered by at least 15 feet of fine gravel, and finally sand and clay, more nearly horizontally stratified and extending across the valley before mentioned. This remarkable depression is bordered much of the way by a steep bank of till, especially on the north. It extends for about 3 miles along the base of the high hills, when it comes out to a very low north-and-south pass through the range. To the west of this pass rises Hogback Mountain, and I will term it the Hogback Mountain Pass. For a short distance east of this pass the bottom of the U-shaped valley containing the osar-plain is rather stony, then for one-fourth mile or more there is a curious narrow bog, occupying the northern part of the valley, while on the south side is a level terrace, apparently composed of till. This terrace is several feet higher than the bog. A cross section of the valley at this point is shown in fig. 18.

This part of the valley is bordered by a bluff of till 20 to 25 feet high. It is as steep as the banks of most streams, and shows every mark of an erosion cliff. In this part of the valley only very local drainage takes place, since even the little south branch of the Half Moon Stream enters the valley to the east of this point. These facts establish the following conclusions: The osar river came to the northern base of the high hills and turned southwest along a small previously existing valley. This valley consisted of a valley in the rock which had become deeply filled by till. The stream flowing in the valley eroded the till to a considerable depth, leaving its channel bordered by cliffs of erosion. The narrow bog above described was once an erosion channel deeper than the rest of the glacial channel. Originally it formed a small lake, but by degrees has become peated over. As the velocity of the osar river diminished during the final melting, the osar-plain was deposited in the lower part of the channels, though near the highest point of the region crossed but little if any gravel was deposited.

FIG. 18.—Section across channel eroded in the till; Montville. *a*, bog in channel of erosion.

At the north end of Hogback Mountain Pass the system we have been tracing from Hartland and St. Albans is joined by a tributary branch, which begins near Freedom Village. It follows a low pass southward, over a hill about 100 feet high, where its course is bordered by a bluff of till so steep

HOGBACK MOUNTAIN. LOOKING WEST ACROSS SOUTH END OF PASS.

Hillside esker, tributary to main system, in foreground. The house on the left is situated on plain of lake deposits of glacial gravel.

as to suggest that it has been eroded, then passes Halldale and soon crosses the valley of the south branch of Half Moon Stream. Here it expands into a plexus of reticulated ridges near one-fourth mile wide and 1 mile long. Thus, at their junction these two glacial rivers must have behaved very differently. The long Hartland glacial river swept everything before it and eroded a deep channel in the till, while the shorter Freedom River deposited a very large amount of sediment. For some reason the waters of this river were slowed down as they came to the level ground north of the junction of the two glacial rivers, though they must

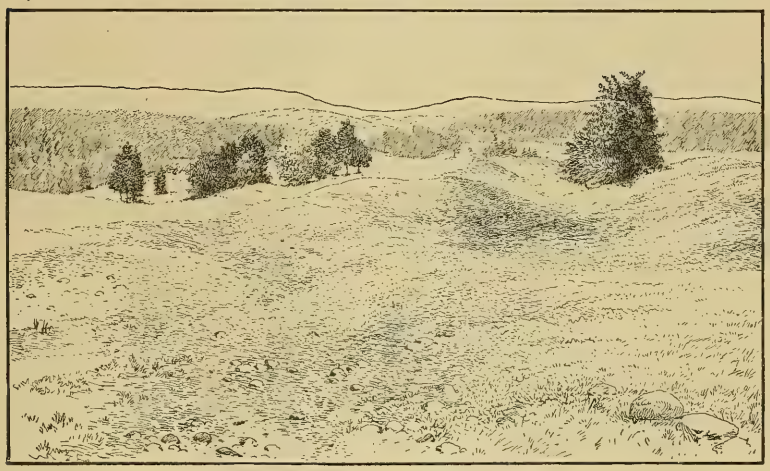


FIG. 19.—Reticulated ridges and Hogback Mountain, from the north.

have been swift to the north of this place in order to have swept down so much gravel, much of it containing cobbles and bowlderets. South of their junction I have not been able to distinguish the gravels of the two streams.

A series of broad and somewhat reticulated ridges, inclosing kettle-holes and large basins containing peat swamps, extends southward through the Hogback Mountain Pass. The roadbed occasionally sinks into the peat of one of these swamps. The pass is somewhat more than a mile long and less than a fourth as broad. At the south end of the pass a short hillside esker comes down the slopes of the hill lying on the east side of the pass and joins the main system in the valley. The gravels

at the south end of the pass present some very interesting developments. The east branch of Georges River (or St. Georges River, as it is named on many maps) rises in the hills east of Hogback Mountain. It flows westward to the south end of the Hogback Mountain Pass, and then south and east through Montville and Searsmont. A plain of gravel bowlderets and bowlders (all well rounded) extends from the south end of the pass for a half mile down the valley. The material is coarse even to the margins of the plain. Southward in this valley the glacial gravel is scanty and discontinuous for about 2 miles on a down slope of 20 to 40 feet per mile, yet at intervals it is found in small masses. It forms a small terrace on the western side of this stream at Center Montville, and, becoming more abundant toward the south, soon spreads out into a rather level plain 2½ miles long and more than 1 mile wide. This is situated not far northwest of North Searsmont. Toward the south the gravel of this plain passes into sand, and this again into clay, which extends continuously down the valley of Georges River to the sea. This is evidently a marine delta, and seems to terminate the gravel system in that direction.

We now return to the plain of coarse glacial gravel at the south end of Hogback Mountain Pass. This deposit is somewhat triangular in shape. One apex is at the south end of the pass, another extends down the valley of the east branch of Georges River, while the third lies in a depression along the southern base of Hogback Mountain, about one-half mile southwest of the first. From the last-named point a narrow plain of glacial gravel and cobbles extends for a short distance southwest along the base of the "mountain." The Muskingum Stream drains the area south of Hogback Mountain and joins the west branch of Georges River near South Montville. It has several tributaries, the largest two of which I will call the east and west branches. We have seen that the osar river followed the base of the mountain southwest for a time. By turning to the south and crossing a col only 20 or 30 feet high, it might have flowed south along the east branch of the Muskingum Stream. It actually rejected this pass, and about one-third of a mile farther west turned southward along the valley of the west branch of Muskingum Stream. Within 3 miles it left this valley and went obliquely southwestward over a low divide into the valley of the east branch of the Muskingum Stream, the same valley it could so much

DIVERGING DELTA BRANCHES OF OSAR; HOGBACK MOUNTAIN PASS. LOOKING NORTHEAST.

Field bare of trees in front of pass consists of gravel deposited in glacial lake. One line of gravel extends westward along the base of Hogback Mountain (on the left); the other extends southward down the valley of East Branch of Georges River (on the right).

more easily have entered at the southern base of Hogback Mountain. On the down slopes in this part of its course the system is somewhat discontinuous. Near where the system enters the valley of the east branch of the Muskingum Stream it expands into a plain of reticulated ridges, with an outlying bar directed toward the southwest, but I could find no prolongation of the system in that direction. Just north of this plain lies a narrow, almost V-shaped, valley, bordered by rather steep cliffs of till. No ordinary stream flows in the valley, except the merest brook, and the appearances are as if the glacial river had here eroded the till. The gravel system here turns east and crosses the road leading up the valley of the east branch, and then becomes a prominent feature of the valley southward to the settlement in Montville known as the "Kingdom," being alternately on the east and west sides of the road. The gravel appears like a rather level terrace at the side of the stream, but there is no corresponding terrace on the east side of the valley. Well-rounded bowlderets and bowlders abound in the gravel and at once betray the glacial origin of the deposit. Near the "Kingdom" the gravel expands into a large plain—the Liberty Plains—which nearly fills the broad level valley, in the midst of which lies Trues Pond. One tongue or expansion of these plains reaches from near Liberty Village southeastward almost to South Montville, but the principal expansion is south and west, and this seems again to divide into two parallel plains inclosing between them Stevens Pond and then continuing on southwestward through Liberty into Appleton. Near the "Kingdom" and Liberty Village these plains consist of broad reticulated ridges of very coarse matter, inclosing kettleholes and even lake basins. Southeast toward South Montville they become rather level on the top and finer in composition, while the long narrow plains which extend southwestward into Appleton show very clearly the transition from coarse sediments on the north to fine on the south, characteristic of the delta. On the south these sand plains pass by degrees into sedimentary clay, which extends all the way down the Medomac Valley to the sea. The more level portions of the gravel-and-sand plains of Liberty and Appleton are thus proved to be marine delta-plains. In the narrow valley of the west branch of Georges River at South Montville no sand or gravel appears for about one-fourth of a mile. Then begins a delta-plain extending about one-half mile eastward toward Searsmont, and then sending out a long tongue southwestward for about 3 miles into Appleton.

I find no signs of any glacial streams that could have deposited the last-named plain except that delta branch of the Hartland system which radiated southeast from the "Kingdom;" neither could I trace this system farther south than the delta-plains in northern Appleton.

SUMMARY.

The Hartland-Montville osar river must have deposited its gravels late in the osar period, or, like the Katahdin and other osars, it would have deposited gravels all the way to the sea. At this time the sea stood at or near the contour of 230 feet, and the delta-plains of Liberty and Appleton do not extend much below that elevation. In the Sebasticook Valley, for about 20 miles, from Hartland to Unity, the system traverses a region that was at one time submerged in the sea, as is proved without a shadow of doubt by the great numbers of marine fossils found in the sedimentary clays which partly or wholly overlie the glacial gravel. But at the time when the delta-plains in Liberty, Appleton, Searsmont, and Montville were being laid down, the Sebasticook Valley must have been covered by ice, as is proved by the great size of the glacial streams by which only could so large plains be deposited. The glacial waters of the Sebasticook region then poured southward through the Hogback Mountain Pass over a divide not far from 200 feet above the level of the osar at Unity Pond. Into the north end of this pass two glacial rivers flowed from the north, one from Unity and Hartland, the other from Freedom. At the south end of the pass the system received another tributary, while from the enlarged channel or glacial lake at that point two delta branches diverged, one flowing south and the other southwest, and they emptied into the sea at points about 10 miles distant from each other. The narrow delta-plains in Liberty and Appleton are in a level region, where, if the glacial river had flowed into the open sea, they ought to have spread out in fan shape. That they remained so long and narrow is an indication that they were not deposited in the open sea, but in bays of the sea which extended back into the ice. The question whether a stratum of floating ice was over these plains will be considered elsewhere. The plain northwest of North Searsmont is more broadly fan-shaped. Its northern end extends across the valley of Georges River, and the delta was probably deposited in the open sea.

Did the two glacial rivers, which diverged from the south end of the

Hogback Mountain Pass, flow simultaneously? I was unable to find any conclusive facts in the field. Two reasons can be given why it is probable that the Liberty branch was the earlier.

1. The delta-plains of this system seem to date from a time when the ice had not receded so far north as at the time the North Searsmont Plain was being deposited. 2. The glacial stream which formed the last-named plain flowed not only down a valley of natural drainage, but parallel with the direction of glacial flow. The gravel, too, is scanty for some distance on the steep down slopes, so that the glacial channels did not there become clogged with sediment. I see no reason why this stream should cease to flow, or why, after it once had been established, it should not carry away all the water that poured southward through the pass. On the other hand, the southwestern channel was over higher ground, and for a time was transverse to the lines of flow of the ice. At any time the south channel should be opened this stream would cease to flow, except possibly when the water was very high. The history of the gravel plain at the south end of the pass is probably about as follows: Originally the glacial river flowed by the southwestern channel and solid ice blocked the valley of the east branch of Georges River. Then a lake was formed within the ice at the south end of the pass, in which was deposited the coarse matter of the plain, or a part of it. The lake gradually enlarged, so as finally to extend for one-fourth mile or more eastward into the valley of the east branch of Georges River, which, as already stated, extends eastward from the south end of the Hogback Mountain Pass. In this enlarged lake was deposited the thick sheet of sedimentary clay and silt which covers this valley to the east of the pass. Finally the barrier of ice in the valley was in some way penetrated toward the south and a new channel was established down the valley to Center Montville and to the sea near North Searsmont. This channel would naturally come to be lower than the other, so that it would carry off all the water of the glacial lake, except in times of great floods, when the southwestern channel might still, for a time, serve as an overflow channel. In process of time the south channel would become enlarged so as to take off all the water by the lowest route. All the field phenomena could be produced by two streams flowing simultaneously. But much the larger stream flowed southwest, and it deposited far more gravel than the other. These facts favor the conclusion that it flowed much longer than

the other stream. If the two channels were formed simultaneously, I can conceive no reason why the south channel on a down slope should not enlarge as fast as the southwestern channel on an up slope. If they enlarged with equal rapidity, the larger amount of sediment ought to have been deposited by the eastern instead of the western stream. These facts all combine to justify the conclusion that the diverging delta streams were for most of the osar period not simultaneous, but that the Liberty branch was the earlier.

During the final melting there must have come a time when the thinning ice could no longer flow southward over the hills and when the supply of glacial water from the north would be diminished. The glacial river flowed sluggishly, and presently in the osar channel northeast of the north end of Hogback Mountain Pass there was deposited an osar-plain of fine gravel and sand, and finally clay. As the ice continued to melt, the ice front began to retreat northward from the hills, and there came a time when a lake occupied the valley of Half Moon Stream. This valley is widely covered by a sheet of sedimentary clay to a height of at least 260 feet above the sea. The small Half Moon Stream could not have deposited this clay as ordinary valley alluvium, for it reaches at least 30 feet above the stream. The most probable interpretation is that in Thorndike, Knox, and Unity there was a glacial lake several miles long confined between the ice on the north and the hills on the south, east, and west. It may not have always stood at the same height. For a time this lake may have overflowed south through Hogback Mountain Pass. Into the lake still poured a supply of glacial water from the north, and in it was deposited the delta-plain situated between Unity and Thorndike which overlies the ridges previously deposited in narrow ice channels in the midst of the valley of Sandy Stream. This delta reaches from near Unity Village almost to Thorndike station. But in the meantime the sea had been advancing up the valleys of the Kennebec and thence eastward over the broad valley of the Sebasticook River. If it first advanced along the south side of the high hills which border the Sebasticook Plain on the south, then it might be that the extreme northern part of the delta-plain south of Unity Village was deposited in the sea. With possibly this exception, the advance of the sea was so simultaneous over the Sebasticook Plain that no marine deltas were formed by this glacial river in that part of the State,

unless the plain in Cambridge and Harmony, soon to be described, was formed by a remnant of this glacial river which still continued to flow after the ice in the main Sebasticook Valley had disappeared but while the ice still lingered north of Moose Pond

The length of the system is 45 miles.

CAMBRIDGE-HARMONY GRAVELS.

A series of low sand-and-gravel ridges, or narrow plains, extends from near Main Stream in Cambridge northward past Cambridge Village and then for 2 or 3 miles into the southwestern part of Parkman. The stones are barely rounded on the angles, and in general the gravel is fine. On the south the series spreads out into a sand plain in the Main Stream Valley. This plain appears to have been deposited in the valley after the ice had there melted, though still remaining northward; yet the sand may have been laid down in a glacial lake. The currents which assorted these sediments were rather gentle, and probably the formation dates from a very late portion of the Glacial period.

Another ridge is found near the line between Harmony and Cambridge, ending in the south near the northern shore of a large pond above Main Stream Village. Toward the south the material becomes fine, consisting of sedimentary clay overlying fine sand.

A short gravel deposit is found near Main Stream about a half mile south of Main Stream Village.

A gravel plain, probably glacial, is found in the south part of Harmony, in the valley of a small stream. It resembles an osar-plain. It is possible that this extends northward past Harmony Village. I have note of sand and clay in the valley of the Sebasticook above Harmony, and they may be of glacial origin in part.

Probably a large area in Cambridge, Parkman, Wellington, and Harmony was at one time drained of its glacial waters by the large glacial river which flowed from Moose Pond south past Hartland. But if so, the proof is not easily derived from the distribution of the gravels. The gravels in this region seem to date from a late period, when the ice had retreated north of Moose Pond, and the glacial streams were in fact soon discharged beyond the ice front into the open valleys.

PALERMO-WARREN SYSTEM.

This system begins in Palermo near where the towns of Palermo, Freedom, and Montville join. Here a north-and-south ridge of till becomes more stony toward the south, and by degrees passes into unmistakable glacial gravel within one-fourth of a mile. The fact that the glacial gravel consists of the till with the finer detritus washed out of it is here well exhibited. Near the east branch of the Sheepscot River this ridge turns southwestward, and follows the valley for several miles. This stream flows along the northern base of the high northeast-and-southwest range of which Hogback Mountain in Montville is a part. Much of the way along the valley the gravel is in the form of a ridge, but it becomes terrace-like and somewhat discontinuous as it approaches Sheepscot Great Pond. This pond lies in the midst of a cirque 5 miles in diameter. This broad, rather level valley is surrounded on all sides by rather high hills except at a few narrow passes. The lowest depression is southwest down the valley of the east branch of the Sheepscot River, but the glacial waters rejected the valley of natural drainage and took a course over higher ground to the south and southeast. Two lines of glacial gravel extend from Sheepscot Great Pond southward. For 2 or 3 miles they are nearly parallel and only from one-fourth to one-half mile apart. The western series takes the form of an osar-plain one-eighth to one-fourth mile wide. It penetrates a low pass along the western base of the high granite peak called Patrick Mountain, and continues as an osar-plain till it nears Jones Corner, on the road from Somerville to South Liberty. Here it takes the form of a two-sided ridge of arched cross section for about 1 mile. In this part of its course it turns east by a rather abrupt curve and then closely skirts the southern base of Patrick Mountain. In so doing it crosses a hill about 75 feet high, the gravel disappearing for one-third of a mile on the up slope. Near the top of this hill it takes the form of an osar-plain for a short half mile, and then, on a steep down slope, there is no gravel for near 1 mile to Branch Stream, which flows south into Damariscotta Great Pond at East Jefferson.

We now go back to the swampy plain south of Sheepscot Great Pond in the midst of the remarkable Palermo basin, where the two lines of glacial gravel are found side by side. The more eastern of the two formations has the form of a broad osar, with arched cross section. It soon diverges from

the western series and takes a southeast course through "The Gore," a portion of land unattached to any town, and passes around the northeastern base of Patrick Mountain. In so doing it goes up and over a hill 100 feet high, and then descends into the valley of Branch Stream, where it turns southward and soon unites with the series which diverged from it near Sheepscot Great Pond to go around the western base of Patrick Mountain. Except on the steep down slopes and one gap on an up slope, the gravels are continuous along the courses here indicated. The material is in general rather coarse, many cobbles, bowlderets, and some bowlders being mixed with the sand and gravel. The stones are all very round, an indication that they are part of a long system, not of a local one. The field proof is positive that these large glacial rivers diverged from each other so as to go around opposite sides of a high hill and then came together. In both cases we find little or no gravel on down slopes of from 50 to 100 feet per mile, but it is certain the glacial streams came from the north to the top of the hills, and must have flowed down them; and at the base of the hills the gravel begins again. It is a fair inference that on the steep slopes the glacial streams were so rapid as to deposit little, if any, sediment.

From where the two glacial rivers united, in the valley of Branch Stream, a nearly continuous osar-plain extends southward near the stream for a few miles, when the gravel leaves this stream and takes a course southeastward, soon expanding into a large, somewhat fan-shaped plain, situated not far southwest of Newhalls Corner, in Washington. This plain consists, toward the north, of broad reticulated ridges inclosing shallow hollows. The material here is coarse. Toward the south the plain becomes quite level and the gravel passes into sand and finally into the marine clay. It is 2½ miles long and more than a mile wide. It is plainly a marine delta, and its shape is such as to make it probable that it was deposited in the open sea, possibly in a very broad bay of the ice. Its outlet has cut down a channel 100 or more feet wide to a depth of about 4 feet, and numbers of ordinary till bowlders are exposed where the gravel has been removed. The little polishing they may have received from the gravel has been obliterated by weathering. The same thing is observed over a considerable area, and proves conclusively that the glacial gravel and sand overlie the till and are without admixture of till; hence they were deposited after the melting of the ice at this place. The outlet of the lake above described

flows southward. In the southeast part of the plain the gravel is deeper and has been eroded considerably by boiling springs. A ravine 10 feet deep has been eroded back into the plain for one-fourth of a mile or more. In many places this delta-plain is overlain to the depth of 1 to 3 feet with marine clay. From this point southward the system is discontinuous and consists of short ridges, lenticular mounds, and round-topped plains, except a delta-plain at its south end. The gravels are separated by intervals of from one-eighth to one-half of a mile, generally the shorter distance. It is specially noticeable in case of the southern part of this system that the gravels appear on the tops of low hills or at the brow of broad hills, while the lowlands show little or no gravel. The series crosses Medomac Pond, and thence its course is easily followed along the road from North Waldoboro to Warren. At the western edge of the valley of the Warren ponds the system divides into two series. One crosses to the east side of the valley at once, the other follows the eastern brow of the hills which border this valley on the west. In a mile or two this series also crosses to the east side of the valley, and then takes a course nearly parallel with the other series. They pass southward, and not far southeast of Warren station they end in sand plains. For the last mile or two they are quite continuous and form plains one-eighth to one-fourth mile wide, and hence resemble the parallel plains of Liberty and Appleton. Their shapes and their situation on the tops of hills prove that they were deposited within ice walls, or the gravel would have spread out into broad fan-shaped plains. The discontinuous portion of this system—that part where gaps form a constant feature of the system, not an occasional gap on a steep down slope—is noticeable for the large amount of gravel which it contains, the lenticular plains which cap the hills being larger than the average. In the valley of Georges River and the Medomac above Waldoboro the gravels are in or near the lowest parts of the valley. But in general this system seems to delight in the highest ground that lies in its course, leaving the low valleys for the gaps.

Two or three short tributaries entered the main glacial river near Sheepscot Great Pond. They drained the large Palermo cirque. Their gravels are but little water polished, and they are evidently only short branches of the main system.

Length from Palermo to Warren, 23 miles.

SHORT ESKERS IN WALDOBORO.

Two small and rather level plains of sand and gravel are found a short distance south of the terminal moraine in Waldoboro, elsewhere described, one on the road from Waldoboro to North Waldoboro, the other about half a mile east of this on the road to Union. Both seem to be small marine delta-plains. Their north ends lie a short distance south of the terminal moraine, but thus far I can not connect them with this moraine in a genetic way. The marine clay covers the deposits on the flanks and makes it difficult to trace the connections of these sands.

MEDOMAC VALLEY SYSTEM.

This system begins in the valley of the Medomac River about 2 miles north of Winslows Mills, and extends southward to Waldoboro Village. For most of this distance its course is near the stream in the lower part of the valley. The series consists of short ridges and elongated mounds, or sometimes more nearly cones, separated by intervals of one-eighth to one-third of a mile, and is discontinuous from one end to the other. None of the deposits are more than about 20 feet high, and many of them are much lower. They are often covered wholly or in part by the marine clay. Toward the north end of the series the gravel is but little waterworn, and at the last can hardly be distinguished from a sandy till. The relations of this gravel system to the terminal moraine at Winslows Mills will be referred to hereafter.

Length, about 5 miles.

LOCAL GRAVELS IN NOBLEBORO AND JEFFERSON.

A gravel ridge comes from the north and enters the so-called Great Bay at East Jefferson. It can readily be traced northward up a hill for about a mile, where it seems to end in a low pass. To the north of this pass, in the northern part of Jefferson, is a short ridge of subangular glacial gravel, but I could trace no evident connections southward. Gravels are reported at various points along the Damariscotta Great Pond, but I am uncertain whether they are old beaches or not. Near Muscongus Bay station of the Maine Central Railroad is a small plain of glacial gravel. Another appears about one-fourth of a mile farther south, and a third

within a mile farther, near Nobleboro Post-Office. The three gravel plains south of Muscongus Bay have a linear arrangement; probably they all are deltas, and they may have been deposited by the same glacial stream. Whether they are connected with the East Jefferson gravels is uncertain. Two other small gravel plains are found in Nobleboro north of Duckpuddle Pond. A small ridge of glacial gravel is found near the west shore of Damariscotta Great Pond, about 3 miles north of the south line of Jefferson; and 3 miles farther north another small ridge is found on an east-and-west road. All of these local gravels are found in a region that was under the sea. Old beaches abound in the same region, and it requires some care to distinguish the glacial from the beach gravel.

DYERS RIVER SYSTEM.

A very discontinuous system seems to begin in Jefferson, west of Dyers Long Pond, and extends southward about 4 miles along the valley of Dyers River. It then passes obliquely out of the valley southeastward into a rolling plain near 100 feet above the stream, and appears to end near Great Meadow River in Newcastle. So far the system is pretty well defined. About 2 miles from the north end of the system, as above described, are two short gravel ridges, and a mile farther north, at West Jefferson, is a gravel-and-sand plain one-half mile long and a full eighth of a mile wide. This is probably a marine or lake delta. A trotting track has been made on it. One mile northwest of West Jefferson are two short but good-sized ridges, and 2 miles north of them are two small ridges, in the valley of the west branch of the Sheepscot River. Two miles farther north is a small gravel deposit, near Coombs's store in Windsor. All of these last-named gravel deposits have a linear arrangement and are situated along a route level enough for the passage of a glacial river without its having to cross hills higher than about 100 feet, but the gaps between the gravels are so long and the deposits so small that it is uncertain whether they were deposited by the same glacial stream. Most of the deposits of Dyers River system, as well as the very widely separated gravels north of them, are situated on the tops of hills, or on their flanks, 50 or more feet above the adjacent valleys. The gravel is all pretty well rounded.

Its length is 12 miles.

SOUTH ALBION-CHINA SYSTEM.

About 2 miles east of South Albion (Puddledock), at the northern base of the high hills which border the Sebasticook Plain on the south, is a plain one-fourth mile long and more than half as wide. It contains many well-rounded bowlderets and bowlders 2 to 3 feet in diameter. On all sides it ends in a bluff 20 to 30 feet high. To the north is the gently rolling plain of the Sebasticook Valley, covered for many miles with marine clays. I could find no similar deposits to the north or east of this plain. A series of similar broad level-topped plains, separated by short intervals, extends southwest of this point along the northern base of the hills, at a height of 50 to 75 feet above the clay plain. Some of these plains are bordered on both sides by steep banks; others were deposited against the side of the hill as terraces. These plains present a curious alternation of areas of coarse gravel, containing bowlderets and bowlders, with areas of sand, as if these were a series of deltas deposited in broad channels in the ice which were practically glacial lakes. The terraces become narrow near South Albion. From this point for several miles they are in a narrow valley in which a branch of Fifteenmile River flows northeast to South Albion. Usually the gravel takes the form of terraces on the east side of this valley, while one-fourth of a mile distant on the opposite side of the valley, or often less than half that distance, are a large number of morainal heaps and ridges. In several places the appearances are as if a glacial stream flowed through the valley while the ice was still thick. Then later a narrow and thinner tongue of ice, practically a local glacier, lingered for a time in the valley, and at this time the glacial river assorted the moraine stuff that was cast down on the east side of the valley, while on the west side the lateral moraine retained its pellmell structure. These heaps of till may be in part the terminal moraines of the hypothetical local glacier formed during its retreat northward. If these peculiar masses of till are not due to a local movement, as suggested, they are a strange freak of the general movement.

In the southwestern part of Albion the system crosses a very low divide and continues straight on through China to the northeastern base of Parmenter Hill. It here turns abruptly westward and skirts the north and west bases of this high hill, taking the form of a narrow plexus of two or

three ridges inclosing numerous kettleholes and one or two lake basins. The ridges become broader toward the south and coalesce into a level plain of sand, which ends near the road from Branch Mills to China Village. Within a short distance the gravels begin again and continue in a nearly straight line southwestward, ending about one-fourth of a mile south of Weeks Mills, in the southeastern part of China. For several miles the gravels are in the form of a long plain one-fourth mile or less in breadth. Near Weeks Mills the plain consists of one or more ridges of arched cross section, flanked and sometimes covered by fine gravel and sand, and the plain is bordered by sedimentary clay, which extends down the Sheepscot Valley to the coast.

The structure of the plain indicates that a ridge was first formed in a narrow channel within the ice. Subsequently a marine or estuarine delta-plain was deposited in a broad channel open to the sea to the south, but still confined between ice walls at the sides. In some respects this delta-plain resembles the osar-plain in its form and relations to the central ridge, but in this case the original ridge was less modified than is usually the case in the osar-plain, so that the distinction between it and the bordering plain is quite sharply defined.

This system is remarkable for its large size at the extreme north end. This indicates a northward extension of the system, but I have not been able to find any. The country is so deeply covered by the marine clay that large gravel ridges might exist beneath the clay and not attract attention. Several ridges and mounds, probably of glacial gravel, are found near the east base of Parmenter Hill, and they may be a connection of this system.

The large size of the bowlders contained in the gravel plains at the north end of this system, together with their topographical relations, suggest that they were formed at the front of a mass of moving ice. Several other facts support the same conclusion:

1. This glacial river formed a marine delta in the southern part of China, 40 miles or more from tide water, at an elevation of about 200 feet, and there is no proof that it at any time flowed farther south. It must have been pretty late in glacial time when the ice had melted so far north as this.

2. As before noted, the ice could no longer flow south over the hills

which extend nearly east and west from Albion and Palermo to Newburg after it became less than 500 or 800 feet thick. About the same time that the flow was arrested here it would be arrested by another east-and-west line of hills situated about 30 miles farther north (those lying south of the Piscataquis Valley). The broad level valley of the Sebasticook would be filled by a sheet of ice sloping south, and it would for a time send out projecting tongues over the lower cols. One of the lowest of these passes is that which is followed by the South Albion-China system of gravels.

3. Since at this time the melting waters could escape only by the low passes, they collected near the hills and then flowed east or west till they found an exit. This water, being exposed to the sunlight, would melt the ice rapidly near the base of the hills which lay as a barrier to the south, and thus considerable sized pools or channels might be formed. The glacial streams from the north would flow into these, and at the same time there was a limited flow from the north of the ice. Thus the matter brought down by the glacial streams would be mixed with matter brought to the edge of the pool by the moving ice and subsequently dumped into the pool by the melting of the ice that held it. On this hypothesis the plains which lie along the northern bases of the hills near South Albion are a mixture of water-washed moraine and ordinary kame matter.

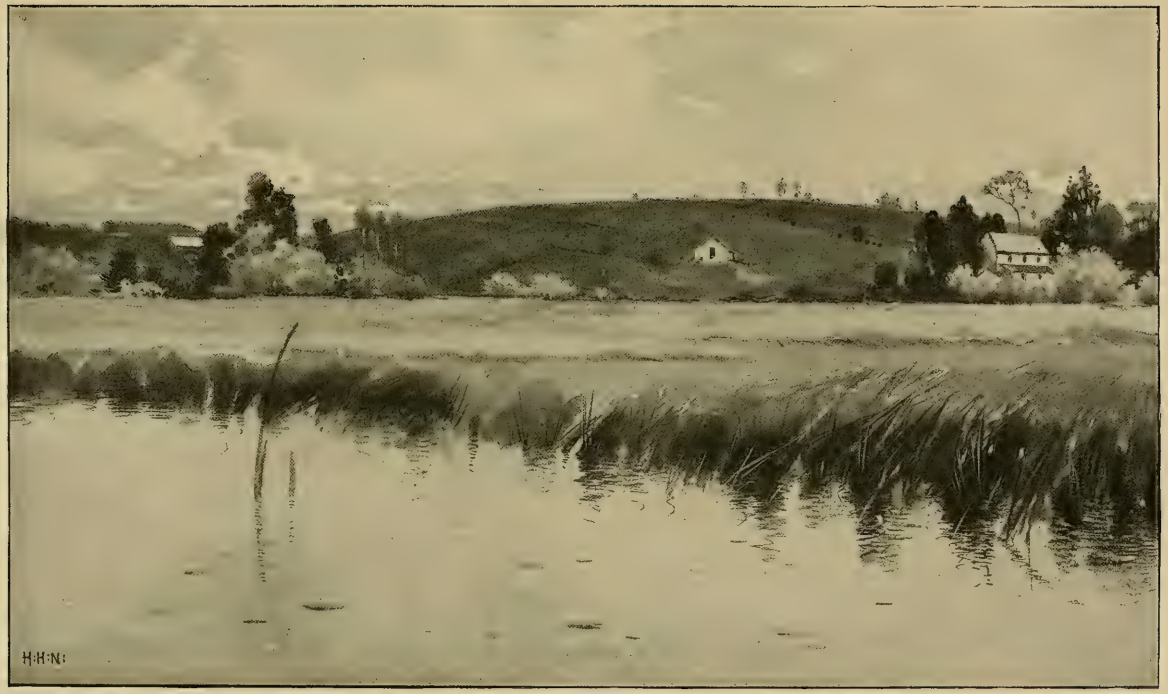
The local conditions at South Albion certainly favor a flow of ice to this point until very nearly all the ice was melted. The valley of Fifteen-mile River narrows toward the southwest so as to converge the movements into the narrow pass. A very small motion of the separate particles of ice over the broad plain stretching 30 miles northward would cause a considerable movement in the narrow valley. The ice there, being crowded against the hills, would not form a glacial lake extending from the hills back to a considerable distance northward. But the glacial motion could bring forward moraine stuff and throw it down into the broad channels and pools of the glacial river which drained the ice field lying to the north.

There are several enlargements of the delta-plain in China which are somewhat fan-shaped but not broad. They may indicate a gradual recession of the ice before the sea and the formation of a series of small deltas in the open sea, or perhaps frontal deltas.

The length of the system is about 15 miles.

CLINTON-ALNA SYSTEM.

This notable gravel system appears to begin in the southeast part of Canaan. It takes its course to Clinton Village by a line which in general is quite straight, but has many minor meanderings. It is here a nearly continuous osar. At Clinton it turns southwest and follows the valley of the Sebasticook River for about 3 miles, and here it is somewhat discontinuous, either because it was so deposited or on account of erosion by the river. About halfway between Clinton Village and Benton Falls the gravel leaves the valley of the Sebasticook and turns southward over a rolling country in Benton, Winslow, and Albion, being osar-like in form, but with several gaps at long intervals. From China southward the series becomes conspicuously discontinuous, the short ridges being separated by intervals up to more than a half mile in length. The system follows the west shore of China Pond, passing a short distance west of South China, and at Chadwicks Corner, in the south part of China, expands into a plain near a mile long and more than half as broad. This plain ends in a rather steep bank on all sides. A well 73 feet deep, dug at a point on the slope of the plain, and probably 50 feet below the top, did not penetrate the sand and gravel. Overlying this plain is a scattered drift closely resembling till and containing many bowlders of shapes characteristic of the till. South of this point is a series of lenticular domes separated by the usual intervals; then a broad plain near a half mile wide extending from West Windsor to a point 2 miles south of Windsor Village. This plain is rather level on the top, except that here and there are shallow basins and one deep lake basin. These plains are everywhere covered at the base by the marine clays, and are sprinkled on the tops and flanks by angular bowlders. The same sort of bowlders are scattered over the clays, though not so abundantly as on the higher gravel hills. They are probably of ice-floe origin. In Whitefield the gravel takes the form of a discontinuous series of short narrow ridges separated by numerous intervals of the usual length. It approaches the Sheepscot River near North Whitefield, follows this valley for several miles, and then in the southern part of Whitefield and northern part of Alna it expands into a delta-like plain three-fourths of a mile in breadth and nearly twice that length. This plain is situated on the tops of the hills, 50 to 100 feet above the Sheepscot River. South of this plain



LENTICULAR GRAVEL HILLOCK; CHINA.

A common form of the isolated domes of a discontinuous osar system.

there is an interval of a mile or more without gravel, and then a discontinuous series of short and not very broad ridges, which extends from Alna Post-Office (Head of the Tide) southward to Sheepscot Bridge, lying most of the way along a valley situated west of the Sheepscot River. A short distance north of Sheepscot Bridge the glacial river turned abruptly east and flowed up and over a hill, and then descended into the valley of the Sheepscot River, where the gravel becomes a little broader. Thence a series of low mounds and short ridges is found near the river to a point about half a mile south of Sheepscot Bridge, where the system ends at the shore of Sheepscot Bay. Like many other systems, the mounds of gravel become smaller toward the south. I explored the country in Newcastle and Edgecomb lying south of where the system disappears. There are many old beaches in the region, but no glacial gravels were found.

At three places this large glacial river deposited deltas in the sea. These are situated near the line between Alna and Whitefield, in the central part of Windsor, and possibly another at Chadwicks Corner, in the south part of China. Perhaps near the top of the hills in the southern part of Clinton the system was above the sea, but in all the rest of its course it lies in a country covered by the marine clays. No system in the central part of the State contains so much gravel as this.

Its length is 45 or more miles.

ALBION BRANCH.

A series of short ridges, separated by intervals of half a mile to more than a mile, begins about 1½ miles northwest of Albion Village, and takes a course south and west to join the main system about a mile north of China Village. Toward the north the gravel is but little water washed; so the series probably does not extend far in that direction.

WINSLOW-WINDSOR BRANCH.

A discontinuous series of short ridges begins about a mile south of the Sebasticook River in Winslow and extends southward along the crest of the hills bordering the valley of Outlet Stream on the east. It thence extends southward past East Vassalboro and near the northeast angle of Webber Pond; thence southeastward to the head of Threemile Pond; thence across this pond and in nearly a straight line to a point about 2 miles north of Windsor Village, where it joins the main system.

This series penetrates a rather level region and does not cross hills more than about 100 feet high. For its whole course it has been under the sea, and its bases are flanked and more or less covered by clay, often containing great numbers of marine fossils. The clay is more abundant along the line of the gravels than away from it on ground as favorably situated for the deposition of sediment by the sea. At the south end of Three-mile Pond, in Windsor, I had some difficulty in tracing the course of the osar river, as no gravel appeared on the surface. But passing obliquely up the hill at the south end of the pond was a belt about one-eighth of a mile wide which was free from bowlders, whereas there was a considerable number of bowlders on each side. Examination of the ravines of erosion on the hillside showed that here was a strip of clay much deeper than the marine clay on each side, which was not thick enough to conceal the larger bowlders of the till. Going southward along the line of thick clays, the glacial gravels soon reappear, and plainly underlie the clay. I infer that the gravels were first deposited in a rather narrow channel in the ice. This channel was subsequently greatly enlarged, although still bordered by ice walls. In this broad channel kame border clay was deposited. In the southern part of Vassalboro, not far from Webber Pond, a fine blue clay, apparently the kame border clay, is highly fossiliferous. Finally the ice all melted and the whole region lay beneath the sea. A thin sheet of purely marine clay was now spread over the kame border clay and all the previously deposited drift.

At several points along the line of this series short ridges are found at right angles to the main ridge. These were probably deposited by small tributary streams, yet in some cases they may be due simply to an abrupt enlargement of the main channel. Near the line of this series are a number of pinnacles and cones of till of quite irregular shape, which are more fully described elsewhere. Wells dug along the line of this series show that in general the sedimentary clay overlies the gravel. One well in Windsor, near the junction of this glacial stream with the main river, is dug through gravel into fine blue clay. Whether the gravel was deposited in this position by the glacial stream, or was washed down upon the clay by the waves of the sea, is uncertain.

The length of the branch is 14 miles.

SUCCESSION OF THREE LENTICULAR ESKERS, PART OF A DISCONTINUOUS OSAR; WINDSOR.

Shows linear arrangement of gravel masses, classified as discontinuous osars, and attributed to discontinuous sedimentation by a single glacial river

LOWER KENNEBEC VALLEY SYSTEM.

The northern connections of this system are not explored, and they may extend into Harmony and Wellington, and perhaps farther. A gravel plain about one-half mile in diameter is found in the southwestern part of Harmony and southeastern part of Athens. Thence a discontinuous series of low bars and terraces extends several miles southwestward along a low pass. In places the appearance is as if an osar-plain had been eroded so as to leave fragments of its former self here and there, but in general the gravel seems to have been originally deposited discontinuously. In the southeastern part of Cornville the gravel takes the form of a ridge, which extends nearly continuously through Canaan Village and thence southwestward through Clinton. It crosses the Kennebec River a short distance north of Somerset Mills and, as a continuous osar, follows the west side of the river through Fairfield Village and Waterville, below which place it becomes regularly discontinuous. Near Riverside, in Vassalboro, the series again crosses the Kennebec, and is found on the east side of the river through most of Augusta. In Hallowell and Gardiner the ridges are again found on the west side of the river. At South Gardiner the system crosses to the east side again, and continues on that side through Pittston and Dresden, expanding into a broad plain-like ridge or terrace opposite Richmond Village. This plain is a delta of some sort, but under what conditions it was laid down I have not determined. South of this point the gravels are increasingly discontinuous. Glacial gravel appears at three places on the east side of Swan Island (Perkins Plantation); also at Abagadassett Point, in Bowdoinham, at the head of Merrymeeting Bay, the broad body of fresh water or lake into which the Kennebec and Androscoggin rivers flow.

At South Gardiner and near Iceboro the gravels of this system form small islands in the Kennebec River. The largest plain in the whole system is the one near Moose Pond, in the southwest part of Harmony, at the north end of the system as here described. At this point a glacial stream flowed into either a glacial lake or the sea. It is not easy to determine the height of the sea in the vicinity of Moose Pond. Clays plainly marine extend up the Sebasticook Valley to Palmyra, where marine fossils are found.

Sedimentary clays of uncertain origin extend up the Sebasticook to near Hartland Village, not far from the southeast end of Moose Pond. From the southwest angle of the same pond a strip of sedimentary clay one-eighth to one-half of a mile wide is found along the line of the glacial gravel south and west through Cornville into Canaan, where they are plainly marine. A line of clays is also said to extend from Canaan eastward into Hartland. These facts prove that clay extends continuously up to the elevation of Moose Pond, 244 feet. The marine fossils in Palmyra have an elevation of 215–230 feet. It will be an interesting problem to determine how far the marine clay extends and where the kame border or the fluviatile clay begins, for the clays along the line of the gravel system in Cornville may have been deposited in a broad channel in the ice. The delta-plain near the west end of Moose Pond is two or three times as broad from west to east as from north to south. The coarsest matter is on the north; hence the streams flowed from that direction.

In Cornville and Canaan both the gravel system and the bordering clays are strewn with numbers of large granite bowlders. Similar bowlders overlie the marine clays all the way to the sea, and they are probably floe bowlders.

From Waterville to Bowdoinham the gravels of this system lie along the Kennebec River, or only a short distance from it. The road gravel of Augusta, Hallowell, and Gardiner comes from this series. In a few places the mounds and short ridges form hills 50 to 70 feet high, and some of them form a conspicuous feature of the scenery of this beautiful valley. Among these is the hill situated on the west side of the river just south of South Gardiner, where the Maine Central Railroad has cut through about 30 feet of gravel and cobbles.

This system shows a decided tendency below Waterville to follow the crests or slopes of the hills on one side or other of the river rather than to follow the bed of the river. In general the material is from the size of cobbles down to sand grains, but here and there the higher hillocks contain bowlderets, and sometimes bowlders 2 to 3 feet in diameter. A pinnacle near the north line of Augusta consists, judging from what can be seen on the surface, of a mass of stones and bowlders but little water polished and much resembling till.

Length of system, 55 miles.

Short eskers are reported by E. P. Clarke as occurring not far from Sidney Post-Office. They lie more than a mile west of the Kennebec Valley system, and are either local, or, perhaps, branches of this system.

SHORT ESKERS SOUTH AND SOUTHWEST OF MOOSEHEAD LAKE.

Several short "horsebacks" have been reported to me as being found in the western part of Shirley, in East Moxie and Bald Mountain townships, and in the western part of Blanchard, near Bald Mountain Pond.

Near the west end of Kingsbury Pond, in Mayfield and Brighton, a series of several gravel ridges comes from the north down a hill into the level ground near the pond. They become reticulated, and then toward the south the ridges become lower and broader and finally coalesce into a rather level delta-plain. The ridges are hardly a mile long, and they appear to be simply a side-hill system.

Another hillside esker is found on the southern slope of a hill which lies on the north side of Kingsbury Pond, near the line between Mayfield and Kingsbury. The ridge ends near the base of the hill, but does not expand into a delta-plain, unless it be beneath the pond.

Low passes extend from Kingsbury Pond both north and south, so that all the above-named gravels might possibly form a series connecting either with the Hartland system through Harmony Village, or with the Lower Kennebec system through the west part of Harmony and Athens, or down the Wesserrunsett Valley into Brighton and Athens, or southwest along the valley of Fall Brook toward Solon. I have not explored the country thoroughly. From present information I regard all the short kames above mentioned as local, isolated eskers, not branches of a common system. They were a feature of the last part of the Glacial period, when the ice was retreating northward.

LOCAL ESKERS IN RICHMOND AND BOWDOINHAM.

A short ridge of glacial gravel and cobbles is found in the western part of Richmond Village. About 2 miles west of the village, near Abagadassett Stream, are a few short, rather flat-topped ridges with no traceable connections. They appear to be small marine deltas. A few miles southeast of this place is an east-and-west ridge of till on the east side of Swan Island, in the Kennebec River. This is probably a small terminal moraine.

If so, these local kames in Richmond date from about the same period and were probably deposited by short glacial streams in the sea at or near the front of the retreating ice. Another short local kame is found near the line of the Maine Central Railroad about 1½ miles south of East Bowdoinham.

SEDIMENTARY DRIFT OF THE UPPER KENNEBEC VALLEY.

The student of the drift of Maine who begins at the mouth of the Kennebec River and travels northward will at once observe that the lower portions of the valley are bordered by no such system of terraces as those of the classic upper Connecticut Valley. There is a low terrace of valley drift near the present limit of high water. Above that the only terraces are those eroded in the marine clay or till. The marine clay near the river differs but little in composition from that found several miles away from it, and is thus proved to be a rather deep-water deposit. The clays cover the valley to a breadth of many miles.

From Waterville northward there is a change in the character of the sediments of the valley. Resting on the till or unmodified glacial drift is a thick sheet of sedimentary clay, overlain by a stratum of coarser sediments. The latter composed the delta sands of the river when the sea stood at 230 feet. Marine fossils have been found in the lower clays as far north as Norridgewock. At North Anson fresh-water clam shells have been found in brick clay several feet below the surface. This clay is apparently of the same age as the rest of the underclay of the valley. But the unio shells were found near the base of a terrace of erosion, so that it is not certain whether they were deposited in the original underclay of the valley or in a more recent erosion channel. From Norridgewock to the coast the lowest layers of the clay are dark in color, often almost black, and often with the odor characteristic of the clam flat. Farther up the valley the underclay becomes bluish gray in color and is slightly coarser, sometimes even silty. The underclay extends continuously up the Kennebec Valley to a point 2 miles north of Bingham; also up the larger tributaries for a considerable distance above their junctions with the Kennebec. The underclay partly covers the Anson-Madison glacial gravels, and near Solon overlies local beds of well-rounded cobbles. It is thus evident that glacial gravels were first deposited at various points in the valley, and that these were subsequently covered by the clay. From being near three-fourths of a mile

wide at Bingham, the clay broadens to 2 miles or more in Solon, Embden, Anson, and Madison, while below that point the marine beds are several miles in breadth. It is not probable that the clay covers the central parts of the valley north of Solon Village.

From Waterville northward to Norridgewock we find overlying the sedimentary clay a stratum of sand rather horizontally stratified, except where it has blown under the action of the wind. In Fairfield and Skowhegan this sand forms plains extending back from 1 to 3 miles from the river, and it is plainly a marine formation, i. e., the fluviatile Kennebec delta. In places it has been removed by the wind or by stream, and it is difficult to trace its original distribution. Northward the sand becomes coarser by degrees and in Madison passes into mixed sand and gravel, while by the time Solon is reached cobbles and bowlderets are found more than a foot in diameter along the central parts of the valley. From this point to within three miles of the Forks well-rounded pebbles, cobbles, bowlderets, and in places bowlders are found along the central part of the valley, while at the sides of the valley the stones are not so large and are less waterworn. At the sides of the valley this coarse stratum plainly overlies the underclay. The sections observed by me did not show clay beneath the gravel at the axis of the valley; yet this may be due to the sliding down of the overlying gravel. Only at a few places did I find clay in the banks of the river above Solon, and then it was uncertain whether it was sediment of recent deposition or an uneroded portion of a stratum which once covered the valley. It thus appears that there is little or no clay beneath the coarse drift found along the axis of the valley.

The so-called "horsebacks" are among the most interesting features of the upper Kennebec Valley. From Solon to Bingham a nearly continuous two-sided ridge is found along the west side of the river, and from that point northward to within 3 miles of The Forks a similar ridge is found for most of the way on the east side. These ridges rise 20 to 80 feet above the alluvium at their sides. What is the cause of these ridges?

Where they are broad enough to have a flat top, they have, by aneroid, substantially the same height as the broadest of the alluvial terraces at the sides of the valley, that which constitutes the main sedimentary plain. Where they are narrow, they are usually lower than this terrace, and often almost merge into an uneven or hummocky terrace many feet lower than

the principal terrace. The slopes of these "horsebacks" are about as steep on the side away from the river as the erosion cliff which forms the bank of the river. The depression between the central ridges or horsebacks and the alluvial terraces at the sides is of varying breadth up to one-eighth of a mile or a little more. This depression, being of varying depth and confined between the central ridge and the lateral terraces, presents a succession of basins or kettleholes. Some of these are so deep as to contain lakelets without visible outlets. Some of these ponds are said to rise and fall with the water of the river. One pond in Moscow is said to be 40 feet deep in time of high water. By aneroid its surface was several feet higher than the river; hence it must be fed by springs from the side of the valley faster than the water seeps through the alluvium into the river. All this favors the hypothesis that there is a body of coarse alluvium along the central part of the valley rather easily permeable by water. In some other respects the interpretation of the facts is beset with difficulties. The ridges plainly have the appearance of being uneroded portions of an

FIG. 20.—Section across Kennebec Valley. *a*, present situation of river.

alluvial plain which once extended across the valley. It is not so easy to account for the basins and lakelets in a valley of erosion. Here is the bottom of a so-called channel of erosion 50 to 75 feet higher at one place than at another only a short distance up or down stream. Such ups and downs are of frequent occurrence in the depression situated between the ridges and the terraces at the sides of the valley away from the river. If this depression has been cut down into the alluvial plain by water, then we must account for the very unequal depth of the channel. This question will be referred to hereafter. If we assume that the two-sided ridges result from the unequal erosion of a once continuous alluvial plain, why did not the river continue enlarging its channel laterally instead of forming a new one on the other side of the valley, leaving the central portion of the plain uneroded? The true answer to this question probably is that the alluvium of the central part of the valley is composed of so much larger stones that it is less easily eroded than the drift at the sides. In many places the central ridge is largely composed of cobbles and bowlderets, and for some

distance in the southern part of Forks Plantation it also contains many bowlders 2 to 4 feet in diameter.

Is there an ordinary osar along the axis of the valley, which was subsequently covered and flanked by river drift? I regret that the numerous sections examined by me along the windings of the river were not free from surface sliding. I could not find an ordinary osar of arched stratification along the valley, but the sediments appeared to become finer by degrees as we go back toward the sides of the valley, and the coarse central belt showed no distinct border. This kind of assortment is characteristic of the osar-plain, and probably also of fluviatile drift. The stratification of the central ridge could not be distinctly made out, but appeared to be rather horizontal. The pebbles and cobbles are well rounded, far more so than in ordinary valley drift off from lines of glacial gravel. The average slope of the Kennebec River from Moosehead Lake to tide water at Augusta is about 9 feet per mile, and from The Forks to Norridgewock it is probably not more than 4 to 6 feet per mile. Below Bingham the central ridges contain bowlderets more than a foot in diameter at a point where the alluvial plain is near three-fourths of a mile wide. Above Bingham the valley narrows to about one-fourth of a mile, here and there expanding to a half mile or more. If the whole alluvial plain is ordinary river drift, a very broad and swift river is necessary to transport such large stones and to roll and round them so thoroughly. The question as to whether so moderate a slope could have given the necessary velocity of current will be considered later. My exploration of this part of the Kennebec Valley was made in 1879, before I recognized the osar-plain. I therefore somewhat doubtfully outline the history of the upper Kennebec Valley as follows:

First, glacial gravels were deposited in the valley between The Forks and Solon by glacial streams flowing in narrow channels between ice walls. These gravels are now deeply buried and have been found only here and there. Subsequently an osar-plain was formed along the axis of the valley in a much broader ice channel. This channel gradually broadened, until at last it extended across the whole valley, at which time the river ceased to be a glacial stream. The gradual retreat of the ice from the center of the valley is probably the explanation of the fact that the alluvial plain of the Kennebec does not extend back into several of the lateral valleys which

join the main valley in this part of its course. A well-marked instance is found on the west side of the Kennebec about 3 miles north of Solon Village, where a valley covered by ordinary till comes from the northwest into the main valley. The Kennebec alluvial plain rises 8 feet or more above the lateral valley, and once formed a dam across it, but shows no tendency to extend back into the valley. This valley would have formed a lateral bay of the main river at the time the alluvial plain was being deposited if it was not covered by ice. Near the mouth of the Pleasant River—a small stream forming the outlet of Pleasant Pond, in Carratunk—there is an abrupt enlargement of the valley of the Kennebec toward the east, and the coarser sand and gravel plain found near the river does not expand to fill the broad valley, but is bordered by an area of silt and clay on the east side. This clay extends for some distance up the lateral valley. I see no reason why all the lateral valleys would not be covered by such a clay at least to the height of the higher Kennebec terrace, if the water were free to flow back into them at the time the terraces were being deposited. The fact that some of the lateral valleys are not covered by such sediments, though they are not so high as the higher terraces, favors the hypothesis that the ice still lingered in them after it had disappeared in the main valley.

Directly after the melting of the ice in the valley the currents flowed gently, and the underclay was now laid down in the bottom of the valley, flanking the previously deposited osar-plain. Finally there came a time of swifter floods, when the clays were covered by coarse sediments over the whole of the valley (up to 3 miles broad). Much of this sand and gravel and cobbles was probably derived from the central osar-plain, which was now in part eroded and spread laterally over the whole valley. At this time the river was pouring its mighty volume of waters into the sea in Anson and Madison or northward, while estuarine conditions prevailed for some miles above that point. Subsequently the sea retreated to its present position, but at this time the Kennebec had become much reduced in volume, and the change in level must also have been quite rapid, or a delta-plain of sand would have been left over all the lower part of the valley. As it is, the delta sands of the Kennebec poured into the sea can not be traced south of Waterville. Below that place the whole of the broad area occupied by the sea is covered by clays, and these were rather deep-water deposits, formed some considerable distance from where the Kennebec River

poured into the sea at the time it was depositing the broad delta sands of Solon, Embden, Anson, Madison, Skowhegan, and Waterville.

A comparison of this valley with others at the same distance from the coast strongly points to the conclusion that the broad gravel, sand, and clay plains extending from Embden and Solon northward are frontal or overwash plains, dating from the time when the ice had retreated to a point north of Bingham. These vast deposits, consisting of the underclay and the surface sands and gravels, were laid down upon a series of still older gravels which were of purely glacial origin and have been seen only in a few places. The glacial river probably flowed down the Kennebec Valley to Norridgewock and then southward, not along the river to Skowhegan. A low valley covered by clays and silts, probably marine, extends from Norridgewock southeastward into Fairfield, and two other valleys, covered by fine sediments, extend southwestward into Belgrade. The last named are along lines of glacial gravels.

The glacial, fluviatile, estuarine, and marine sediments are all represented near Norridgewock, and the region is a difficult one to understand.

A sedimentary plain several miles broad covers the lower portion of the valley of the Sandy River. Its general character resembles that of the Kennebec Valley at the same elevation. This alluvial plain connects southward by two lines of clay with the marine clays. One of these lines of clay extends from Mercer Village southeastward through Belgrade to Augusta; the other from Farmington Falls southward through Chesterville, Fayette, and East Livermore to Leeds and Sebatis. The origin of these sediments situated above the 230-foot contour will be discussed later.

ANSON-MADISON SERIES.

A dome of kame gravel 75 feet high is found on the south bank of the Carrabassett Stream about 4 miles northwest of the village of North Anson. Three other similar deposits, separated by gaps up to a mile in length, are arranged in a line from this point southeastward. Then appears a rather continuous ridge which crosses a very low divide and subsequently follows the valley of Getchell Brook for several miles southeastward through Anson. The gravels pass one-half mile west of Anson Village (Madison Bridge), cross the Kennebec a short distance north of the mouth of Sandy River, and then appear as a ridge on the east side

of the river for about three-fourths of a mile. The southern portion of this ridge is so disguised by the sands and clays of the valley that it is uncertain whether it ends in a delta-plain or not.

The stones of the series are polished, but in general not so much so as those of the long systems. A noticeable feature of this series is that it is discontinuous at its northern extremity in the same way that the long osars usually become discontinuous at their southern ends.

The relation of this system to the osar border clay and the alluvium of the Carrabassett Valley is interesting. The gravels at the southern extremity of the series are more or less covered by the clay and sand of the Kennebec Valley. Northward in the valley of the Carrabassett the gravels are flanked by a plain of nearly horizontally stratified fine sediments. This bordering plain is of varying breadth up to one-fourth of a mile, and extends all the way to the Carrabassett Stream. Clay and silty clay are most abundant in the border plain, but some layers of sand alternate with the clay. The fact that this plain follows the course of the glacial stream up and over a divide, rising above the alluvial plain of the Carrabassett Valley 20 or more feet by aneroid, proves that the clay along the line of the kames was not due to an overflow of the Carrabassett River, but was deposited in a broad ice channel. Here and there on the border plain of clay are bowlders 2 to 4 feet in diameter. They have the shapes of the ordinary till bowlders, and were probably deposited by floating ice. Near the line of the gravels 1½ miles south of the Carrabassett, wells 30 feet deep do not reach the bottom of the clay. At this point is an interesting feature of the osar border plain. Toward the east it is continuous with and fully as high as the broad plain of sand and clay which extends about 5 miles northeastward across the Carrabassett River into Embden. But toward the west the clay border plain slopes down rather steeply to a swamp, one-half mile or more wide, which is about 20 feet lower than the plain itself. A small brook flows from the swamp northeastward across the sedimentary plain to the Carrabassett, having eroded a deep and narrow ravine in it. This small stream can not have eroded the clay over several hundred acres at the swamp and only a narrow strip over the rest of the alluvial plain. On the north side of the Carrabassett opposite this point there is a valley extending back farther from the river than this, yet it is covered with

sand and clay to the base of the high hills. It does not seem possible the kame border plain could end so abruptly as it does on the west at the swamp above mentioned, unless at the time of deposition, of the border clay as well as of the alluvium of the Carrabassett Valley at this point, the area where the swamp now is was then covered by ice. It is possible that the border clay itself happened to be just high enough to prevent the water of the Carrabassett from passing westward, though that condition would be extraordinary.

Apparently the glacial history of the region along this gravel series is as follows: A small glacial stream deposited the gravels in rather narrow channels within the ice. By degrees this channel became widened to several times its original breadth, and in this broad channel was deposited the osar border clay. Then the ice on the east side of the border clay melted and the border plain was submerged in the great sheet of (estuarine?) water which then filled the valley of the Carrabassett to a breadth of several miles. But the ice on the west side of the osar channel, where the swamp now is, probably still lingered for a time and prevented the deposition of fine sediments over that part of the valley. The swamp would naturally be covered by a pond previous to the cutting of the ravine of erosion to the Carrabassett by the small brook, its outlet.

Some of the short deposits of gravel at the north end of the series may be small delta-plains, and mark stages in the extension of the broad glacial channel northward. A possible connection of the Anson-Madison series is found in Embden. A kame about three-fourths of a mile wide is found between Fahi and Sands ponds, in Embden, and another near Hancock Pond. I did not explore the region about Embden Great Pond, and do not know whether there is a continuous series of gravels between the two noted. It is quite possible this is a branch of a Kennebec Valley glacial river.

Length of the Anson-Madison series, about 10 miles.

NORRIDGEWOCK-BELGRADE SYSTEM.

Provisionally these gravels are classified as a distinct system, though a sufficiently careful search beneath the sedimentary sand and clay of the Kennebec Valley may yet show that they are a continuation of the Anson-Madison system, and that both are connected with the gravels of the upper Kennebec Valley.

The series begins near the south line of Norridgewock as a number of ridges separated by intervals varying up to near 1 mile. The series extends southwestward along a low pass to Smithfield Village, where it expands into a plain more than 50 feet high. On the north the plain is continuous for about one-fourth of a mile from east to west, and it sends out three parallel tongues south for one-third of a mile. The material is coarse gravel and cobbles at the north side of the plain, but becomes rapidly finer toward the south, passing into fine sand, and this into sedimentary clay. A continuous plain of sedimentary clay extends from Norridgewock along the line of this gravel series, and thence all the way to Augusta. The surface of this clay is strewn with numbers of stones and angular bowlders 2 to 12 feet in diameter, but not with anything resembling a sheet of till; hence I refer the erratic bowlders to floating ice. The bowlders may have been deposited either in a broadened osar channel, in which case this is a plain of osar border clay, or in an arm of the sea, or in an overflow channel of the great Sandy River (Kennebec estuary of that time). The gravel plain at Smithfield Village is a delta-plain of some sort, and it is situated at about 350 feet elevation by aneroid. This makes it probable that the glacial stream here flowed into a glacial lake, or, what is equivalent, a broadened osar channel. For several miles south of this point the clays bordering this gravel series have an elevation of more than 250 feet.

South of Smithfield Village there is apparently no gravel for about 2 miles, and then a series of gravel ridges crosses the northeastern arm of Belgrade Great Pond. It appears for about a mile on the east shore of the pond, and at Horse Point runs southward into the water as a long gentle sloping cape. It reappears on the south side of the pond, and soon takes the form of a series of reticulated ridges inclosing kettleholes and lakelets. About a mile north of Belgrade station of the Maine Central Railroad a rather level plain extends for one-fourth of a mile or more to the east of the main ridge. It was thrown out from the west around the south end of the high hill known as Belgrade Ridge. It consists of rather horizontally stratified fine gravel and sand, with a few layers of clay, and is plainly a small delta. To the east of this deposit lies the valley of Messalonskee (Snows) Pond, in Belgrade and Sidney. The plain in question is from 40 to 60 feet above the pond, which is 240 feet above the sea. East and northeast of the delta-plain just described no sedimentary clay appears on the northwest side

of Messalonskee Pond for several miles toward Oakland. If the sea stood at the level of this delta-plain, it would at that time have filled the valley of Messalonskee Pond, and a deep sheet of salt water 4 miles or more wide would have extended northward from the northwestern part of Augusta through Belgrade, Sidney, Oakland, and Waterville, and such a body of water must have deposited abundant sediments. The sudden disappearance of the clay a short distance east of the osar-ridges north of Belgrade station is inconsistent with the hypothesis that the delta above mentioned was deposited in the open sea. On the contrary, these facts strongly favor the theory that the delta-plains which appear at intervals in the course of the system from the south part of Norridgewock to Belgrade station were deposited in glacial lakes, and that the bordering plain of sedimentary clay is osar border clay, laid down in a very broad channel within the ice, or perhaps partly bordered by the hills.

South of this point the gravel takes the form of a continuous ridge for several miles, being cut through by the Maine Central Railroad at Belgrade station. Just south of the station the ridge is strewn with many good-sized bowlders having till shapes. In the southeastern part of Belgrade the system expands into a broad series of reticulated ridges inclosing numerous kettleholes and basins containing twenty lakelets, most of them without visible outlets. On the west of these plains the ridges have steep side slopes, and are simply windrows of coarse gravel, cobbles, bowlderets, and bowlders, all very well rounded. Going south and east we find the ridges becoming lower and broader and the matter contained in them finer, and they presently blend into a rather level plain of fine gravel and sand in the northwestern part of Augusta, and this soon passes by degrees into marine clay at an elevation of near 250 feet or more.

A short ridge in Manchester is the only glacial gravel found south of this system, and that is probably not connected with this. This series dates from the last part of the Glacial period, when the ice had retreated so far northward that the glacial river flowed into the sea in the northwest part of Augusta. South of where this glacial river flowed into the sea the clay is very deep. A stream has eroded it to a depth of 80 feet, and yet apparently has not cut to the bottom. There is an old sea beach on the hill lying just west of Augusta, being especially well developed on the southern brow of the hill near the top. Otherwise I have not been able to find any very

well-developed beach in this region. It is therefore evident that the deep sheet of clay northwest of Augusta represents eroded till in only a small proportion, but was chiefly composed of the mud brought into the sea by the glacial river at the delta of Augusta and Belgrade above described.

NORTH POND BRANCH.

A north-and-south ridge of glacial gravel crosses North Pond in the northeast part of Rome. It nearly divides the pond into two parts. Its connections are unexplored. Probably it is a branch of the Belgrade system, yet it may prove to be a local deposit.

MERCER-BELGRADE BRANCH.

An irregular mound of glacial gravel 80 feet high and one-eighth of a mile in diameter is found not far south of Mercer Village, at the northeast base of Hampshire Hill. A nearly north-and-south valley in Mercer, Rome, and Belgrade extends for several miles along the eastern base of this high hill, and in this valley two streams take their rise, one flowing north to Mercer Village, the other south and west into Belgrade Great Pond. A well-defined gravel series extends along this valley, now taking the form of terraces near the base of the hill and now appearing as a two-sided ridge in the midst of the valley. The ridges are 10 to 20 feet in height—nowhere so high as the large hummock at the north end of the series. The series does not expand into a delta-plain near Belgrade Great Pond, into which it runs from the north, making it probable this was a tributary of the Belgrade system. At the southwest angle of this pond a short gravel ridge, which is in a line with the Mercer-Belgrade series, is found, about half a mile west of the main system, which may be a part of the Mercer series.

The valley along this gravel series is deeply covered by sedimentary sand and clay, which on the north is continuous with the broad alluvial plain of the Sandy River Valley, and on the south there is a line of similar clays along the outlet of Belgrade Great Pond all the way in its circuitous route to Messalonskee Pond, near Belgrade station. There seems to have been an overflow of the great Sandy River estuary this way, and previous to the melting of the ice there may have been some border clay deposited along the flanks of the gravel ridges. This makes the problem of the clays of this valley rather complex.

The glacial gravels in Mercer, Norridgewock, Smithfield, Rome, and Belgrade are found in a region diversified by numerous quite high hills, many of them granite knobs. Between these hills are several valleys, forming very low passes from the valley of the Sandy River south and southeast. The courses of the glacial rivers were over a gently rolling surface.

The length of the series from Mercer to Belgrade is about 10 miles.

LATE GLACIAL HISTORY OF THE UPPER KENNEBEC VALLEY.

When we compare all the facts regarding the Kennebec Valley with those elsewhere recorded regarding the neighboring valleys situated at about the same distance from the sea, viz, the East Branch of the Penobscot, the Pleasant River, the upper Piscataquis, Dexter, and Main streams, the upper Sebasticook, Carrabassett, and Sandy River valleys, we seem to have ground for the following interpretation of the facts:

The earlier glacial streams of the upper Kennebec Valley left no sediments (that I have discovered), or they have been buried out of sight. The osar river that flowed from Norridgewock southward dates from a late period, when the ice had already melted so far north that this river flowed into the sea in the northwestern part of Augusta. The northern tributaries of this river must have drained the upper Kennebec Valley, but it is as yet uncertain whether they deposited any gravels during the time in which the river continued to flow south of Norridgewock. The flow of this glacial river south of that place was presently stopped by the retreat of the ice and the advance of the sea up the Kennebec Valley to near Madison Bridge, north of Norridgewock. The Anson-Madison osar probably dates from about the time the sea advanced to Norridgewock. About this time the upper Kennebec osar river began to deposit gravels in that part of its channel lying north of Solon. Later the ice over the bottom of the valley had all melted as far north as Embden or Solon. By this time the osar channel extending nearly from The Forks to Solon had broadened to an osar-plain channel, with reticulations and outliers in various parts of the valley, and the mighty glacial river that poured south from Bingham and Solon formed a frontal plain of gravel and sand which extended a few miles southward and then was continued to the sea as a frontal plain of clay (the underclay of the valley drift of this part of the valley). The character of

the sedimentary drift of the interior of the State thus evidences the progressive retreat of the ice, also the probability that the longer glacial rivers did not deposit sediment in all parts of their long channels simultaneously.

SHORT ESKERS IN MANCHESTER AND LITCHFIELD.

The following gravel deposits do not seem to have connections, and are probably so many local kames.

A small ridge is found a short distance east of The Forks, Manchester. A similar ridge is found in the east part of Bowdoin, and still another a short distance east of Litchfield Post-Office; and there are several ridges forming almost a series in the valley of the Cobbosseecontee Stream in Litchfield. All these are well disguised by the marine clays. Litchfield Plains are a small marine delta, without traceable connections. This plain will be more fully described later.

LITCHFIELD-BOWDOIN SYSTEM.

Purgatory Stream rises in the southwestern part of Litchfield and flows northeast into the Cobbosseecontee Stream. About a mile north of the south line of Litchfield an osar-plain begins in the valley of Purgatory Stream and goes southward up this valley to its end. The gravel system then crosses a hill about 100 feet above its north end, being somewhat interrupted near the top of the divide, and then continues southward through Webster into Bowdoin. Not far north of West Bowdoin the series expands into a plain 2 miles or more long, the gravel becoming finer toward the south and quite level on the top, passing from sand into marine clay. It is somewhat fan-shaped, and was a delta deposited in the open sea. At the first settlement of the country it was overgrown by huge pines and was called the "Pine Nursery." Many masts of ships were procured here. South of this point the system becomes very discontinuous, and consists of several lenticular ridges or domes, separated by rather short gaps. A mound of this series situated just east of West Bowdoin incloses a deep kettlehole. Its flanks are partly covered by blowing marine sand, and it is sprinkled with some large bowlders having the shape of till bowlders.

This is a short series, but contains a large amount of gravel and sand for its length. The stones are fairly well rounded. The breadth of the gravel plain at the north end of the system is one-eighth mile or more, a

A TUNNEL IN DOME-LIKE GRAVEL MASSIVE: WEST BOWDOIN

Hollow due to accident of original deposition, not to erosion

B RAVINES IN GRAVEL PARALLEL IN DIRECTION TO THE GLACIAL RIVER; DURHAM.

greater breadth than usual in such a situation. The valley of Purgatory Stream to the northeast is from one-third of a mile to more than a mile in breadth. The appearances are as if the valley was occupied by a local tongue of ice which continued its motion while the gravel plain was being deposited. If so, the space between the front of the ice and the hill to the south would be occupied by a broad glacial stream, or by a lake, and the osar-plain may in part partake of the nature of a water-washed terminal moraine.

The system evidently dates from a late period of the Ice age, since the marine delta near its southern extremity is situated so far from the present coast.

LOCAL ESKERS IN NORTHWESTERN MAINE.

Horseback at Leadbetter Falls.—These falls are situated on the Penobscot River near its source. Prof. C. H. Hitchcock describes a ridge, presumably of glacial gravel, as follows: "At the farther end of the portage is a large horseback, which terminates here in a ledge larger than the ridge itself. We traced this horseback up the river for 3 miles, and found it was not parallel with the river itself."[1]

Parlin Pond horsebacks.—Professor Hitchcock also describes a horseback near Parlin Pond, as follows: "Northwest from Parlin Pond there is a curving horseback three-fourths of a mile long."[2] I am informed that there is another similar ridge northeast of the pond, near its outlet.

Kibby Stream horseback.—A two-sided ridge, probably of glacial gravel, is reported by Mr. A. J. Lane, of Lexington, and others as being found between Spectacle Pond and Kibby Stream, which flows into Dead River at Grand Falls.

DEAD RIVER-JERUSALEM SYSTEM.

From the great bend of the Dead River in Dead River Plantation, a very low valley extends southward past the east base of Mount Bigelow. Bog Brook takes its rise near the highest part of this pass and flows sluggishly northward to the Dead River. A ridge of sand and gravel begins a short distance south of Dead River and follows the valley of Bog Brook. It forms a natural roadway through a low level region near the axis of the

[1] Second Annual Report upon the Natural History and Geology of the State of Maine, p. 345, 1862.
[2] Ibid., p. 399.

valley. According to the information which has reached me, there are two low passes from the head of Bog Brook, one southward along a branch of Sevenmile Stream to Kingfield, the other southeastward through Lexington to New Portland. A large plain of sand and gravel is found in the valley of Sevenmile Stream above Kingfield; also in the Carrabassett Valley above North New Portland. These sediments extend across the valleys in the position proper to valley drift. The gravel may have been brought down from the Dead River region by glacial streams at a time when the ice still remained in the valley of Dead River, but had melted over the valleys to the south. It is quite possible also that some of the alluvium of these valleys is after the order of the osar-plain. My exploration of these valleys did not reach above Kingfield and North New Portland.

Stratton Brook horseback.—A two-sided ridge is reported by Rev. Stephen Allen, of Winthrop, as being situated between Stratton Brook and the road from Eustis to Kingfield. It is said to begin 4 miles from Eustis and to extend 3 miles southeastward.

A horseback 3 miles long is reported as being found near the divide between Arnold River, a tributary of the Chaudiere, and the Dead River, above Chain Lakes.

NOTE ON THE NORTHWESTERN PART OF MAINE.

West of the Kennebec River and north of a line drawn from the upper Androscoggin Lakes to Anson, the glacial gravels appear to be scanty as compared with those of the area south of that line. But the same can be said of the whole of the State northeastward at the same distance back from the coast. The distinct ridges are short, and several of them are lost in a sedimentary plain that presents the external features of a frontal plain of glacial sediments. The relations of the osars to the frontal plains of apparent valley drift, and of these to the silty and clayey plains which reach all the way down to the old sea-level, furnish an intricate problem. The matter will be discussed more fully hereafter. A comparison of the alluvium of the valleys of the streams situated in the interior of the State, from the Sandy River to the East Branch of the Penobscot, reveals many features common to all of these valleys. Perhaps no one of them would alone warrant the belief that these plains of sand, gravel, silt, and clay which reach from the extremities of the short osars

are frontal plains of glacial sediments, but all together make out a strong case. Every time I review the subject I am more impressed with the weight of this cumulative evidence.

All the facts so far as known indicate that the short eskers and osars of northwestern Maine are a feature of the very last part of the glacial epoch, when the ice had retreated as far north as this region, and the glacial rivers were consequently rather short.

READFIELD-BRUNSWICK SYSTEM.

This interesting system begins 2 miles northeast of Readfield Village as a low ridge of rather fine subangular gravel, which extends about 1 mile south to Lake Maranocook. No glacial gravel is known to appear on the shore of this lake until we reach Winthrop Village. The eastern part of the barrier which separates the upper and lower Winthrop lakes is underlain by rock at a depth of a few feet. Along the line of the Maine Central Railroad, in the western part of the village, is a north-and-south valley extending from one lake to the other. The surface of this valley rises about 20 or 25 feet above the upper pond, and wells show it to be covered by glacial sand and gravel, flanked by sedimentary clay, to a depth of more than 40 feet. Evidently the preglacial drainage flowed along this valley, and the barrier of sand, gravel, and clay which now separates the ponds dates from glacial time, or in part was contemporaneous with the sea. In several places in Winthrop Village and the vicinity marine fossils have been found at an elevation of 200 to 214 feet. Probably the plain which separates the upper and lower ponds was a delta-plain, deposited in the sea by a small glacial stream from Readfield.

About three-fourths of a mile south of Winthrop Village, on the west shore of the lower pond (Lake Anabescook), is a short ridge of gravel and well-rounded cobbles, which at one place rises into a cone or mound 30 feet high. This ridge has been extensively excavated by the railroad company. Then there is an apparent gap in the system till we reach the south end of the lake. Here a short distance north of East Monmouth, on top of hills rising 50 to 100 feet above the lake, is a capping of glacial gravel one-third mile long from north to south and not quite so broad. The gravel is a rather round-topped plain, divided along the center by a narrow north-and-south ravine, which does not reach to the bottom of the gravel. No

water showed in this ravine at the time of my exploration. The hill slopes outward in all directions, and it does not seem possible there could be so large an amount of erosion in such a position by either surface waters, boiling springs, or frost damming. The ravine is in places 10 feet deep, and on the lower slopes of the hill no gravel could be found that appeared to have come from this ravine. There is therefore no proof that the shape of the deposit has been materially changed since its original deposition.

South of this gravel plain in Monmouth is a rather level country showing only very low hills. At intervals of about a half mile there are two other slightly round-topped deposits of nearly the same size as that near the lake. Both of them are also divided into nearly equal parts by north-and-south ravines. Seen from the high hills of southern Monmouth, these three ravines appear to be arranged in a nearly straight line. In neither case is there any pointed hill or rock in a line with these ravines, and there is no feature of the ground surface which accounts for them. The gravel and cobbles of all three of these plains are well rounded, and they all contain coarser matter toward the northern and central parts of the plains. They all are imperfect deltas of some sort. The more northern plain is situated at an elevation of about 275 feet, and the gravel plainly does not pass by degrees into the marine clays. It must have been formed where the glacial stream was only partially checked, since it contains fine gravel and coarse sand to the edge, where it ends abruptly. This indicates that a glacial river here flowed into a broad pool within the ice. The two more southern of these plains are situated in the midst of the marine clay, yet the transition from the plain of sand to the clay is very rapid. The current here was more fully stopped than at the northern plain. It is uncertain whether these latter are marine deltas or deltas of glacial lakes. Even if the glacial river here flowed into the sea, it seems to have been confined between ice walls at the sides. The ravines, on this theory, were formed in front of where the glacial torrent shot into the stiller water, the gravel which was carried along by it, so long as it was confined within a narrow ice channel, being thrown out at each side as it entered the broader waterway. The ravines are the channels of the rivers.

No gravel is found for about one-third of a mile as we continue to go southward, and then we come to a very large mass, on which a cemetery is situated. In addition to sand and gravel, it contains great numbers of

well-rounded cobbles, bowlderets, and bowlders up to 2 feet in diameter. This gravel deposit is very irregular in outline, and it sends out several spurs both north and south. The surface is very uneven, showing a great variety of mounds, ridges, terraces, and shallow kettleholes. Most of the ridges trend north and south. It rises 40 to 80 feet above the plain of sedimentary (probably marine) clay which partly covers its base. It is about three-fourths of a mile long from east to west, and the longest spurs are about a half mile from north to south. These dimensions show that it contains a very large amount of glacial gravel. The formation is much finer in composition in some parts than in others, but these parts are interspersed irregularly among the areas containing coarser matter, so that it must be considered a compound delta or plexus of broad reticulated ridges, composed of a number of more or less distinct but adjacent deltas, rather than a single delta. So far as I could discover, none of these incomplete deltas pass into marine clays by degrees, and the glacial streams flowed into pools within the ice rather than into the open sea.

A broad low valley extends from the foot of Sabatis Lake, in Webster, northeastward through Wales and Monmouth, broadening as it approaches Cobbosseecontee Great Pond and Lake Anabescook. This plain is all the way covered by clay, which in several places contains marine fossils. It is thus proved that there was once a continuous body of salt water extending from the Kennebec Bay westward to Winthrop, and thence southwestward to Sabatis and Lisbon, where it broadened into the Androscoggin Bay of that period, which covered a large part of Topsham, Brunswick, Lisbon, and Durham.

South of the plain at the cemetery in Monmouth there is a gap of about 3 miles, where no glacial gravel was seen rising above the marine clay. Then a series of low bars separated by short intervals begins not far north of East Wales and extends south along the eastern base of the high hills known as Monmouth Ridge and Sabatis Mountain. These gravel deposits lie in the midst of the clay-covered plain before described, and are partly covered by the clay. Near the south base of Sabatis Mountain the series expands into a very high broad ridge, becoming broader toward the southwest and of finer material, ending in sand, which is overlain at the base by the marine clay. Here the glacial streams flowed into a glacial lake or into the sea, but if the latter, the transition from the sand to the

clay is so abrupt as to indicate that the glacial waters were quite suddenly checked after entering the salt water. This delta is situated near the southeast angle of Sabatis Pond. Going south we find no glacial gravel rising above the marine clays for somewhat more than 2 miles. Then a low plain about half a mile long is found on the west side of Sabatis Stream, and then there is another gap of half a mile. A nearly continuous, low, broad ridge then begins and extends southward to Lisbon station of the Maine Central Railroad. Just north of the station it expands into a broad ridge or mound called Whites Hill, which rises fully 100 feet above the clay covering its base. Wells show this clay to be more than 40 feet deep. From this place southeastward to Lisbon Falls extends what is known as Lisbon Plain. It is a rather level plain of horizontally stratified sand and clay, while here and there low ridges of glacial gravel rise above the finer sediments which overlie it. This plain lies in the angle between Sabatis Stream and the Androscoggin River, and at the time the sea was expanded would be subject to the action of the tidal currents of both the valleys. On general grounds this plain might be considered a marine delta, brought down from the north by the glacial river we have been tracing, but its proximity to the Androscoggin makes it certain that it is in part an Androscoggin River delta. East of Lisbon Falls this gravel series consists of four broad ridges or plains, all situated on the north bank of the Androscoggin River. The first is situated about one-fourth of a mile east of Lisbon Falls. The second is about 1¼ miles east of this, and consists of two large and broad ridges, inclosing a deep kettlehole. The kame stuff is here very coarse, containing great numbers of very round cobbles, bowlderets, and bowlders. This deposit is half a mile long from east to west, and about half as broad, and rises 100 feet above the Androscoggin River. About 1½ miles farther east is another mass of glacial gravel of about the same size as the last named, but rather level on the top and containing few large stones. At the river bank it forms a steep bluff 100 feet high. After another interval of about 1½ miles a fourth plain of sand, gravel, and cobbles is found as a terrace rising only 30 or 40 feet above the Androscoggin River. It is not more than one-fourth of a mile long and less than half as broad. Its situation near the river and its level top make it resemble valley drift, from which it can readily be distinguished by a comparison with the drift of the river above and below this point. The stones of this gravel

terrace are much rounder than those of the Androscoggin flood plain or those in the bed of the river, and no continuous sheet of such drift is found along the river. This plain is situated 2½ miles west of Brunswick Village, and I have been able to find no similar gravels east or southeast of it. I therefore assume this to be the end.

In a few places this system is situated above the contour of 230 feet, as, for instance, in Readfield and near East Monmouth. In several places the tops of the ridges rise above that contour, though their bases are below it. This system is discontinuous from one end to the other, and by this it is meant that the gravels were originally so deposited. The forms of the gravel masses vary much and the system can hardly be classified among the discontinuous systems of lenticular masses. The deposits of this system are more hummocky and irregular in shape. Nearly all of the plains show some of the characteristics of the delta, but not such deltas as would be formed in the open sea, unless the plain near the foot of Sabatis Pond be such a one.

The length of the system is 25 miles.

WAYNE-MONMOUTH BRANCH.

This series begins a little more than 2 miles east of Wayne Village. At the north end it is a small, rather straight ridge. The stones here preserve their till shapes, and the mass is quite like till in appearance, having a rather pellmell structure; yet close examination shows that the finest detritus has been washed out of the mass and the stones are a little water-worn. Farther south the ridge becomes very crooked and meandering and the stones are much more worn and rounded. There are many water-polished bowlders in the ridge. Within less than a mile the system becomes double, consisting of a continuous low ridge in a valley and a parallel discontinuous series of domes or short plains forming low broad caps to a series of hillocks lying along the west side of the valley. Just south of Evergreen Cemetery there is a short gap in the series, and then another gravel cap on top of a low rock ridge, which ends near a small stream that flows southwest into Wilson Pond. No glacial gravel appeared along this stream or pond. Right in front of the last-named gravel deposit is the southwestern spur of Mount Pisgah, a high hill situated in southwestern Winthrop and northern Monmouth. Over this hill the road is made which

leads from Wayne to North Monmouth, and it rises 150 feet while crossing the spur of the hill. Parallel with the road is a U-shaped ravine from 20 to 40 feet deep on the steeper slopes of the hill, but hardly perceptible for a short distance near its top. The ravine is found on both the north and south slopes. Till shows in the bottom of the ravine, and it is strewn with many more bowlders—2 to 4 feet in diameter—than appear in the fields of till at each side. This fact indicates that this is a ravine of erosion. The bottom of the ravine is rather level in cross section and is from 30 to 100 feet wide. This is an extraordinary amount of erosion in the till. But the drainage slopes are only about a half mile long on each side of the hill, no springs or streams appeared in the valley at the time of my examination, and the bottom was wholly grassed over, except a small channel on the southeastern slope eroded by the rains. Assuming that this canal-like depression with rather steep banks is the result of erosion, the rains and shower streams do not seem competent for the work, judging from the amount of erosion accomplished by the streams of this part of the State.

Passing a short distance down the southeastern slope, we come to a ridge of well-rounded glacial gravel which extends through the village of North Monmouth and then becomes discontinuous. Two or three small plains of gravel take us to the plain at the cemetery southeast of Monmouth, already described. Here this tributary probably joined the main river, and one or more of the northern spurs of that irregular plain may have been deposited by it.

It is thus proved that a glacial river flowed from the north to the base of the southwestern spur of Mount Pisgah. The only trace of any connection is found on the southeastern side of this hill. It is thus made highly probable that a glacial river flowed up and over this hill, 150 feet high, along the line of that remarkable ravine. The great erosion, which could not be accounted for by the action of the rains, thus becomes intelligible. A glacial stream here eroded a large body of till, probably in considerable measure a part of the ground moraine. Why did it not erode the till at the top of the hill equally with that farther down its slope?

The large size of the bowlders near the north end of the series favors the hypothesis that this was a subglacial stream. There are some remarkable heaps of till on the southern slopes of Mount Pisgah that deserve study.

The length of the branch is 7 miles.

GRAVELS NEAR SABATIS POND.

About 1½ miles northwest of Sabatisville and a short distance west of Sabatis Pond is a ridge of gravel, cobbles, and bowlderets, having an arched cross-section. It is hardly an eighth of a mile in length, and appears to have no connections except a deposit on a hillock a few rods to the south. The gravel cap on this hillock is only 50 feet in diameter. Excavations near the road show that 4 to 6 feet of gravel covers the top of a hillock of till. The gravel is distinctly but not very much polished and rounded.

The plain at the southeast corner of Sabatis Lake has already been referred to. The main part of this plain was deposited by the glacial river which flowed from the direction of East Wales and Monmouth, but a spur extends for one-eighth of a mile or more northwest along the lake toward Leeds. The Maine Central Railroad cuts through this ridge, but I could find no recent excavations showing the lines of stratification. There is therefore no direct evidence as to the direction of the glacial stream which deposited it, except the fact that the material is coarser on the north than farther south. This negatives the theory that it was thrown out westward around the southern base of Sabatis Mountain by the eastern glacial river (that from Monmouth and Wales). The proof is reasonably strong that it was deposited by a stream from the northwest, i. e., the direction of Leeds. About a mile southwest of this point a small terminal moraine is found in the southern part of the village of Sabatisville. The moraine is but little water washed and its base is overlain by the marine clay. It was probably formed at the foot of the ice where it confronted the sea. All the facts agree in proving the presence of the sea as far north as the foot of Sabatis Pond.

MOUNT VERNON ESKER.

This is a small hillside system less than one-fourth of a mile in length. It is found a short distance east of Mount Vernon Village. It begins near the southern brow of a rather flattish-topped hill, and at the base of the hill it ends in a small enlargement appearing to be a diminutive delta-plain, which incloses a depression (kettlehole?) occupied by a small peat swamp. It is a small deposit, but a fair type of the sidehill eskers.

CHESTERVILLE-LEEDS SYSTEM.

This important system appears to begin about 1½ miles north of Chesterville Village as an osar-plain or terrace, which soon becomes a narrower ridge. It passes a little to the east of Chesterville Village, and thence takes a nearly straight course southward to the Twelve Corners in Fayette. For several miles south of Chesterville Mills it takes the form of a high, broad ridge, with outlying plains and ridges inclosing kettleholes and some small lakes. It is here called Chesterville Ridge, and as it rises 50 or more feet above a very level plain, it forms a remarkable feature of the landscape. In the southern part of Chesterville the main ridge becomes lower and broader, and passes into an osar-plain, which continues south through a very low pass at Twelve Corners and thence past the Camp Ground in East Livermore. Then there appears to be a short gap in the system, but it soon begins again as a two-sided ridge of arched stratification. This low and broad osar crosses to the west of the Maine Central Railroad not far north of North Leeds, and for the rest of its course lies near that railroad. Near North Leeds outlying ridges appear inclosing kettleholes. Southward these reticulated ridges become lower and broader, and not far north of Curtis Corner, in Leeds, they coalesce into a rather level plain about one-fourth of a mile wide, which toward the south expands in fan shape to the breadth of 1 mile, and the material becomes finer and finally passes into sand overlying clay. The sand ends about 2 miles south of Curtis Corner, at an elevation of about 300 feet, and from this point a plain covered by clay extends to Sabatis Pond, and so on, to the sea. The fan-shaped plain at Curtis Corner is plainly a delta.

The problem as to the extension of this system north of Chesterville is complex. For years before I had worked out the diagnosis of the osar-plain I suspected that the plain of well-rounded gravel extending along the valley of the Sandy River from Farmington Falls to Phillips was, in part at least, of glacial origin. It is but justice to add that I passed through this valley in 1879, before it was possible for me to distinguish the osar-plain from fluviatile drift. There was a glacial overflow from West New Portland, through New Vineyard, down a small stream that joins the Sandy River a mile above Farmington Village, and there was another from Kingfield to Strong, but in these cases the only recognizable glacial gravels were

small kames near the jaws of low passes. The great size of the gravels in Chesterville demands a large supply of water from the north. For these reasons I consider it highly probable that the gravels of the upper valley of the Sandy River are partly an osar-plain and partly an overwash or frontal plain, and that this glacial river drained a large area north of Phillips and south of Mount Abraham. From Farmington Falls south the probable course of the glacial river was along the valley of Chesterville Stream. The relations of this osar system to sedimentary clay and sand are interesting. From Chesterville south this system is, throughout its whole course, flanked and partly or wholly covered by a broad plain of sedimentary, bluish-gray clay, overlain by more or less sand. Toward the north this clay plain connects with the similar plain found in the valley of the Sandy River by two low valleys, one along the Chesterville Stream and the other lying 2 or 3 miles east of it. The broad Chesterville plain of sedimentary clay connects with a similar plain that borders the Androscoggin River by two routes, one around the northern base of Moose Hill, in Jay, and the other along a low pass that leads northwest from near the Camp Ground in East Livermore. Whether the water flowed from the Sandy River over into the Androscoggin or in the opposite direction is uncertain; possibly the flow was alternately in opposite directions, as the flood height of these rivers varied. South of the Camp Ground the clay plain bordering the osar is continuous with that of the Androscoggin Valley, as far as North Leeds, where a hill intervenes between the two plains. South of this point we have, in addition to the Androscoggin plain, two other plains covered by clay. One lies directly along the line of the osar, past Curtis Corner to Leeds Junction and Sabatis Pond. Another is from 1 to 3 miles west of the last named and occupies the eastern base of Quaker Ridge in Greene. A short distance north of Greene station this plain turns east to the head of Sabatis Pond. All of the clay plains just described are above the contour of 230 feet except at their south ends, near Sabatis Pond and Lewiston, and near Androscoggin Pond. Wherever I crossed them they filled the valleys they occupied from side to side, as if they were valley alluvium. On general grounds we might expect the deposition of osar border clays in a broad ice channel along the flanks of the gravels, but if such were deposited they seem to be lost in the midst of the fluviatile clays and sands that were deposited later. It will require some nice discriminations in order to mark

out in the field the limits of the glacial, fluviatile, and estuarine drift of this region, and to write out its full glacial and postglacial history.

Androscoggin Pond, in Wayne, furnishes an interesting study. To the west of it is situated the clay plain (overlain by sand) bordering both the osar and the Androscoggin River. The pond is so nearly on a level with the river that its outlet is called the Dead River. In time of flood the water of the Androscoggin River is higher than the pond, and the flood rushes with violence southeastward into the lake, carrying so much sediment that a large delta has been formed on the western shore of the pond. Such an overflow into the pond would be much more vigorous directly after the melting of the ice in the valley, when the Androscoggin River stood at least as high as the top of the clay plain about 50 feet above its present level. Under these conditions, why was there not a much larger delta formed on the western shore of the lake? Or, rather, why did not the whole south end of the pond fill up? It could not have been from lack of sediment, for these same waters covered many square miles to the south of this point with from 20 to 60 feet of clay and sand. But it is possible that the depression where the pond now is was originally so deep a rock basin that even a sheet of clay as deep as the plain of the Androscoggin River could not fill it up. I have not examined all parts of the shore of this large pond (it is about 5 miles long and 3 or 4 miles broad), but at several points I did not find evidence that there had been deposition to such a depth. A broad, open valley extends from Androscoggin Pond northward through Wayne and Fayette into Mount Vernon and Vienna. In late glacial time there would be a flow of ice down this valley for some considerable time after the general ice movement had ceased. If this flow was sufficiently rapid to replace the ice as fast as it was melted at the eastern margin of the osar channel or afterwards by the waters of the swollen Androscoggin River or the sea, the place where the pond now is may have been covered by ice during the time of most active sedimentation. This will account very plausibly for the fact that the pond did not fill up. According to the late Hon. J. S. Berry, of Wayne, the greatest depth of the lake is about 60 feet, and over most of the lake it is much less.

A nearly north-and-south ridge of glacial gravel is found a short distance west of Leeds Junction. It ends at the south in a series of short ridges separated by intervals. This series is about a mile in length. At

one place this gravel has been excavated by the Maine Central Railroad Company. There is an interval of at least 3 miles between this ridge and the delta-plain at Curtis Corner, which forms the apparent termination of the Chesterville-Leeds system.

About 4 miles southeast of Leeds Junction a large mound rises in the midst of the large swamp at the north end of Sabatis Pond. It is probably composed of glacial gravel.

At various points along the shores of Sabatis Lake there are small bars and terraces of glacial gravel at various heights above the lake up to 100 feet. The material is but little waterworn and forms a thin cap of semi-morainal yet water-washed gravel overlying the till. It is uncertain whether these gravels south of Curtis Corner are any part of the Chesterville system. I provisionally marked them as distinct. The gravels along Sabatis Lake, taken in connection with the terminal moraine at Sabatisville, afford some prima facie evidence of a local glacier moving down the valley of Sabatis Lake, which is bordered by hills several hundred feet high. The shortness of the moraine shows that the ice movement was then confined to the valley. North of Sabatis Pond are two open valleys, along which the ice could easily flow on a descending grade to Sabatisville. One opens northward into Monmouth, the other extends northwestward through Leeds toward Wayne and East Livermore. After the general movement of the ice-sheet had ceased, on account of transverse hills, ice could still for a time continue to flow in these favorable valleys. Such a local tongue of ice in the valley of Sabatis Lake would account for: (1) the terminal moarine at Sabatisville; (2) the water-washed moraine stuff on the sides of the hills near the lake (i. e., these were formed along the margin of the local glacier); (3) the fact that the basin of the lake was not filled up by the clays, which may be due in part to the fact that the valley was filled by ice till a rather late date. The length of the system from Chesterville to Curtis Corner, Leeds, is 20 miles. This portion of the system must date from late glacial time.

I have not here explicitly classified the water drift of the Sandy River above Farmington Falls as an osar-plain overlain by later frontal sediments. The critical reader, however, who compares this system with those of the other valleys lying eastward at the same distance from the coast, as, for instance, the gravels of the Carrabassett and upper Kennebec valleys, will discern that the sedimentary drift of all these valleys has many features in

common and probably has a common origin. If so, a glacial river once flowed through the upper Sandy River Valley to near Farmington Falls, and thence southward, and was a part of the Chesterville-Leeds system. It deposited a somewhat discontinuous osar-plain along this route. Subsequently, as the ice melted, a great quantity of frontal matter was poured out into the open Sandy River Valley in front of the retreating glacier. The floods now more or less washed away and reclassified the previously deposited glacial gravels, and flanked and covered them with later sediments. The finer matter, being carried southward, formed the great sedimentary plain that borders the Sandy River from near Farmington to its mouth, and also furnished the sediment for the overflows through Mercer and Norridgewock to the Kennebec River, also that through Chesterville to the Androscoggin, and thereby helped to form the broad clay-and-sand plains of Chesterville, Jay, East Livermore, Leeds, Greene, etc. In other words, these great clay plains situated above 230 feet are frontal plains, composed of the glacial mud poured out from the diminished glaciers which yet lingered in some of the larger valleys in this region and covered nearly all the country situated 20 to 30 miles to the north. This was the chief origin of the mud, no matter at what elevation the sea stood at this distance from the coast. At the place of deposition this fine sediment now forms a part of the valley sediments.[1]

FREEPORT SYSTEM.

This is a short system appearing to begin in Brunswick near the southern brow of a broad hill of granite, a short distance southeast of South Durham. For about a mile it is a nearly continuous ridge with a meandering course and obscure stratification. The gravel here is but little waterworn and has a morainal aspect. Going southward, we find the stones more rounded and the series becomes discontinuous, consisting of short ridges one-half mile or less in length and separated by intervals of varying length up to 2 miles. One ridge of the series is found in Freeport Village, near the railroad station. The size of the ridges and hummocks of the series decreases toward the south. The last of the series seems to be a small bed of gravel situated about a mile southwest of Freeport Village. Except

[1] The sea may have reached to Farmington, and these great plains be in large part fluviatile marine deltas. This I now (1893) consider probable.

at the north end, this series lies in a region covered by marine clay. Its length is about 5 miles.

A small plain of gravel, cobbles, and rounded bowlders, which appears to have no connections, is found about 2 miles northwest of Freeport Village. It will be more fully described later.

LEWISTON-DURHAM SERIES.

This is a discontinuous series of short ridges, domes, and plains, separated by the usual intervals. It appears to begin as a terrace in the southern part of Greene, a short distance east of the Androscoggin River and about 75 feet above it. The gravel here is but little waterworn, yet plainly has had the finer detritus washed out of it. From this point the series continues along the left bank of the Androscoggin River through Lewiston to the west line of Durham, but for 2 miles in Auburn a nearly parallel series is found also on the right bank. One of the smaller mounds of this series is found in the city of Lewiston, a short distance from the end of the upper wagon bridge between Lewiston and Auburn. It is composed of well-rounded gravel and cobbles.

The two parallel series of gravels in Lewiston and Auburn are found at or near the brow of the steep banks on each side of the river channel. These places would be favorable to the formation of crevasses in the ice, and the appearances indicate that a subglacial river flowed on each side of the valley, and that they united into one stream about a mile east of Lewiston. The domes of this series vary in height from a few feet up to 100 feet. They are covered or partly covered by the marine clays as far north as Lewiston, and how much farther is uncertain. The lower clay at Lewiston contains various marine shells; the upper clay is sparingly fossiliferous. The only fossil I have been able to find in the upper clay is a marine alga, a frond of sea lettuce, found a short distance north of the Androscoggin River in Lewiston. This was at an elevation of about 220 feet. When the sea stood at the contour of 230 feet, it would extend 2 or more miles above Lewiston.

The condition of western and central Maine during the last of the Ice period proper and during the subsequent time when the ice was melted over the valleys but still lingered in the country lying to the north will, when fully investigated, form the basis for an interesting chapter in geological

history. In connection with the investigation of the glacial gravels, I have been able to gather many facts as to the periods in question. The aspect of the coast was then very different from what it is at present. The sea certainly extended up the Kennebec Valley to Madison, and up the Androscoggin to a point not far north of Lewiston, and in both valleys it may have extended several miles farther. The Sandy River from Farmington Falls eastward was from 1 to 5 miles wide, and this portion of the valley was probably occupied by an estuary. The Sandy River at that time overflowed southward, as before stated, or arms of the sea extended and joined the Androscoggin in Jay, East Livermore. South of Livermore Falls the alluvial plain of the Androscoggin was between 2 and 3 miles wide for a large part of its course southward to the sea. At the present day the highest stage of these rivers in time of flood affords far less water than then flowed in them. At about this time there was apparently an extensive overflow of the Androscoggin River southward from Canton through a low pass in the western part of Livermore into Turner, where it joined a broad sheet of water which filled the valley of Twentymile River as far west as Buckfield and overflowed southward from Buckfield Village through Minot into a similar body of water which filled the valley of the Little Androscoggin River to a point west of Mechanic Falls. A line of clays also extends south from Turner to Lake Auburn. This is in part osar border clay, but in a greater part is an overflow of the Twentymile River after the ice had melted. All these were probably arms of the sea. For the greater part the broad sheets which filled these valleys extended from side to side of their valleys. Apparently the ice had then melted in the valleys, or nearly so. At this time a narrow arm of the sea extended from the Fair-ground, Lewiston, eastward along a low valley to Crowleys Junction, where it connected with the sea in two directions, one northeastward to Sabatisville, the other southeastward to Lisbon. Tide water extended up the valley of the Little Androscoggin River several miles above Auburn, perhaps as far as South Paris. Below Lewiston the Androscoggin Bay of that period was from 1 to 3 miles wide, and in Durham a strait extended southward through Pownal and soon opened out into the bay 10 to 20 miles wide which then covered the valley of Royal River. The whole of the coast region of Maine to a breadth of from 10 to 30 miles was then submerged, except the higher hills, which appeared as a multitude of islands off the coast. The

rivers were pouring a vast body of muddy water into the sea, and extensive deltas of sand and clay were being formed off the coast of that period. Above the sea vast rivers occupied the valleys. They were laden with sediment, and rapidly filled up their valleys with alluvium or valley drift. At first the sediment was clay, but later the floods were higher, or the slopes steeper, and sand was deposited by the swifter waters. This sand, being poured into the sea by the Androscoggin and other rivers, was carried far and near by the tidal currents and spread over the previously deposited marine clays. A broad area of delta sands brought down by the Androscoggin at this time extends from Lewiston to Brunswick and Topsham, and almost to Bath; also from Durham southward to Yarmouth. The area of this delta sand is diversified by frequent dunes of blown sand. A small portion of the sand overlying the marine clays may be due to erosion of the till by the sea. But this sand is not most abundant next the high hills, and there is no body of beach gravel corresponding to the sand. It is plainly delta sand brought down by the Androscoggin, which not only emptied into the sea near Lewiston, but also near the south end of Sabatis Pond by way of Leeds.

The Lewiston series of discontinuous domes and mounds ends near the west line of Durham. About 3 miles southwest of this point another series of mounds and broad plain-like ridges begins and extends past West Durham into the northern part of Pownal, where the series ends, unless a small ridge near Pownal Center be a connection of the series. Here, in Lewiston, Durham, and Pownal, are illustrated the difficulties of classifying glacial gravels. According to general analogy, the gravel systems end in either a delta-plain or they become discontinuous and form a series of short ridges and domes, which become smaller and smaller toward the south, and the intervals between them longer and longer. The Lewiston series ends in the manner last mentioned near the Androscoggin, in the northwestern part of Durham, and the West Durham series ends in the same way in Pownal. These series are situated nearly in the same straight line, and the interval between them is less than 3 miles—facts which favor the theory that they are a continuation of the same system and were deposited by the same glacial river. But each series ends in a way characteristic of the terminations of the independent systems, and I therefore hesitate to

assign them to a single glacial river, although the same river can be conceived as running two independent careers at different times.

The vicinity of Lewiston is a favorable locality for studying the differences between the glacial gravels and the valley drift. Only two theories can be admitted as accounting for the ridges and mounds of gravel and cobbles of the Lewiston series—they are either glacial gravel or they are uneroded fragments of an ancient sheet of valley alluvium.

1. From Bethel to the sea the alluvium of the upper terraces of the Androscoggin Valley is in general either sand or clay. For a short distance below where the river has cut through ridges of till, there are limited areas of gravel, also at the parts crossed by glacial gravel systems or near the mouths of the swifter tributaries. Low terraces of sand and gravel are found along the banks of the river, reaching 5 or 10 feet above it, but nowhere below Bethel does the low flood-plain terrace contain any such rounded cobbles or bowlderets as are found in the ridges of the Lewiston series, except where crossed by osars and near the mouth of Swift River. The stones of the flood-plain terrace and those in the bed of the river are not nearly so much rounded, and many of them have till shapes, with but little modification by water action

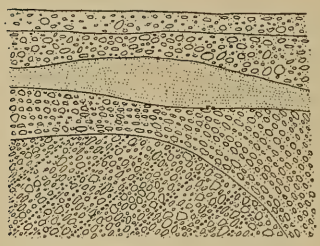


FIG. 21.—Stratification of lenticular gravel.

2. The two-sided ridges and mounds of gravel, cobbles, and bowlderets of the Lewiston series cover but a small part of the valley—here and there a dot, so to speak. If they are uneroded portions of a sheet of similar matter which formerly filled the valley to a height of about 100 feet, then there has been a vast erosion of coarse matter from the valley, and this ought to appear as plains of such material in Brunswick and Bowdoinham and along the shores of Merrymeeting Bay, where the Androscoggin unites with the Kennebec. But those regions show only fine sediments—sand and clay.

Two-sided ridges and domes rising 50 to 100 feet above the level ground on all sides of them can not be any form of beach terrace or sea wall. Their forms and situations make this impossible. In short, these gravels can not be any form of marine or ordinary fluviatile drift.

The length of the Lewiston series is 9 miles; that of the West Durham series, 5 miles.

HILLSIDE ESKERS IN JAY AND WILTON.

About 1½ miles south of Beans Corner, in Jay, is a good specimen of the short sidehill systems as they appear in a region of granite rock. Four parallel ridges begin on the rather steep southern slope of a hill and extend about one-fourth of a mile southward to the base of the hill, where they expand into low broad ridges and then appear to end in a dome of coarse matter. To the south and east are some rather level till-covered fields, and then the great clay-covered plain of Jay and Chesterville, but I could trace the glacial gravel no farther in that direction. The ridges are composed of a mixture of gravel and large stones of all sizes, up to bowlders 3 feet in diameter. The finer detritus has been washed away, but the stones are hardly more rounded than those of the terminal moraines of the local Androscoggin glacier in Gilead and Shelburne. The hillside systems usually become finer in composition at their south ends, where they terminate in a sort of delta, but in this case the ridges are composed of coarse matter, even to their extremities. The large size of the contained bowlders favors the interpretation that these ridges were deposited beneath the ice.

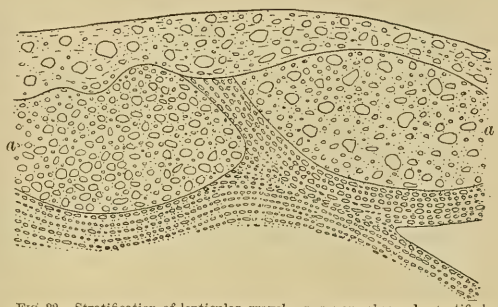


FIG. 22.—Stratification of lenticular gravel. *a*, *a*, very obscurely stratified portions of kame, almost pellmell in structure.

Another short system begins at the top of the hill which lies directly south of Wilton Village, and extends for somewhat more than a mile southward, into Jay, on the slopes of a long hill. Its course lies along the bottom of a ravine 100 to 150 feet wide, which is bordered by steep banks of till 10 to 30 feet high. The gravel forms a terrace lying against and upon the till which forms the eastern bank of the ravine. On the west side the bottom of the ravine is quite level and covered with soil finer in composition than the surface till of the surrounding country. It is either a very clayey till or a sedimentary clay into which some tillstones have been

washed by the rains or other means. At the base of the hill (after a fall of about 100 feet) the gravel spreads out into a narrow fan-shaped series of several ridges situated side by side. These ridges extend a short distance out into the valley of a small stream which flows southwestward into the Androscoggin River. This valley is covered by a sheet of sedimentary clay and coarse sand to a breadth of one-fourth of a mile. These sediments overlie the glacial gravel ridges. On the south they are continuous with the high alluvial terraces of the Androscoggin.

The ravine on the side of the hill must be accounted for. The till of this portion of Franklin County is collected into a great number of long lenticular masses with smooth outlines, and is remarkably free from steep ridges or hummocks or depressions. This ravine has every appearance of having been cut into the deep sheet of till which covers the hillside. No stream flows in this ravine except in time of rains, and the ravine reaches *to the top* of the hill. The ridges at the bottom of the hill have steep slopes on both sides, and could not be formed as a delta at its base by an ordinary surface stream eroding the till on the hillside and sweeping the eroded matter down into the valley. Usually the glacial gravel is piled above the surrounding level, and there is no evident depression showing an erosion of the till, betraying where the kame stuff came from. But here, as in several other places, a channel with steep lateral banks is cut into the till. A fair inference from all the facts is that a stream flowing between ice walls here flowed down the hill and eroded the ravine in the till and carried the material down into the valley. The terminal ridges must have been formed between ice walls. Beyond the ridges the plain of alluvium in the valley may be in part composed of the finer sediment brought down by this small glacial stream, if the stream dates from a late period when the ice was retreating up the valley, as was probably the case.

CANTON-AUBURN SYSTEM.

A broad mountain cirque between high hills is situated in Weld, Carthage, Mexico, and Dixfield. This valley is drained southward into the Androscoggin River at Dixfield. Considerable alluvium is found in the valley, most of which appears to be valley drift, i. e., frontal overwash, but with some signs of an osar-plain along the axis of the valley; and the same can be said of the valley of Swift River in Byron, Roxbury, Rumford,

and Mexico; and perhaps there should be added the Androscoggin Valley from the mouth of Swift River to Canton. There has been a large amount of erosion along the Androscoggin and Swift rivers, and this makes it doubly difficult to discover what was the original condition.

A well-developed osar-ridge begins not far from the Androscoggin River at Gilbertville (Canton Point), and passes southward through the wide plain covered by sedimentary clay and sand which here borders the Androscoggin on the south. It passes about half a mile east of Canton Village, and then ascends the valley of Bog Brook to its source at a small pond in Livermore. In this valley the gravel takes a somewhat unusual form. A two-sided ridge is found along the axis of the valley, bordered on each side by a ravine of erosion, while on each side of the valley is a level terrace of fine gravel. The central ridge consists of gravel with cobbles and bowlderets, all very much rounded. It rises 10 to 20 feet above the terraces at the sides of the valley. Evidently a glacial stream at one time flowed in a rather narrow channel in the midst of the valley, and in this narrow channel was deposited the central ridge of coarse matter. Later the channel widened until it extended nearly or quite across the valley, and in this broad channel the finer gravel was deposited as a plain extending from the central ridge to each side of the valley. The current in the broad channel was not so rapid as in the narrow one, and the gravel was finer and did not reach to so great a height as the original osar. Finally valleys of erosion have been excavated in the osar-plain along each flank of the osar.

In several places the terraces along the sides of the valley can be seen to overlie till. Many bare ledges appear in the southern part of the pass, as if the till had been washed away by the glacial river. The top of this pass is so level that for a considerable distance we find a stream flowing northward on one side of the osar ridge and on the other side a stream flowing in the opposite direction.

On the west and southwest sides of Brettuns Pond, at Livermore Post-Office, the gravel takes the form of a narrow plain of reticulated ridges and hummocks of gravel, cobbles, and bowlderets. Extending from this plain eastward around the south end of the pond is a rather level plain composed of gravel on the west but becoming sandy toward the east. It is about one-third of a mile in diameter, and is evidently a delta-plain. It lies between Brettuns Pond and the valley of Martins Stream. This valley is

widely covered by sedimentary clay from Livermore Center eastward to Livermore. The currents which deposited the delta south of Brettuns Pond must have flowed for near a mile along the west and southwest sides of the pond, bordering it with high, steep banks of gravel, cobbles, and bowlderets. If the area where the pond now is had been bare of ice at the time these waters flowed south from Canton, the delta would have been formed where the pond now is. The facts indicate that the valley of Martins Stream was occupied by a glacial lake or other body of water at the time this delta was formed, while the area where the pond now is must have been occupied by ice. The finer sediment brought down by the glacial stream passed beyond the delta of gravel and sand, and furnished the clay which covers this valley.

A rather level osar-plain, from one-eighth to one-half of a mile wide, extends along the valley of Martins Stream southward nearly to the Twentymile River. Between Livermore and North Turner the plain has been irregularly eroded so as to leave a marginal terrace on each side of the valley and a ridge, or, rather, series of ridges arranged as a single line in its midst. These ridges appear as narrow islands in the midst of the artificial pond (produced by the dam at North Turner), which now occupies the valleys of erosion on each side of the central ridge. The central ridge here has the same height as the marginal terraces, except where it has been reduced by erosion. South of North Turner the osar-plain is bordered by a wide plain covered by sedimentary clay, overlain by some sand. This alluvial plain is connected with the plain of sedimentary clay that covers the valley of Twentymile River by two lines of clays, one southward down the valley of Martins Stream, the other southeastward past the west side of Pleasant Pond and then by a low pass to Bradford Village (Turner Center). I could find no glacial gravel along the last-named route, and infer that this large area of fine sediment was not deposited in a broad osar channel, but at a time when the lowlands were all bare of ice and covered with water, probably either fluviatile or estuarine.

The osar terrace becomes finer as it nears the Twentymile River, and thus shows some of the characters of the delta-plain. It appears to be interrupted for a half mile or more near Twentymile River, but soon begins again as a series of low reticulated ridges or plains from one-fourth to one-half of a mile broad. The reticulated plains extend

southward along a low pass. They inclose several lakelets, some without visible outlets. Toward the south the ridges coalesce into a level plain, the materials of which become finer, the gravel passing by degrees into fine sand, and this into sedimentary clay about a mile north of the northeast angle of Lake Auburn. This clay extends along the east side of the lake and thence to Auburn and Lewiston, where it is plainly marine. A little silt or clay is found in the valleys of the small brooks which flow into Lake Auburn, which is probably valley or lake drift. With these insignificant exceptions, the only clay found along the shores of the lake is that found along the northeastern side, where a plain of fine blue clay rises 30 feet above the lake and apparently forms part of the barrier that holds it back. If Lake Auburn was bare of ice or was occupied by an open arm of the sea at the time this clay was being laid down, the clay ought to have extended farther west, probably all around the lake. The water which poured south from Turner was certainly muddy, as is shown by the great depth of clay at the northeast angle of the lake. This makes it highly probable that the clay was deposited in a broad channel within the ice at a time when the area which Lake Auburn now occupies was covered by ice.

No gravel rises above the clay for about 2 miles, and then we find a rather level gravel plain near the southeast angle of Lake Auburn. It is about a mile long and more than half as broad. The gravel, cobbles, and bowlderets of which it is composed at its north end are not much water-worn, and often have almost a till shape. Toward the south and east the material is somewhat finer and the plain appears to be a delta deposited either in a bay of the sea that was inclosed between ice walls or in a glacial lake. About half a mile south of this is another similar one. It ends in steep banks on all sides except one, where it lies like a terrace against a hill. This plain is only about one-fourth of a mile in diameter, and becomes sandy on the south and east sides, and is thus shown to be an incomplete delta.

South of this point I have been able to find no glacial gravel for about 8 miles. The system ends on a hill overlooking the valley of the Little Androscoggin. The system dates from a time when the sea had advanced up the valleys of the Androscoggin and Little Androscoggin to a point some distance west of Auburn. The ice still lingered to the north. Three delta-plains were formed in Auburn during the flow of this large glacial

stream, and perhaps a fourth was afterwards formed in Turner north of the Twentymile River. For many miles this great osar river flowed in a channel one-eighth to one-half of a mile wide. In this channel was deposited a level plain of rather fine gravel of the type which I have named the osar-plain. Whenever the system expands into plains of reticulated ridges the material is very coarse. The very great size of the glacial river which flowed south from Canton makes it highly probable that it drained the valleys lying north and northwest from it, including Swift River. If so, the original gravels have been much disguised by later sediments. Indeed, we might expect that during the retreat of the ice there would come a time when the ice was melted over the Androscoggin Valley but still lingered toward the north, and overwash or frontal plains would at this time be brought down into the main valley and cover out of sight much of the earlier sediment.

The length of the system from Canton to Auburn is about 25 miles.

NOTE ON THE ANDROSCOGGIN VALLEY.

For about 60 miles from Gorham, New Hampshire, to Jay, the direction of the Androscoggin River is a little north of east. It is a valley of preglacial erosion excavated in highly crystalline rocks, chiefly granite. On each side of the river the hills rise steeply, becoming higher as the White Mountains are approached. The river is bordered by a plain of valley drift, which for most of its course is less than half a mile in breadth, but here and there spreads out into much broader intervals, 1 to 3 miles wide. Such a plain is found in Canton. About 3 miles east of Canton the river has cut through a sheet of till 70 feet thick. This body of till dammed the river in the Valley Drift period and formed a lake where the broad Canton intervale now is. It is probable, but not certain, that this raised the level of the Androscoggin sufficiently to cause an overflow southward to Livermore along the Bog Brook Pass. As already noted, the valley drift of the Androscoggin is noticeable for its fineness over most of the course of the river.

HILLSIDE ESKERS IN HARTFORD.

Whitney Pond lies a short distance southwest of Canton Village. About a mile north of this pond, on the road from Canton to Sumner, are

two short systems of sidehill kames or eskers. They are situated in small north-and-south valleys which descend steeply toward the south. The ridges begin on the hillside, and after descending about 100 feet to rather level ground, they end within a mile in small delta-plains. At their north end the ridges do not have the smooth and arched cross section so common to kame ridges found near the present sea level, but they have the steeper lateral slopes and the irregular heaping characteristic of the lateral moraines of a local or valley glacier. The material has been but little polished by water, yet the finer drift has been washed out of it. The two systems are only about a mile apart. The western system consists of three parallel ridges which become confluent in the terminal plain.

PERU-BUCKFIELD SYSTEM.

Worthley Pond, Peru, lies in a narrow valley bordered by steep, high hills. The outlet of the pond flows northeastward into the Androscoggin River at South Peru. South of the pond the valley narrows so as to form an almost V-shaped pass through the high hills which lie not far south of the Androscoggin River. The highest part of this pass is situated only a short mile south of Worthley Pond and about 100 feet above it. South of the pond, in the bottom of this narrow valley, are several short ridges of sand separated by gaps. Only a small brook flows in the valley, and it is quite incapable of depositing ridges such as these, in respect either to form or to size. Lying across this part of the valley, or forming irregular terraces along the lower slopes of the bordering hills, are numerous piles and heaps of sandy till which have the appearance of moraines of a local glacier. Probably a tongue of ice projected south through the pass in late glacial time and left these moraines during its retreat northward. During the retreat of the ice front down the northern slope, a small lake would naturally form between the ice and the hill to the south. The drainage of the local glacier would pour into this small lake and then overflow southward over the col. If a large stream flowed into such a lake, the whole valley ought to be deeply covered by a lake delta. On the contrary, the sand and fine gravel are found in the form of several isolated ridges. This seems to indicate that the sand ridges were deposited by small streams in channels within the ice, and that after the formation of the lake at the ice front there was either little sediment or the drainage flowed northeastward

to the Androscoggin. I could find no proof that these sand ridges were uneroded portions of a delta that once filled the valley.

No kame material was found for a short distance near the top of the pass, and then begins a series of low ridges and terraces of fine gravel containing but few large stones, and those are but little polished by water. In numerous places these deposits could be seen to consist of a thin sheet of gravel (2 to 5 feet thick) overlying the till. All these facts combine to prove that the glacial stream that flowed south through the Worthley Pond Pass was very small, compared with the mighty rivers which flowed out of the Androscoggin Valley at Canton and Rumford. The system follows the valley of the main east branch of Twentymile River to Sumner station (Sumner Flats), and then its course lies near the railroad to a point near Buckfield Village. The gravel appears as low, rather level-topped ridges, like a narrow osar-plain, except that they inclose some shallow kettleholes. Often these plains appear like terraces on the sides of the valley, and erosion of the central parts of the plain by the stream often increases this resemblance. The system is somewhat interrupted by short gaps north of Sumner station. South of that point the separate ridges coalesce more and more, and not far north of Buckfield the system passes into a delta-plain one-fourth to one-half mile wide. The sand of the delta passes by degrees into the clay which covers the valley of the Twentymile River all the way from its mouth to a point several miles above Buckfield. At a few points not far south of Sumner excavations showed that a number of low ridges had first been deposited in a separate, narrow channel, bordered by ice walls. Subsequently the depressions between the ridges were filled up so as to make of the whole a level-topped plain. Probably the tops of the original ridges were in part washed away by the broad body of water which at the last swept over the whole breadth of the gravel system, and may have furnished part of the material to fill up the depressions. This is a sort of structure to be anticipated for the osar-plains, but in this case the plain extends across the valley from side to side in such a manner as to make it difficult to judge whether this plain was deposited in a broad channel within ice walls or in the open valley after the ice had melted. Even if the upper part of the plain be valley drift of less age than the ice occupancy of that region, the underlying ridges are plainly contemporaneous with the ice occupancy.

The delta-plain northeast of Buckfield Village has been deeply eroded by streams and springs. At one place a long ridge has been left uneroded. It is locally known as the "Whalesback." On the surface it appears to be composed of nearly horizontally stratified sand and gravel like the rest of the delta, yet there must be some reason why this portion of the plain has resisted erosion, and it may be there is a ridge of coarse kame stuff along the axis of this "Whalesback." Evidently this delta dates from a late period, when the ice had melted as far north as this place.

The apparent end of this system northeast of Buckfield is only about a mile from the West Sumner-Poland system. It is therefore possible—perhaps probable—that they were at one time connected, but thus far I am unable to prove it. The Peru glacial river may have joined that from West Sumner by flowing southwest from the above-mentioned delta-plain through Buckfield Village or along a very low valley situated about a mile farther east. These valleys are all so deeply covered by sedimentary clay that only large deposits of glacial gravel would rise above the surface. This clay is probably of estuarine origin.

The length of the system from Worthley Pond to Buckfield is 13 miles.

WEST SUMNER-POLAND SYSTEM.

This system appears to begin about a mile south of West Sumner, in the form of an osar-ridge which follows the valley of the west branch of Twentymile River for several miles and then expands into a delta-plain a short distance west of Buckfield Village. From this point a broad, low valley extends southward to Mechanic Falls. Along this valley the railroad is constructed. The bottom of the valley is covered with sedimentary clay, continuous on the north with the clay of the valley of Twentymile River and on the south with that of the Little Androscoggin Valley. A series of low ridges, terraces, and deposits of glacial gravel resembling the broad osar is found along the valley its whole length. Near Buckfield the gravels skirt the base of the high hills lying west of this valley, near East Hebron they lie in the midst of the pass, and at West Minot they are on the west side again. As we approach Mechanic Falls the gravels rise out of the valley and are found on the slopes of the hills on the east side. There are several apparent short gaps in the series. The intervals are more frequent toward the south and the deposits become narrower and finally form simple

eskers not at all plain-like. Near the Little Androscoggin River there is apparently a long interval of 2 miles where there is no gravel. About 2 miles east of Mechanic Falls is a sand-and-gravel plain in Poland, which extends for more than 2 miles southeastward near the line of the Grand Trunk Railway. The plain becomes finer on the east and south edges, and passes by degrees into sand and at last into the clay which covers the valley of the Little Androscoggin from Auburn many miles west. These plains in Poland are a delta, but it is uncertain whether they were formed in a glacial lake or in the broad body of sea water which subsequently covered Little Androscoggin Valley.

Subsequent to the melting of the ice there was an overflow from the valley of the Little Androscoggin southeastward along a low pass, past Danville Junction. There are several mounds of true glacial gravel in the valley of Royal River in New Gloucester. These are properly situated to be branches of either the Canton-Auburn or the West Sumner-Poland system, but I have been able to trace no connection between them, although the Danville Junction Pass is a favorable route for a glacial overflow. It thus appears that both the long systems named end in deltas near the Little Androscoggin River, and are therefore a feature of the later history of the Ice age, when the ice had receded so far north that this valley was covered by an arm of the sea or by an estuary.

The length of the system from West Sumner to Mechanic Falls is 12 miles.

BRANCHES IN HEBRON AND NEAR WEST MINOT.

In the northeast part of Hebron is a short series of hillside kames situated in the valley of a small brook named Bicknells River. They expand toward the bottom of the hill into small terrace-like plains. One of these plains is one-eighth of a mile in diameter. It consists of three rather level terraces, each rising 6 to 10 feet above the next below it. The gravel is but little waterworn. The general course of the series is southeast, and the terminal plains are only about a mile from the main system at East Hebron. It is uncertain whether this is a local series or whether it was deposited by a tributary of the main glacial river.

About three-eighths of a mile north of West Minot is a series of kames which begins on the side of a hill and extends down the hill for a short fourth of a mile to join the main system in the valley.

A. MOUND OF BOWLDERS FORMING THE SOUTH END OF HILLSIDE ESKER; ABOUT 2 MILES SOUTH OF BEANS CORNER, JAY. LOOKING EAST.

The remainder of the esker extends northward up the hill at the left.

B. HILLSIDE ESKER ENDING IN GRAVEL TERRACES; HEBRON. LOOKING NORTH.

HILLSIDE ESKERS IN OXFORD COUNTY.

There are several short hillside osars in Paris, Woodstock, Sumner, and other hilly parts of Oxford County. A particular description of them is omitted, since they are so small as not to illustrate the mode of formation of this class so well as the larger deposits already described.

YARMOUTH-CAPE ELIZABETH SYSTEM.

This is a discontinuous system, consisting of rather level plains up to one-fourth mile in breadth, and of low, broad ridges with arched cross section. The intervals between the successive deposits are nowhere more than about 1 mile. The gravels of this system are usually found on the tops of low hills as a rather thin cap overlying the till. The system appears to begin as a low plain of gravel situated not far north of Yarmouth Village. In Yarmouth Village it takes the form of a small plain of gravel and very round cobbles, and then there is a space of about a mile where the gravel does not appear above the marine clay. Not far north of Cumberland Post-Office the gravel begins again, and the intervals between the successive ridges are then very short for several miles. The shore road (Falmouth Foreside) follows the course of the gravel series as far south as the marine hospital near Portland. Near this point is a small kame situated a short distance west of the main system (near an old rolling mill and foundry), which was probably deposited by a small lateral tributary. The next gravel deposit of the series is on the top of Munjoy Hill, in the eastern part of Portland, as a sheet of gravel and cobbles capping a lenticular mass of till. A discontinuous series of gravel plains extends southward through Cape Elizabeth to within a short distance of the sea at Bowery Beach and Two Lights. I could discover no sign of the system having at any time extended south of this point into the sea.

As most of the gravels of this series are on hills less than 100 feet high, they were in exposed situations while covered by the ocean, and much of the glacial gravel has thereby been washed away from the top of the ridges, often being spread over the adjacent fossiliferous marine clays. Although these plains externally resemble delta-plains in several of their features, yet the original structure has so far been modified on the surface by the sea that it is unsafe to assert that the glacial gravel was originally

deposited by glacial streams in the sea over the marine clays. This can be established only by excavations reaching below the beach gravels.

In Portland and Cape Elizabeth the gravels of this system are suspiciously near those of the great Androscoggin Lakes-Portland system. No connection is yet proven between them, and they are therefore classified as distinct systems. The stones of this series are in general well rounded, though not so much worn as in many of the longer systems.

The length of the system is 18 miles.

ANDROSCOGGIN LAKES-PORTLAND SYSTEM.

This is a large and important discontinuous system of peculiar type and affording many interesting problems for investigation. For convenience it will be referred to as the Portland system.

The course of the Androscoggin River is circuitous. Its head waters flow west into New Hampshire, and this part of its valley is a gently rolling plain from 5 to 20 miles wide. In this plain is situated a series of large lakes, which may be termed the Androscoggin Lakes. From Gorham, New Hampshire, the river turns eastward into Maine again, and this part of its valley is bordered on each side by high hills, which thus separate it from the valley of the upper Androscoggin as well as from the valleys of Crooked River, the Little Androscoggin, and other streams flowing southward. From the region of the Androscoggin Lakes several low passes lead through the high hills, one southeastward from Umbagog Lake along the valley of the west branch of the Ellis River, and another from Lake Molechunkemunk southward down the Swift River. I have not explored these passes. The valleys of both the streams just mentioned contain much alluvium, which may wholly or in part be an osar-plain or frontal plain. A third pass leads from Rangely Lake southeastward down the valley of Sandy River. The highest part of the pass is 205 feet by aneroid above Rangely Lake. I could find no glacial gravel along this pass. The lowest of all the passes leads from Lake Welokennebacook southward along Black Brook to Andover. This I will name the Black Brook Pass.

An interrupted gravel ridge begins on the west shore of Lake Moosehlookmeguntic and follows that shore to the outlet of the lake (here running east and west), when it crosses to the south shore and thence follows the east shore of Lake Welokennebacook for some miles, when it appears to

cross the lake obliquely—at least the ridge soon appears on the western shore and continues thus to the south end of the lake, where it forms a prominent two-sided ridge. The region lying south and southeast of the lake is so low that only a few feet of digging would be required to drain the lake southeastward down Black Brook. I am informed that in time past it has repeatedly been proposed to cut a canal at this place in order to use the water for lumbering purposes on Black Brook and the Ellis River. One branch of Black Brook takes its rise within a half mile of the foot of the lake. The osar continues southeastward along the broad and level valley of Black Brook for about 3 miles, sometimes broadening into a plain resembling an osar-plain in appearance. It then enters a narrow V-shaped pass where the hills rise steeply, almost precipitously, on each side up to near 1,000 feet. The glacial river flowed through this pass, but in its narrow part I saw no glacial gravel for a short distance. It can hardly be expected that any but the larger stones and bowlders would be left by the stream in the narrow gorge, and if there were any such they have been covered out of sight by débris that has fallen from the high cliffs. South of the narrow pass Black Brook has for several miles a fall of 50 feet or more per mile, and here most of the gravel was swept away by the force of the glacial river. Approaching Andover the slopes become gentle, and then for 3 or 4 miles the valley is covered with a hummocky plain which soon becomes nearly horizontally stratified. This plain is composed of coarse gravel, cobbles, etc., at the north, and passes by degrees into sand at the south. It fills the valley from one side to the other and is of varying breadth up to nearly a mile. The valley of the Ellis River in Andover forms a broad valley or mountain cirque several miles in diameter, surrounded on all sides by high hills, except on the south. Into this rather level plain pour the Black and Sawyer brooks, also the east and west branches of the Ellis River, all uniting not far south of Andover to form the main Ellis River. Sedimentary plains of gravel, sand, and silt extend up all these valleys for a mile or more. Part of these plains must have been brought down by these streams as fluviatile alluvium, yet the alluvium is so abundant near the mouth of Black Brook as to suggest the theory that the glacial river here flowed into a lake which extended up the tributary valleys. The cause of such a lake will be discussed presently.

The valley of the Ellis River narrows near South Andover, and from

there to Rumford is from one-fourth to one-half of a mile wide. It is a U-shaped valley bordered by high steep hills. The fall of the stream per mile is very small. A plain of well-rounded glacial gravel is found in the valley all the way from South Andover to Rumford Point. For several miles it lies as a level osar-plain on the east side of the valley, but for 2 miles north of Rumford Point it is on the west side and takes the form of a plexus of reticulated ridges inclosing kettleholes and a lakelet. The fact that this gravel plain does not extend across the whole valley is proof that the gravel is not valley drift but is of glacial origin. Along with the gravel are many cobbles and well-rounded bowlderets, and the slope of the Ellis River is here so gentle that it is impossible to accept such coarse, well-rounded matter as ordinary stream wash. The portion of the valley not occupied by the gravel plain is covered to a considerable depth with silt and clay. The base of the gravel plain appears to underlie the clay, but in places along the margin of the plain the gravel can be seen to overlie the clay. The great breadth of the level portion of the Ellis River Valley as compared with the drainage basin makes it certain that the fluviatile drift would be fine and the river currents comparatively gentle, even in time of flood. This makes it more probable that the deposition of the gravel overlying the clay took place in a broadened osar channel than that it was the work of the Ellis River after the melting of the ice.

For about 3 miles from Rumford Point to the mouth of the Concord River there are occasional low ridges and hummocks of gravel on the west side of the Androscoggin River. They rise out of a low terrace of erosion and externally appear like uneroded portions of the plain of valley drift which originally must here have bordered the Androscoggin. But examination shows that they are composed of gravel, cobbles, and even bowlderets—much coarser matter than is contained in the alluvium of this part of the Androscoggin Valley. They are therefore glacial gravel. It is thus proved that the course of the glacial river crossed the Androscoggin River at Rumford Point. If the osar-plain was originally deposited continuously, it has since been eroded by the river. This must have happened since the Valley Drift period, for the upper alluvial terraces of the valley for many miles below this point do not contain gravel similar to that of the osar-plain. For a short distance north of the mouth of Concord River a two-sided ridge of well-rounded gravel and cobbles lies parallel with the

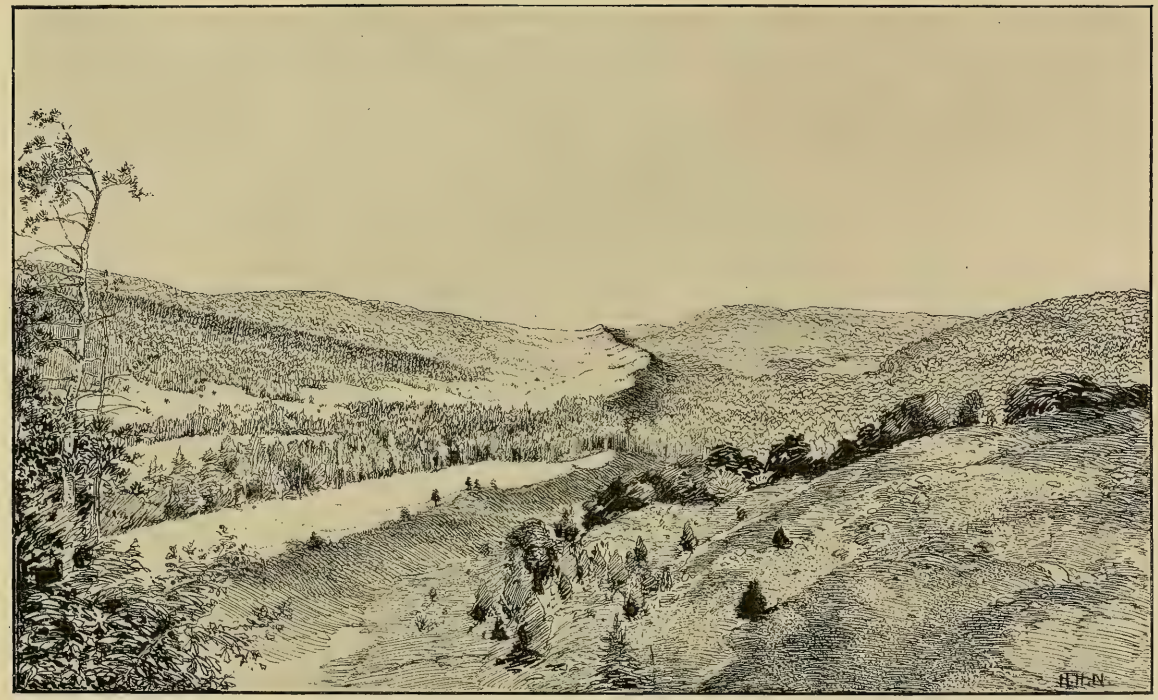
Androscoggin River, which here is flowing southeastward. The gravel soon turns southwest and ascends the valley of the west branch of the Concord River through Milton and Bethel to the top of the divide near North Woodstock, which is fully 125 feet above Rumford Point, and perhaps as much as 140 feet. From the Androscoggin River to North Woodstock this valley affords an instructive study. The average slope is not far from 25 feet per mile. The bottom of the valley was once occupied by an alluvial plain from one-eighth to near one-half of a mile in breadth. The osar ridge near the mouth of the Concord is lost in the plain of finer sediments soon after it leaves the Androscoggin River. South of this point a ridge is found along the axis of the valley. It is from 10 to 60 feet in height, and is locally known as the "Whalesback." Both sides of the valley are bordered by terraces having nearly the same height as the central ridge, but composed of somewhat finer drift. Near the Androscoggin River the material is sand. Going southward, it becomes coarser until, at North Woodstock, we find only coarse gravel, cobbles, and bowlderets. Both the central ridge and the lateral terraces are usually bordered by rather steep banks. They are simply uneroded portions of the original plain which extended across the valley. Two valleys of erosion have been formed, one on each side of the central ridge. These erosion valleys, where observed, do not cut down to the till, hence the osar-plain must have been originally of great depth. The valley is only about 8 miles long, and the small brook that flows in it does not receive any large tributaries. It is quite too small to have deposited, even in the highest floods, such a gravel plain as once filled the valley. Indeed, at first it seemed to me surprising that it could have eroded the two large valleys on each side of the "Whalesback." It was not until I had studied the remarkable erosive power of boiling springs that I could assign any physical cause for so great an erosion in so short a valley.

The alluvial terraces of the Androscoggin Valley rise from 30 to 50 feet above the river at the mouth of the Concord. The Androscoggin at the time it stood at its highest level must have backed up the valley of the Concord for 2 miles or more, and would fill that valley with more or less river alluvium. At North Woodstock the gravel rises 70 or more feet above the highest terrace of the Androscoggin at Rumford. It is thus proved conclusively that the gravel along the North Woodstock Pass was not

deposited by an overflow of the Androscoggin River after the melting of the ice. Only an ice dam at Rumford could cause an overflow up the valley of the west branch of the Concord and over the col at North Woodstock.

The following is the probable history of this interesting valley: First, a glacial river flowed southwestward through the North Woodstock Pass in a narrow channel along the axis of the pass. This was bordered on each side by ice walls, and in the channel was deposited an osar-ridge. Subsequently this channel gradually broadened, and in the broad channel was deposited an osar-plain. At length a time came when the channel extended from side to side of the valley, and the osar-plain thus came to resemble a plain of valley drift in its external form. The broader the channel became the less rapid, on the average, was the glacial river and the finer were the sediments deposited by it. The erosion of the plain has proceeded more rapidly in the medium gravel than in the very coarse gravel of the central part of the valley or in the finer sand and gravel at the margins. Now a dam of 125 feet at North Woodstock would flood back the water in the broad osar channel for many miles up the valley of the Ellis River. If the channel was open on the top to the air, or for any reason the broad osar river was not confined within the ice under high hydraulic pressure, the dam would cause the glacial river to form practically a lake one-eighth to one-half mile wide, extending from North Woodstock to Andover, where it would be at least 50 feet deep. The glacial river pouring from the north down Black Brook would deposit in this dammed osar-plain channel or back-water lake the plains near Andover Village which so much resemble lake deltas. In this long reach of quiet water would be deposited the fine clays of the Ellis Valley that border the narrower osar-plain. The osar-plain of the Ellis Valley had been deposited in still earlier times when the channel of the glacial river was not so broad as that of the later osar border clay. It is also possible that the sedimentary drift near Andover is in part frontal matter.

The highest part of this pass is a short distance north of North Woodstock. Here a small brook takes its origin and flows southward along a gentle slope to Bryants Pond. The osar-plain continues in this valley and the material becomes coarser, and near Bryants Pond contains very round bowlders 2 and even 3 feet in diameter. Here the plain becomes a plexus



BROAD OSAR PENETRATING A LOW PASS; WOODSTOCK.

of two or three broad ridges, inclosing one deep and symmetrical kettlehole, besides several shallower basins. The gravel skirts the eastern border of Bryants Pond and then it follows the valley of the Little Androscoggin River for many miles southward.

South of Bryants Pond we have a very difficult problem, i. e., to distinguish an osar-plain from valley drift on a southern slope where the glacial river flowed in the same direction as the ordinary river which afterwards flowed in the valley. It thus becomes necessary to state the facts from which a conclusion may be drawn.

1. The gravel plain which extends from Rumford to North Woodstock, and so on to the south end of Bryants Pond, is, without doubt, of glacial origin. The ice must have covered the Androscoggin Valley or the water would not have flowed southward over the divide at North Woodstock. No geological fact can be more certain than that a mighty glacial river, large enough to assort and polish the gravel, cobbles, bowlderets, and bowlders of a plain one-eighth to one-half of a mile wide, and that, too, on an up slope of 25 feet per mile, flowed southward over the North Woodstock divide and thence to the south end of Bryants Pond. Such a river as this can not disappear by accident, and a river capable of doing so great an amount of work on an up slope would do still more on a down slope.

2. The osar-plain borders Bryants Pond for about three-fourths of a mile. If the basin where the pond now is had been bare of ice at the time the gravel plain was being deposited, there would be nothing to hinder the gravel from spreading out in fan shape across the whole valley. Instead, the gravel is confined to a narrow belt along the east side of the pond. Here was a torrent swift enough to make granite bowlders 3 feet in diameter almost as round as marbles, and depositing a gravel plain 10 to 20 feet higher than the present pond, strewing the margins of the pond with steep bluffs of bowlderets and bowlders, yet scrupulously confining itself to the eastern border of a mountain valley.

The only satisfactory explanation of these facts is that the glacial river was confined between ice walls and that the area which Bryants Pond now occupies was then covered with ice. True, in the pass north of North Woodstock the glacial river may at this time have extended from one side of the valley to the other, like an ordinary river, yet it could not have followed the course it did without the presence of ice some miles to the

north in the Androscoggin Valley at Rumford, and also in the Little Androscoggin Valley at Bryants Pond. Practically it was a glacial river as far south as the south end of Bryants Pond.

South of this point the valley of the Little Androscoggin is bordered by high hills. A plain of mixed sand, gravel, cobbles, and bowlderets, with some bowlders, extends along the valley to West Paris. This plain is about one-fourth of a mile wide, and the stones are all very much rounded, like those of the osar-plain at Bryants Pond. It should be noted that we are near the source of the Little Androscoggin, which stream is here only a a good-sized brook. From Bryants Pond to West Paris the slope of the stream averages about 35 feet per mile; from West Paris to South Paris it is 8 or 10 feet; and it is only 4 or 5 feet from that point to the mouth of the river at Auburn. Now, in the White Mountains, where the slopes are 100 or more feet per mile, the stones in the beds of the streams are much rounded; but I have nowhere seen them so rounded as those in the valley of the Little Androscoggin from Bryants Pond to West Paris. North of the place where the osar-plain enters the valley of the Little Androscoggin there is no such drift as the plain of very round stones that extends from the foot of Bryants Pond to West Paris. Even in the highest late glacial or postglacial floods the Little Androscoggin could not at this place be a very large stream, for we are near its head waters. From whatever standpoint, then, we look at the plain of very round gravel, cobbles, bowlderets, and bowlders that extends from Bryants Pond to West Paris, we find neither the size of the stream nor the steepness of slope necessary to account for this plain as fluviatile sediments. Besides we know that a great glacial river flowed into the north end of this valley. The steep hills would prevent it from getting out of the valley. It must have flowed down the valley doing its characteristic work. The result was this plain, which is thus proved to be chiefly glacial as far as West Paris.

At West Paris the valley of the Little Androscoggin abruptly broadens into a triangular plain 3 or more miles in breadth. One apex of the triangle is at West Paris, another at Trap Corner, Paris, and the third at Snows Falls, where the valley narrows to 300 feet. The west side of this triangular valley is bordered by a plain of sand, gravel, and well-rounded cobbles which extends in nearly a straight line from West Paris to Snows Falls. It presents the external appearances of an osar-plain. East of this

western border plain the broad valley is covered by sand, silt, and clay. At Trap Corner the fine alluvium extends for a considerable distance up two small tributary valleys to the same height as the clay plain of the main valley at that place. This proves that most of the broad valley was at one time covered by rather still water, approaching the condition of a lake, and this must have happened after the melting of the ice at that place. If the great glacial river that deposited the osar-plain to the north had flowed into the broad triangular valley below West Paris after the ice had melted, it must have filled up the valley with a delta-plain. Instead, the plain of rounded gravel and cobbles is confined to a strip along the west side of the broad valley hardly more than one-fourth of a mile wide. It is thus proved that an osar-plain was formed in a broad glacial channel along the western border of the triangular valley at a time when the rest of the valley was covered by ice. Later, when the ice over the valley melted, this broad valley formed, for a time, a lake, owing partly to the great breadth of the valley at this point as compared with its narrowness at Snows Falls, and partly perhaps to the osar-plain's acting as a dam across the valley near Snows Falls. In the northwestern part of this lake coarse sediment would be deposited by the swollen river of that time, consisting in part of portions of the eroded osar-plain, while east and south only the finer sediments would be laid down. It thus becomes reasonably certain that the drift of the broad triangular valley that extends from West Paris to Snows Falls consists of an osar-plain more or less covered by alluvium of fluviatile and lake-delta origin.

Not far south of Snows Falls the valley of the Little Androscoggin widens so that the alluvial plain has an average breadth of about half a mile. It is finer in composition than it is north of Snows Falls, sand and gravel being most abundant, but it contains numerous pebbles and some small cobbles. For 1 or 2 miles south of the falls the plain shows numbers of low ridges and shallow kettleholes. Then it becomes more level on the top, and soon a two-sided ridge is formed near the river and extends for about 3 miles to South Paris. It is locally known as the "Horseback." It has the same height as the rest of the plain, and the material appeared to be little if any coarser than that of the plain at the sides of the valley. The ridge is the result of erosion of the alluvial plain on each side of the horseback to a depth of 10 to 40 feet. There must be a reason why this

ridge has escaped erosion, and if fresh exposures can be found they will probably show a mass of coarse matter at the bottom of the ridge, perhaps an osar with arched cross section. We have already seen that these erosion ridges are common in the osar-plains, as in the valley of Martins Stream between Livermore and North Turner, and the whalebacks in Rumford, Milton, Bethel, and Woodstock. In the last-named cases it is quite easy to determine that they are ridges of erosion carved out from the original osar-plains. Here we find that the Little Androscoggin is larger than the streams flowing in the valleys just named. Did it deposit the alluvial plain below Snows Falls as valley drift? Its drainage basin above South Paris covers only a few townships, and even in the Valley Drift period its flow was small as compared with that of the Androscoggin and Kennebec rivers, yet it is bordered by an alluvial plain nearly as large as theirs at the same distance from the shore of the sea of that period. There are in the State great numbers of streams having as large drainage basins as the Little Androscoggin above South Paris, yet having very much smaller alluvial plains. This gives an antecedent probability that the alluvium of this valley is largely glacial.

The gravel along the center of the valley below Snows Falls is well rounded, like that of the osar-plain northward. But in many places I noticed that near the margin of the alluvial plain the gravel was but little worn, in some cases the till shapes being hardly modified at all, and the drift was almost morainal. This marginal drift resembles the ordinary valley drift of streams having no greater fall than the Little Androscoggin in Paris, and is just such work as could be expected of the river after the ice had melted, or at the extreme margin of the broad channel of an osar-plain.

We have, then, field evidence of distinctively glacial gravel to within 4 miles of South Paris, and we know that a great glacial river flowed southward in the valley. General analogy, as well as the local facts, indicates that the central part of the alluvial plain of the Little Androscoggin north of South Paris is an osar-plain, deposited in a broad channel between ice walls. Later, as the ice melted, the water extended across the whole valley. Alluvium was then deposited mainly at the sides of the osar-plain, and it was subjected to much less attrition than were the stones of the older glacial gravel. It would naturally happen that after the ice had all melted

in the Little Androscoggin Valley some would still linger in the Androscoggin Valley farther to the north, and therefore a flood of glacial waters still continued to pour south from Rumford to Bryants Pond, and so on, down the Little Androscoggin Valley. These floods of muddy water, augmented by the local drainage of the valley, would wash away and reassort the surface portions of the previously deposited osar-plain, and also carry along its burden of drift washed down from the freshly exposed hills. In this way it might happen that what might be a glacial river toward the north could be considered an ordinary river farther south, where it flowed unvexed by ice to the sea. A considerable portion of the alluvial drift of this valley is undoubtedly a valley delta of frontal glacial sediment, brought down by glacial streams and poured out into the open valley, like the sediments that gather in the valleys below the Alpine glaciers, or like the great plains of water-washed matter that extend south from the terminal moraines of the continental glacier.

South of the South Paris and Norway villages the valley of the Little Androscoggin rapidly widens. By gradual transition the sedimentary plain becomes finer, being composed of a lower layer of silty clay overlain by sand and fine gravel. The upper sands have been extensively eroded, largely by boiling springs. At Oxford Village the plain is about 2 miles wide and the upper stratum consists of fine sand. The Little Androscoggin here turns east. All the way to Auburn its valley is covered by deep clays with some overlying sand. It is uncertain how far up the valley tide water extended above Auburn. It is certain that a broad stream or body of water at one time covered the valley all the way from Norway to Auburn, and the lower (eastern) portion was certainly salt water. Into this body of water poured, not only the local drainage, but also for a time the glacial waters from the upper Androscoggin Valley which then flowed south from Rumford past Bryants Pond. The large amount of water that must at one time have occupied this valley is well shown by the broad extent of sedimentary plains in Oxford. Two lines of clays, overlain by sand, pass out from the main valley and rejoin it again several miles to the south and east. The more eastern of these outlying plains follows the valley along which the Grand Trunk Railway is built. The other plain passes around the west side of a hill lying northwest of Oxford Village and comes to the shore of Thompsons Pond about 2 miles west of the village.

At the shore of the pond it forms a bluff rising 8 or 10 feet above the water. At the narrowest place this plain is about one-eighth of a mile wide, and a large amount of water was required in order to form it. If the ice in the basin of the pond was all melted at the time of the deposition of this plain, the whole pond must have stood at least 8 feet above its present level, and a delta ought to spread out in fan shape from the mouth of the inflowing stream. Now from this point to Oxford Village the pond is bordered by a clay plain, and a sedimentary plain nearly filled up the lake, which was flooded with water by the building of the dam at Oxford. But south of here no sand or clay borders the lake, except a little near the mouths of the streams—certainly no such sheet as could be expected if a large river flowed into the pond 2 miles from its outlet and at a time when it stood 8 feet or more above its present level. At this time most of the basin of Thompsons Pond must have been covered by ice. Thus the sedimentary plains of Oxford appear in part to have been deposited in broad channels bordered by ice, and give good ground for suspecting that these broad channels practically formed a series of glacial lakes in which a part of these fine sediments were deposited. Subsequently the ice melted, and a body of water, probably marine, filled the whole lower valley of the Little Androscoggin. How far this was fluviatile, estuarine, or marine is somewhat uncertain, and the hypothesis is suggested that these broad sheets were, in part at least, bordered by ice.

From Oxford Village a broad, low, plain-like valley (known as Rabbit Valley) extends southeastward to Poland Post-Office. About a mile from the Little Androscoggin a ridge bordered by ravines of erosion is found in the midst of the plain of sedimentary clay and sand which here covers the valley. Farther south what appears to be a continuation of this ridge rises higher than the plain of fine sediment, and soon crosses a pond, which nearly divides it into two separate lakes. Whatever be the character of the erosion ridge farther north, this ridge at the pond is distinctly an osar. Within 2 or 3 miles the ridge is lost in a rather level plain of sand, gravel, cobbles, and bowlderets, which for several miles is from one-fourth to one-half of a mile in breadth. The unmistakable glacial origin of this osar-plain makes it appear possible, perhaps probable, that the rather horizontally stratified plain of clay and sand which borders the ridge toward Oxford Village was laid down in a broad channel within

ice walls, so broad as to approach the character of a glacial lake. In the valley of Range Stream, not far north of Poland Post-Office, the osar-plain broadens somewhat, and becomes finer toward the north and east, passing from gravel into sand, and finally into a clay plain, which extends northeastward and at Mechanic Falls joins the broad plain of clay covering the Little Androscoggin Valley. Here, then, is a delta-plain where the glacial river at one time flowed into the broad body of water which occupied the valley of the Little Androscoggin after the ice had melted to this point but still remained at Oxford.

Approaching Poland Post-Office, the gravel becomes coarser for about 2 miles along the north side of the Lower Range Pond. Here are great numbers of very round cobbles, bowlderets, and some bowlders. Then the gravel becomes finer toward the southeast, and in the valley of the Worthley Brook consists of a rather thin plain of sand, which has been much eroded by the stream.

A series of hills borders on the south the valleys of the Androscoggin and Little Androscoggin from Brunswick to Oxford. Four low passes penetrate these hills. One leads from Durham south through Pownal, one past Danville Junction, a third lies south from Oxford along Thompson Pond, and the fourth is in the eastern part of Poland, leading along the eastern base of the high granitic hills on which the Poland Spring Hotel and the Shaker Village are situated. The osar-plain turns south along the valley of Worthley Brook and penetrates the last-named pass. It is here composed of rather fine drift, and is somewhat interrupted in the jaws of the pass. Soon after entering New Gloucester the system expands into plains from 1 to 3 miles wide, which extend southward nearly to Gray Village. The western portion of this large plain shows a rolling surface and much coarse matter (cobbles, bowlderets, and bowlders). Toward the east and south the surface is more level (except where there are sand dunes) and the material is finer, passing at last into fine sand. In the midst of the sedimentary plain are several hills covered with till.

It will be seen that the eastern portions of the great plain of New Gloucester and Gray present the characters of a delta. Their relations to the marine clays are significant. Two bays of the sea once united at these plains. A line of marine clays extends up the valley of the Presumpscot River to Windham, and thence northeastward up the broad valley of Pleasant

River past Gray Village to North Gray. At the same time a bay 10 to 20 miles wide covered the lower valley of Royal River and extended as far north as Danville Junction. It joined the first-named arm of the sea at North Gray. Thus a large part of Cumberland and Gray at that time formed an island, separated from the mainland by a sheet of water 1 to 5 miles wide in northern Gray and in New Gloucester. The southeastern portion of the great delta-plain of New Gloucester and Gray passes gradually into clay about 1½ miles north of North Gray. The western portion, which partly presents the external features of an osar-plain, partly those of reticulated kames, extends southward to within three-fourths of a mile of Gray Village. The southern portion is a plain of gravel, with cobbles and some bowlderets, from one-fourth to three-fourths of a mile wide. It ends in a steep bank and is covered at its base by the sedimentary clay. The coarseness of the matter composing this plain proves that it was not deposited in the open sea far beyond the ice front.

The late glacial history of this region must be about as follows: First, a broad plain of coarse gravel, etc., was deposited within an ice channel or series of channels along the western side of the great plains. Near Dry Mills, in the northern part of Gray, this plain of coarse matter does not extend back to the hills, but ends on the west in a rather steep bank. It also forms the barrier which has dammed back the waters of Dry Mills Pond.

Subsequently the ice melted, and the sea advanced so that the glacial river formed a marine delta east of the original osar-plain. This is the delta not far north of North Gray. Still later the sea advanced up the valley of the west branch of Royal River, and the glacial river flowed into the sea in this valley not far east of Sabbathday Pond in New Gloucester.

South of the great plains of New Gloucester and Gray there are two discontinuous series. They are provisionally classified as delta branches of one system, though it is difficult to determine whether they were contemporaneous.

The first of the western series is the level plain on which Gray Village is situated. It is separated from the more western plain above described by an interval of more than a mile of marine clay. On the north bowlderets and cobbles abound, but the material grows finer toward the south, and the sand plain ends in marine clay within about three-fourths of a mile.

The transition is quite abrupt, and while the plain is a delta, it is uncertain whether it was deposited in the sea or in a glacial lake. The sedimentary clay continues for about a mile south of Gray Village, and no gravel appears above the clay for about that distance. Then in a low north-and-south valley between high hills is found a somewhat discontinuous series of broad hummocks and low ridges, which expands in the western part of Cumberland and the northwestern part of Falmouth into a broad marine delta. A tongue of this plain one-fourth of a mile or somewhat less in breadth extends southward along the eastern base of Black Strap Mountain for nearly 3 miles in Falmouth. The transition between this plain and the marine clay is so abrupt at the sides that it must have been deposited between lateral walls of ice. There is a gradual transition to finer sediments toward the south, and this indicates a delta of some kind. The glacial stream either poured into a bay of the sea that extended back into the ice or into a glacial lake. In the case of this and many similar deposits it will require cross sections of the deltas and the marine clays to determine the stratigraphical relations of the coarser and finer sediments. Such sections are not easily made without excavations for that special purpose, since most of the excavations for road gravel, etc., are purposely made within the mass of eligible gravel and not at the place of transition from the sands to the clays.

Black Strap Mountain (Mount Independence of the Coast Survey) formed part of an island when the sea was expanded. Along the sides of the "mountain" are numbers of beaches, representing a considerable marine erosion of the till, and these gravels have to be distinguished from glacial gravel. The marine clays about its base are deep and sometimes hide masses of the glacial gravel. This makes the region a somewhat difficult one to explore. I have not been able with certainty to trace this series south of the long narrow plain above described.

There is a small delta at the West Cumberland Fair-ground. It is situated about a mile east of the delta just described, but does not appear to be connected with it. This delta-plain is of rounded fan shape, and on the margins toward the south, southeast, and southwest the transition from the sand to the marine clay is so gradual as to strongly indicate that it was deposited in the open sea by a small glacial stream that probably was not connected with any other stream.

We now go back to the great marine delta-plains of New Gloucester and Gray. North Gray is situated in the valley of a tributary of Royal River. To the south and west of this valley is a broad-topped hill, or gently rolling plateau, which rises about 75 feet above North Gray and extends for several miles southward. A gravel plain about 1 mile broad and 3 miles long is found on the top of this plateau. It comes to the eastern brow of the hill, where it ends in a rather steep slope, almost a bluff. Toward the north the plain consists of broad reticulated ridges, inclosing numerous kettleholes, one of them being a large basin 70 or 80 feet deep. Bowlderets and bowlders are here very abundant, and most of them are well rounded. Toward the south the plain becomes quite level on the top, and changes to fine gravel, and finally to sand. Beyond the sand is marine clay, but I am not certain whether the transition between the sand and the clay is such as to prove that this is a delta deposited in the sea or in a glacial lake. The external appearances favor the hypothesis that this is a marine delta-plain. On the slopes of the hill just north of this plain there are many moraine-shaped ridges running nearly north and south. It is uncertain whether they were piled in their present shapes by the glacier or are erosion ridges left after the glacial streams had washed away portions of the till, leaving these as uneroded ridges.

South of this broad delta in Gray is a level country for 3 or 4 miles, deeply covered by marine clay. Then the glacial gravel begins again as a round plain near one-half mile in diameter, situated at the north end of Walnut Hill, in North Yarmouth. From this point a low level plain one-eighth of a mile or somewhat more in breadth borders the eastern base of Walnut Hill, and continues with perhaps a few short gaps to Cumberland Center, where it ends abruptly. This plain nowhere rises more than 10 to 25 feet above the marine clay which overlies its flanks and which sometimes covers the gravel out of sight. A road is made on top of the gravel plain for several miles in the midst of a thickly settled country. Hence numerous wells have been dug in the gravel plain or near it. Often when the surface shows only the marine clay, wells penetrate the clay into the gravel and prove that the plain is nearly continuous from the north end of Walnut Hill to Cumberland Center. In a few cases (e. g., in the western part of Cumberland Center) wells have passed through the gravel into sedi-

mentary clay. The proper interpretation of this fact is uncertain. The sea waves may have washed away the top of the gravel ridge and strewn the gravel over marine clay previously deposited on the flanks of the ridge. On the other hand, the glacial rivers may have laid down both the clay and the overlying coarse sediments in their present positions, either in a broad kame channel approaching the character of a glacial lake or in a bay of the sea inclosed between lateral walls of ice. But in the last-named case the plain ought to show a transition into the marine clays at the south end of the plain. The abruptness of the transition favors the hypothesis that the plain was deposited in a glacial lake, and that some of the marginal clay is not marine but osar border clay. Yet for a mile north of Cumberland Center the ridge is so situated that it would be much exposed to the waves of the sea. Its surface is gently rounded in cross section, and the above-described phenomena may be due to wave action. It will require study of many sections in order to write out the full history of the plain near Cumberland Center.

Between Walnut Hill station on the Maine Central Railroad and Cumberland Junction there are two plains of glacial gravel lying one-fourth mile east of the main ridge or plain. A projecting spur of the main plain has been extensively excavated by the railroad company a short distance south of Walnut Hill station.

South of Cumberland Center lies a rather level region covered by marine clay, and no gravel appears on the surface for about a mile. About one-fourth of a mile west of Cumberland Junction, Maine Central Railroad, the gravel begins again as a broad ridge, with gently arched cross section, capping the top of a low north-and-south hill. This ridge extends southward to within one-fourth of a mile of West Falmouth station, it being narrower and somewhat discontinuous toward the south. At various places bars or tongues project obliquely down the eastern slope of the hill. South of West Falmouth lies the plain of marine clay that borders the Presumpscot River. No glacial gravel appears in this plain for more than a mile. A short distance south of the river a small gravel plain appears on the top of a low hill. Two other small plains, separated by intervals, bring us to a much larger gravel plain, known as Stevens Plain, situated at Mornills Corner in the town of Deering. This plain is somewhat oblong in shape. It is nearly a mile in length, and about half as broad. It is now very

level on the top, but it is in a thickly settled region and the surface may not be in its original condition. The margin shows on nearly all sides a steep slope outward, and the strata dip correspondingly at the exposures examined. The material of the plain is fine gravel and sand with some thin layers of silty clay. At some of the excavations examined the sedimentary matter rested directly on the solid rock, which has lost most of the glacial striæ and is sand carved and polished under the action of the glacial streams. A broad ridge of glacial gravel begins a short distance north of Stevens Plain and extends north to the Presumpscot River. Wells are said to have been dug 80 feet in this ridge without passing through the gravel. Between this ridge and the delta-plain in West Cumberland and Falmouth, before described as lying along the northwestern base of Black Strap Mountain, there is an interval of fully 4 miles. If the Gray-West Cumberland gravel series has any extension it must be this ridge extending north of Stevens Plain. The local deposits of subangular gravel on the south slopes of Black Strap Mountain are seabeaches so far as examined.

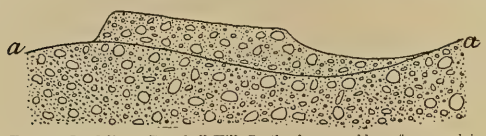


FIG. 23.—Landslip at Bramhall Hill, Portland. *a*, *a*, old surface, overlain with 6 feet of well-rounded gravel and cobbles, with some bowlderets.

Stevens Plain is probably a marine delta. The outward or anticlinal dip of the strata on all sides is probably due in part to the surf washing over the top of the plain. The gravel is slightly coarser on the west side of the plain.

The next deposit of the system is found as a ridge or terrace formed against the west end of Bramhall Hill in the western part of Portland. The osar matter is here rather coarse, containing a large proportion of cobbles, bowlderets, and some bowlders, and most of them are considerably rounded by water. Extensive landslides have taken place on this hillside. Near the Boston and Maine transfer station a section was exposed a few years ago that showed an old sod covered by several feet of well-rounded gravel and cobbles. The roots of grasses and other plants could still be distinguished. The same landslips have covered the fossiliferous marine clays with the glacial gravel. The hills of Portland would be exposed to a somewhat violent surf when the sea stood at their level. The waves have washed away much of the glacial gravel from the hills at each end of the

city, and spread it as beach gravels over the lower slopes of the hills, and often upon the fossiliferous marine clays. In consequence of the landslips and the overlap of the beach gravels, Portland is a difficult locality for investigating the relations of the glacial gravels to the fossiliferous marine clays.

South of Portland Harbor the connections of this system are somewhat obscure. In Cape Elizabeth, near the Boston and Maine Railroad, is a sand-and-gravel plain, not far southwest of Portland, and there is another pretty large plain near Oak Hill station, Scarboro. It is probable that these are the connections of this system rather than the more eastern line of gravels toward Two Lights. Whether any of the sand beaches toward Old Orchard are part of this system is uncertain.

The length of the system, from Lake Mooselookmeguntic to Scarboro, is 100 miles.

KENNEBAGO KAMES.

These are reported by Mr. Huntington, of the New Hampshire Geological Survey, as being found in the valley of the Kennebago Stream, about 10 miles north of Lake Mooselookmeguntic. I explored this river for 2 miles north of the lake, and found an alluvial plain, which possibly is a frontal plain. The kames referred to above are in the proper position to be a branch of the long Portland system, but more probably are a local system of late date, when the ice had retreated up the valley for several miles above the lake.

LOCKES MILLS BRANCH.

The broad alluvial intervale of Bethel extends nearly to South Bethel. At the eastern edge of the alluvial plain begins a series of reticulated ridges inclosing kettleholes, which extends eastward past Lockes Mills in Greenwood. Approaching the top of the divide between Androscoggin and Little Androscoggin waters, the gravel series becomes finer in composition and expands into a small sand plain at an elevation of about 75 feet above the Bethel intervale. From the top of the divide eastward to Bryants Pond there is but little alluvium. A glacial stream from this direction joined the main system at Bryants Pond and left a plain of gravel extending about one-fourth of a mile west from the main osar-plain. From that point to the top of the divide not far east of Lockes Mills I have not been

able to trace the gravels. This makes it probable that not much if any overflow took place from Lockes Mills eastward after the ice had become melted west and northwest of Bryants Pond.

A short line of glacial gravels comes from the north and joins the South Bethel series near Lockes Mills. There are some signs that this series extended northward across the middle intervale of the Androscoggin in Bethel as an osar-plain, and then up the valley of Bear River toward Umbagog Lake. I have not been able to find time for a careful exploration of the route, and provisionally mark this gravel series as extending only about a mile north from Lockes Mills.

It has already been noted that there may have been an overflow from the direction of Umbagog Lake to Andover, and that possibly a branch of the Portland system followed the valley of the west branch of the Ellis River.

GENERAL NOTE ON THE PORTLAND SYSTEM.

Three times this system of glacial gravels goes up a valley of natural drainage to its source and crosses hills into other valleys, but it does not cross hills higher than 150 feet. In order to penetrate the high hills by so low passes, it makes some remarkable deflections in its course. At Oxford there was in front of it a very low pass southward (along Thompson Pond), but it took a higher pass southeastward through Poland, following a course more nearly parallel to the glacial striæ than was the other. The system takes the form of an osar or osar-plain for most of the way north of the Gray-New Gloucester marine delta. South of that point it is constantly discontinuous, i. e., it consists of a series of plains or broad ridges separated by intervals from a half mile up to 3 or 4 miles. In this part of its course the gravels appear on the tops of low hills or along the eastern bases of such high hills as Walnut Hill and Black Strap Mountain. The plain at Oak Hill in Scarboro, Stevens Plain in Deering, the plain at West Cumberland Fair-ground, and the other plain west of it in Cumberland and Falmouth, also a large part of the Gray-New Gloucester plains, I consider as marine deltas. The last named are by far the largest of these, and are situated at an elevation of 200 to 230 feet. Several others of these plains are deltas of some kind, but I am not certain whether they were deposited in the sea or in glacial lakes. Several of these deposits show some but not all of the characters of deltas. Their material is so coarse,

even to the edge of the deposit, as to prove that they were formed between ice walls and not in the open sea. The student of the drift of Maine should certainly explore this system, though in many places it is quite inaccessible and considerable time is required to do it justice.

LOCAL ESKER IN WESTBROOK.

A short kame is situated on the north side of the Presumpscot River a short distance east of Cumberland Mills.

CASCO-WINDHAM SYSTEM.

Thompson Pond extends from Oxford south through Otisfield and Poland into Casco. It occupies a long north-and-south valley, which at the north is 2 or 3 miles wide, but becomes narrower in Casco, so that at the south end of the pond it is hardly one-eighth of a mile wide, while south of the pond lies an almost V-shaped valley, bordered by high granitic hills. At the foot of the pond the bases of the bordering hills are strewn with a number of hummocks of till, also some morainal ridges, which are somewhat transverse to the valley. They appear like moraines of a local glacier occupying the basin of the pond. This narrow valley terminating the much broader valley toward the north would be favorable for the formation of moraines during the final melting of the ice, on account of the great convergence of the movement into so narrow a pass. In the midst of the valley, at the south end of the pond, begins a series of low bars of glacial gravel. The stones have been but little changed from their till shapes, a fact which proves this to be near the north end of the system. Only a small brook flows northward into the lake, and there is no way of accounting for this gravel as fluviatile alluvium. Going south we find the gravel becoming rounder. A very low divide separates the waters of Thompson Pond, flowing north, from those flowing south. The glacial river flowed over this divide and thence in a nearly straight line to Rattlesnake Pond, Casco. Not far north of this pond it flowed over a vertical cliff of rock 20 feet high. The cliff faces south, and a subglacial river flowing in that direction would naturally have eroded the rock at the base of the cliff if it flowed over it so as to form a waterfall, but there is no pothole or visible channel of erosion in the solid rock. The course of the glacial river could easily be traced at this point by the piles of rounded

gravel, cobbles, and larger stones found at short intervals in a strip only about 100 feet wide. The rock, where unweathered, was very smooth, but whether this was due to water polish or to the attrition of the glacier was uncertain. There was little till along the line of the glacial stream. Here, then, was a rather small glacial stream that eroded the till and tumbled over a steep cliff, yet did not erode a traceable channel in the solid rock or form a pothole. The stones of the glacial gravel are all very much rounded here, and must have been subjected to a large amount of rolling. A plausible explanation of these facts lies in the hypothesis that the stream was for a time occupied in eroding the till, and that it ceased to flow soon after the rock had been laid bare. The gravels pass beneath the water at the north end of Rattlesnake Pond and soon reappear on the western shore. The glacial river followed this shore of the pond all the way to its south end. Between Rattlesnake and Panther ponds the glacial gravel takes the form of an osar-plain. The gravel reappears near the south end of Panther Pond, and continues as an osar-plain to Raymond Village. Here, near where the system crosses the outlet of Panther Pond, there is apparently a short gap in the gravel plain. The plain soon begins again, and continues its southwest course till it reaches the shore of Sebago Lake, when it turns south and follows the east shore of the lake for a half mile or more. It rises 6 to 12 feet above the lake, and often ends at the lake in a cliff of beach erosion. In all this part of its course the osar-plain continues an eighth of a mile in breadth, or in places a little broader. There was nothing to hinder an ordinary stream having a southwest course from sweeping its sediments out into the lake. The fact that there is no fan-shaped delta at this point, though the stream that deposited the osar-plain flowed at an elevation of several feet above the lake and was rapid enough to transport cobbles and bowlderets, is conclusive proof that at the time the plain was being deposited the basin of Sebago Lake was covered by ice at this point.

The gravel plain soon leaves the shore of the lake and continues southward over a pass 50 to 70 feet high to North Windham. In this part of its course the system takes the form of a plexus of broad reticulated ridges and hillocks, and it contains many kettleholes and hollows of all sizes up to lake basins. Toward the south the plains spread out in fan shape and the ridges become lower and gradually coalesce into a rather

level plain composed largely of sand and fine gravel, which near North Windham is not far from 2 miles broad. South of this point the gravel narrows so as to form a rather level plain about one-fourth of a mile wide, which continues southward past Windham Hill to a point about one-half mile south of Windham Center. Near the south end of this plain the material is very coarse, consisting chiefly of cobbles with bowlderets and bowlders.

In many places in this system there are great numbers of rounded bowlders 2 to 4 feet in diameter, a fact which favors the hypothesis that it was deposited by subglacial streams.

South of Windham there are several plain-like deposits of glacial gravel in Gorham and Scarboro which are probably marine deltas. The largest of these plains is at Gorham Village. They are in the proper positions to have been formed by the same glacial river that brought down the gravels of the Casco-Windham system. But the country is so level that we have no hills to act as barriers to confine the glacial rivers, and the intervals between the plains are so long that provisionally I mark the system as ending in Windham.

The gravels of this system form, wholly or in part, the dam which caused the formation of Little Sebago Lake, in Windham and Gray. The original outlet of this lake flowed west into the Presumpscot River, and its bed shows only glacial gravel for some distance from Little Sebago Lake. An artificial channel has been dug for the purpose of taking the water of the lake south into the Pleasant River, the small stream flowing from Gray southwestward into the Presumpscot in Windham. This channel is dug wholly in the glacial gravel.

The North Windham Plains pass by degrees into sand, and finally into marine clay toward the south and east. They are marine delta-plains in part, found in the arm of the sea which extended from Windham northward past Gray and joined the bay that then covered the valley of Royal River. But perhaps there is a continuous plain of purely glacial gravel near the axis of the area which is continuous with the Windham Center Plain.

At Raymond Village the osar-plain is bordered and partly covered by sedimentary clay. This is at an elevation of about 20 feet above Sebago Lake. There is no continuous sheet of clays at this elevation around the

lake, and this disproves the theory that the lake or the sea stood at this elevation. This clay is probably osar border clay deposited in a very broad channel within the ice at a very late period of the Ice age.

This system lies in a region where the rocks are chiefly granitic and the till is very abundant. Although not long, it contains a very large amount of gravel.

GRAY–NORTH WINDHAM SERIES.

On the eastern side of Little Sebago Lake is a high range of hills which extends continuously northward to Poland. At a point about west of Gray Village a discontinuous series of short ridges of glacial gravel begins near the eastern base of this high range. At the north end the gravel is but little waterworn, and it is separated from the Gray-New Gloucester plains by a hill more than 100 feet high. For these reasons I regard this series as distinct from the Portland system, although the two series are only 2 or 3 miles apart in Gray. This series extends southwestward, passing about one-fourth of a mile west of West Gray. It soon becomes a continuous osar-plain, and when approaching North Windham rapidly broadens into a delta-plain. Near North Windham it is difficult to distinguish the gravels of this series from those brought down by the large glacial river from Casco and Raymond. Whether this series should be considered a branch of the Casco system is uncertain. If the stream which deposited it began to flow in early glacial time, it would naturally flow into the larger glacial river, but if, as is more probable, it dates from the very last part of the Ice age, then it may have flowed into the sea at North Windham near where the other glacial river also poured into the sea, yet have been distinct from it.

GENERAL NOTE ON THE GLACIAL GRAVELS OF SOUTHWESTERN MAINE.

The systems of glacial gravels thus far described are not so closely connected with one another in any part of their courses but that it is relatively easy to distinguish them. Most of the gravels remaining to be described are connected with one another not only at the great marine delta-plains which were deposited at elevations from 175 to 230 feet above the sea, but also by transverse branches connecting the broad plains of reticulated ridges found above 230 feet. Some of them are also connected by lateral branches at points north of the plains of reticulated kames in

the region of the osar-plains. As employed in this report, the word "system" denotes the gravels deposited by a single glacial river with its branches, both delta and tributary. According to this nomenclature, almost all of the vast gravel deposits of southwestern Maine are connected as a single system. The word "series" will therefore be used to designate a single line or branch of this wonderfully complex network. An inspection of the map will give a far better idea of these reticulations than a verbal description could give. In some cases it is easy to determine which way the water flowed that formed the transverse lines of gravel connecting the north-and-south series, but often this is difficult or impossible. Sometimes the flow has probably been alternately in opposite directions.

NOTE ON THE BASIN OF SEBAGO LAKE.

Sebago Lake is said to have a larger water surface than any other of the Maine lakes. It is interesting in many ways. It occupies a broad north-and-south valley, which is a rock basin if the depth of the lake is correctly reported at 400 feet, or even if it has half that depth. One who stands on the high hills of Waterford and looks south along the deep, almost V-shaped valley which reaches southward through Harrison and then broadens into the beautiful valleys containing Long Pond and Sebago Lake, will see that here are some interesting questions in structural geology. From the standpoint of the glacialist the region is no less interesting. Several valleys converge toward the basin of Sebago Lake, down which the ice could continue to flow long after the general movement across and over the higher hills had ceased. From the north the ice could easily flow down the valley of Long Pond, also down that of the Crooked River. From the northeast the ice could easily flow from Raymond, Casco, and Thompson Pond along the valleys where lies the Casco-Windham system of glacial gravels, while a broad valley from near South Bridgton would allow a flow from the northwest. The valleys would in fact contain their local glaciers, and these would coalesce in the basin of the lake to form a single mer de glace, which, during the final melting, would retreat less rapidly than the ice in adjoining regions so situated that the flow of the ice from the north was more thoroughly cut off by high transverse hills. There are in Maine several places where the ice probably met the sea, and terminal moraines were formed at the ice front. These are: (1) At Readfield Village; (2) on

the southeast shore of Swan Island, in the Kennebec River; (3) in the village of Sabatisville; (4) near the head of Little Kennebec Bay, a few miles south of Machias Village; (5) at Winslows Mills, in Waldoboro. It might be expected that the tongue of ice that filled the basin of Sebago Lake would in like manner confront the sea, and, in consequence of the abundant flow of ice from the north, would retreat with relative slowness, a condition favorable to the formation of a terminal moraine.

NAPLES-STANDISH SERIES.

A terrace-like ridge or level plain of sand skirts the western shore of Long Pond for three-fourths of a mile north of Naples Village. At this point it rises somewhat more than 20 feet above the pond, and there is no similar deposit on the east side of the pond, nor around the pond. The terrace at Naples Village is at least 10 feet deep. Is it an old beach, formed at a time when the pond stood 20 or more feet above its present level?

1. If a terrace 10 feet deep could form as a beach on the west side of the pond and in a sheltered situation, then similar beaches ought to be found in all the sheltered bays of the lake, especially on the east side. There are no such beaches deep enough to be traceable.

2. The erosion cliffs along the shores of the pond at its present level are too small to account for a terrace of sand near one-eighth of a mile wide and 10 feet deep. If the Naples terrace is a beach, then a corresponding erosion cliff or other sign of the erosion ought to be found around the lake. There is proof that the lake must have formerly stood at a higher level than at present, but it has left no cliffs, nor any places denuded of till, nor any recognizable beaches.

3. No stream, except mere brooks about a mile long can ever have flowed into Long Pond at Naples Village. The sand terrace can not, therefore, be a delta brought by streams into the lake at a time when it stood at a higher level than at present.

It thus appears that the sand terrace at Naples is neither a beach nor a lake delta, and the only way to account for it is to assume that it is an osar-plain. The plain continues southward along the west shore of Brandy Pond (Bay of Naples), becoming coarser toward the south; and at the outlet of this pond it has become a two-sided ridge with arched stratification. At this point there are several outlying ridges, somewhat reticulated, one

of which once formed a dam across the Long Pond (here very narrow) and raised it probably 20 or more feet above its present level. The outlet of the pond has in process of time eroded the obstructing ridge and lowered the level of Long and Brandy ponds. All of these ridges at the outlet of Brandy Pond (Songo Lock) are composed of coarse gravel with cobbles and bowlderets. The distinctively glacial origin of these coarse sediments is an additional proof of the glacial origin of the sand terrace at Naples Village, which is connected by a continuous deposit of sand and gravel with these osars. The osar-plain at Naples is remarkable from the fact that it is composed of such fine material at its north end. Whether the system extends northward under Long Pond is uncertain. There are small deposits of sand and rolled gravel reported on the shore of the pond and on islands in that direction, but I now regard them as probably being beach gravels of the lake.

At Songo Lock, at the south end of Brandy Pond, there are a few ridges that have a northeast-and-southwest direction. They are arranged transversely across the valley, as the moraines of a local glacier would be, but on the surface they are composed of rounded gravel, and I consider them probably kames, perhaps deposited by a short tributary.

South of Songo Lock an osar extends nearly continuously to the northern shore of Sebago Lake at a point a short distance west of the mouth of Songo River, which forms the mouth of Crooked River. The ridge ends in a cliff of beach erosion about 35 feet high. Part of the way south of Songo Lock the ridge is flanked by outlying hummocks and by a rather level plain resembling an osar-plain in external form.

The evidence is thus conclusive that a large glacial river flowed south into the basin of Sebago Lake. Numerous credible witnesses report the northwest bay of the lake as being from 250 to 400 feet deep. Glacial gravel reappears at Sandy Beach, on the western shore of the lake, about 3 miles from where it disappears at the north end of the lake. A narrow plain of glacial gravel extends southward for several miles along the western shore of the lake, soon expanding into extensive plains in Standish. These plains are rather level, yet show some basins and reticulations. The glacial river must have flowed across the deep basin of the northwestern angle of the lake. A tongue of these plains extends southeastward to the south end of the lake, where it expands into a rounded plain more than a mile in diameter. Next

to the lake the material of this plain is very coarse, containing great numbers of cobbles, with bowlderets and some bowlders. The surface is here very irregular, and the gravel consists of a series of reticulated ridges inclosing kettleholes and basins of various sizes, some of them occupied by lakelets and peat swamps. The Maine Central Railroad was originally constructed across one of the peat swamps. The peat soon sank under the weight of the roadbed, showing that the peat overlay a lakelet. The chasm was then filled up by an embankment of gravel, 85 feet above the top of the water, which stood at the same level as the lake. A depression 95 feet deep is found on the bottom of the lake a few rods north of the shore at the south end of the lake. It is surrounded on all sides by much shallower water, and is probably a kettlehole. The water at the south end of the lake is from 20 to 40 feet deep except at this depression. No rock in place appears anywhere near the south end of the lake nor along a line extending southeast from this point.

The most probable interpretation of these facts is this: In preglacial time the region where Sebago Lake now is was drained by a valley which extended from the foot of the lake southeastward to the Presumpscot Valley near Saccarappa. In late glacial and early postglacial time this valley was filled by till, glacial gravel, and sedimentary clay to a depth of 100 feet or more. After the final melting of the ice the water found the old drainage valley effectually dammed, and it filled up the basin till it began to overflow 7 miles northeast of the old channel The Presumpscot River (the outlet of Sebago Lake) flows over a rock bed, showing a constant succession of rapids and waterfalls all the way from Sebago Lake to near Saccarappa. This indicates that it is a recent channel for the main stream, though in preglacial time this valley was occupied by a branch of the main stream. Sebago Lake would be about 100 feet lower than it is but for the plain of glacial gravel at its south end, and would be greatly reduced in size. Portland owes the convenience of its water supply to this same dam of glacial gravel.[1]

The plains of glacial gravel that border the lake vary from 10 to 40 feet in depth, except at the south end, where they exceed 130 feet. The

[1]Since the above was written I have discovered that the gravelly nature of the southern boundary of Sebago Lake attracted the attention of Prof. C. H. Hitchcock; see Preliminary Report upon the Natural History and Geology of the State of Maine, p. 288, 1861.

OSAR ERODED BY SEBAGO LAKE, ABOUT ONE-HALF MILE WEST OF THE MOUTH OF CROOKED RIVER.

Locally known as the "Sand Hill." Arched form of cross section is shown, but stratification is obscured by surface sliding. Part of the bowlders on the beach are till bowlders transported from a distance by floes of lake ice.

basin of the lake is somewhat triangular, and the ice would naturally converge toward the narrow end at the south. The unusually deep mass of glacial gravel south of the lake is probably in part a sort of terminal moraine formed at the end of the tongue of ice which occupied the basin of the lake. A small movement over the broad part of the basin and its tributary valleys would cause a much larger flow at the extremity, where it was only a mile wide. This would naturally cause a convergence of the flow of the ice, and also of the glacial rivers to this place, and during the retreat of the ice the deposition of a deep sheet of morainal matter. But there is no unmodified till in sight near the south end of the lake, and apparently the till last deposited has been entirely acted on by the glacial waters so as now to be a part of the plexus of reticulated ridges of coarse gravel, bowlderets, and bowlders that fill the valley. This makes the deposit approach in character the overwash or frontal plains of gravel which extend southward from the terminal moraines of the continental glacier. Ice movements probably converged more than the average depth of morainal matter here, where it was acted on by the subglacial rivers.

Within a half mile from the south end of the lake the gravel of the plains just described becomes finer, and within 2 miles it gradually passes into sand, and finally into clay not far from the contour of 230 feet. A line of sedimentary clays extends from the sea nearly to the lake, and 30 or more feet above the contour of 230 feet. At the north it borders the southern part of the gravel and sand plain, both terminally and laterally. The conditions of its deposition are uncertain. The gravel plain appears to be a marine delta at its southern extremity.

From the foot of Sebago Lake a discontinuous series of broad, table-like ridges extends southward through the western part of Gorham, and thence by a rather meandering course to near Buxton Post-Office, where it seems to end in a delta (probably marine), a mile or more in length. The intervals between the successive deposits are usually less than one-fourth of a mile, but toward the north they are somewhat larger. The gravel plains are from an eighth to a half mile in diameter, and often form somewhat rounded caps on the tops of hills, especially those not far south of Sebago Lake. This series lies in a region wholly covered by the marine clay, unless the clay near Sebago Lake be an exception. Perhaps the whole series ought to be named the Naples-Buxton series. The gravels in

the eastern part of Gorham and in Scarboro may have been deposited by the glacial streams that formed the plain at the foot of Sebago Lake, but more probably, if those gravels have any connections, they will be found in the direction of Windham.

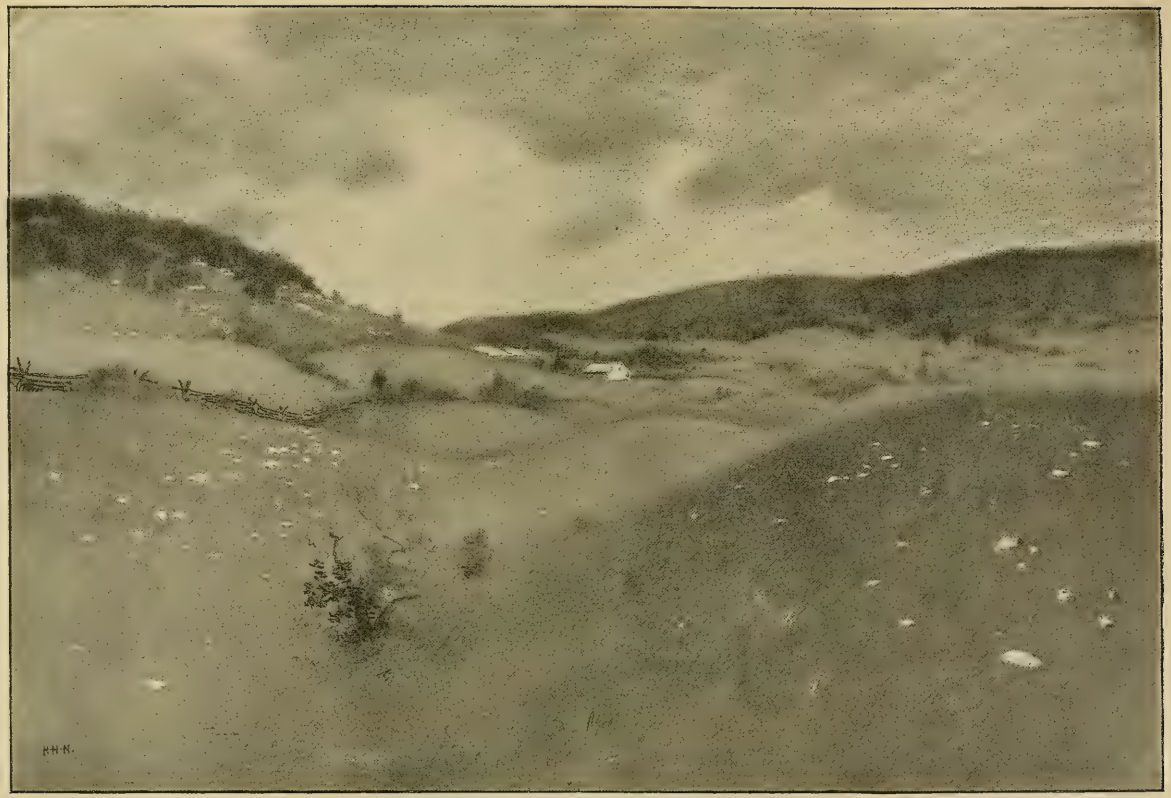
SEBAGO SERIES.

A well-defined but somewhat discontinuous series of glacial gravels extends for several miles along the valley of Northwest River in Sebago, and joins the Naples-Standish series at East Sebago. In the northwestern part of their course these gravels take the form of short ridges, but for several miles above East Sebago they take the form of a broad osar of fine gravel and sand, now much eroded. This series is probably due to an overflow from the direction of Great Hancock Pond, as will be described in connection with the following series. Further description of the plains extending from East Sebago into Standish and Baldwin will also be given later.

BRIDGTON-BALDWIN SERIES.

This important series appears to begin in Sweden as a small ridge of subangular gravel and cobbles situated in the valley of a small stream which flows southward into Highland Lake. The ridge is on the side of a steep hill 20 or more feet above the stream, and there is no corresponding ridge or terrace on the opposite side of the valley. It must therefore be glacial gravel. Several Islands in Highland Lake (Crotched Pond) show water-washed gravel, probably glacial. A short distance from the south end of the lake one of these islands is covered with gravel which is quite certainly glacial, while a large and broad osar ridge comes out of the water at the south end of the lake, forming in part the barrier which dammed back the waters of the lake. It thus appears probable that a single glacial river flowed from Sweden southward across the basin of this lake.

A series of low ridges and hummocks extends from the lake southward through Bridgton Village, and then for about 10 miles the series follows the very low valley along which is constructed the Bridgton and Saco River Railroad. Excavations in Bridgton Village show pretty well-rounded, glacial gravel overlying till, and a gradual transition between them. In several places this series takes the form of an osar-ridge of coarse



BROAD OSAR PASSING OVER HILL 210 FEET HIGH; BALDWIN.

Osar plain or terrace eroded into rolling hummocks in foreground. Glacial river flowed past the house, then turned to the left and flowed over hill beyond, a little to left of house. Osar gravel is here about one-eighth mile wide. The view is characteristic of the hill country of western Maine.

matter, bordered on each side by a level plain of sand up to about one-fourth mile in breadth. It is an instructive instance of the broad osar. At Sandy Creek Village even the central parts of the plain are sandy. The valley followed by the railroad is a remarkably level pass through the high hills of southern Bridgton and the eastern part of Denmark. Near the east line of Hiram and at the north end of Barker Pond the gravels turn abruptly south, while the railroad continues its southwest course to Hiram station. The glacial river here took its course southward along the sides of Barker and Southeast ponds, and then it flowed up and over a hill 100 or more feet high. On the north slope of this hill are several horizontal terraces of sand at various heights above Southeast Pond. I found no recently blown sand in the region, and these terraces have the shapes of beaches rather than the rounded outlines of sand dunes. A considerable erosion has been effected by small brooks which here and there have cut through the terraces at right angles. I do not see how the terraces can be due to unequal erosion by streams of a once continuous plain of sand. The place deserves careful study. The brief examination I was able to give it suggested that the terraces were beaches formed at the edge of a body of water the surface of which was gradually falling. I saw no sign of an erosion of the till. More probably a broad, continuous osar-plain of sand was deposited on the hillside, and this could easily be eroded by even small waves, so as to form cliffs of erosion and corresponding beach terraces transverse to the slope of the osar-plain. At several excavations in the terraces bowlders from 2 to 6 feet in diameter were seen in the midst of the sand. They were till bowlders, not the rounded ones of the glacial gravels. Wind might have covered the bowlders with sand, but can not account for their having been dropped upon previously deposited sand. At the exposures examined the bowlders were surrounded on all sides by well-assorted sand, and there was nothing resembling till upon or within the sand—only a few isolated bowlders, whereas the till contains more small stones than large. If they were dropped from the roof of a subglacial tunnel, the tunnel must have been fully one-fourth of a mile wide, and we must account for the presence of only a few bowlders instead of a sheet of till. The theoretical questions arising in connection with this locality will be discussed more fully later.

Having crossed the hill south of Southeast Pond, the glacial river next

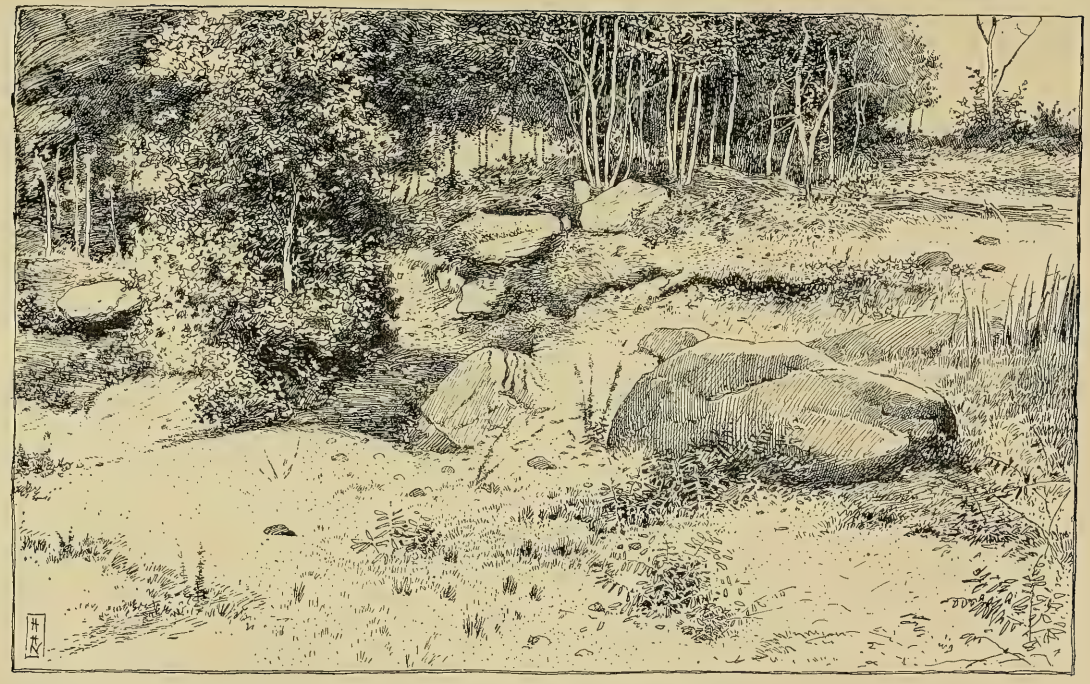
crossed the valley of Breakneck Brook, a small stream which flows southwest to West Baldwin. It occupies a valley bordered by high hills through which there is but one pass southward. The glacial river flowed through this pass to East Baldwin over a hill 210 feet by aneroid above the point where it crossed Breakneck Brook, and probably from 250 to 300 feet above Southeast Pond. Up and over such high hills this large glacial river flowed, and it has left us some interesting questions to solve. The glacial sediments form a broad osar one-fourth of a mile wide, though somewhat narrower in the pass toward East Baldwin. Near the tops of the hills the sediment is scanty. In the valley of Breakneck Brook and toward the base of the south slopes the material is very coarse, while on the north slopes it is sand or fine gravel. The sheet of sand and fine gravel on the north slope of the hill crossed by the system just south of Breakneck Brook has been much eroded by rains, springs, and a small brook, but no forms at all like the horizontal terraces that overlook Southeast Pond have been produced. On this slope there are numerous till-shaped bowlders 2 to 6 feet in diameter lying upon and within the sand and fine gravel. One excavation at the roadside shows several unpolished bowlders lying upon 8 feet of sand and fine gravel, and the excavation does not reach the bottom of the sand. Evidently we have here substantially the same problem as that concerning the bowlders 2 or 3 miles north, in the sand terraces on the hill south of Southeast Pond, except that the sediment is here somewhat coarser. Approaching East Baldwin this series expands into plains of sand, gravel, and cobbles which are confluent with the other great plains of Baldwin, Standish, Limington, and Hollis.

TRIBUTARY BRANCHES.

Three short series of ridges join the main series in the eastern part of Denmark. They were deposited by small streams that carried off the glacial waters of the broad basin in Denmark and Sweden in which Moose Pond is situated.

DELTA BRANCHES.

A delta branch probably left this series near the south end of Great Hancock Pond. At this point a broad deposit of sand and gravel diverged from the main osar-plain and extends for about one-fourth of a mile up a hill toward the south and east. Directly in front is a low pass lying east



TILL BOWLDERS IN OSAR; BALDWIN.

On north slope of hill over which osar passes from Breakneck Brook toward East Baldwin.

of Beech Hill, Sebago. The gravel soon becomes discontinuous, and at the top of the col I could not discover any gravel. The gravels before described as the Sebago series begin a short distance south of this point. These facts make it probable that a glacial stream overflowed from Great Hancock Pond over the divide and down the valley of Northwest River to East Sebago.

Another delta branch diverged from the main series at the point where it crosses Breakneck Brook and followed the valley of that stream southwestward. Originally a plain of coarse gravel, cobbles, and bowlderets extended across the narrow valley to a height of 20 to 40 feet above the present level of the brook. This plain has been much eroded along the central part of the valley, so that now small lateral terraces along the sides of the valley are all that remain of the original plain. By aneroid this brook falls 200 feet in flowing from where it leaves the main osar-plain to West Baldwin, a distance of about 3 miles. With such a rapid fall it is not surprising that only coarse sediment was dropped in the valley. At West Baldwin this series becomes confluent with the great plains of the Saco Valley.

The history of the osar-plain in Breakneck Valley appears to be about as follows: At first the Bridgton glacial river flowed across the valley, then up and over the hill 210 feet high to East Baldwin. This becomes evident when we consider that if the channel had first been opened southwest on a down slope of 60 feet per mile it is extremely improbable that the water could subsequently have been diverted over a hill 210 feet high. The stream to East Baldwin has deposited much more sediment at its terminal plains than the other stream to West Baldwin, and if the former stream was not the earlier, no reason can be assigned why the larger flow should take place along its course. After the channel was opened southwest down the Breakneck Valley the water would all flow that way, unless in time of extraordinary flood.

Few if any students of the drift can see the great contrast in composition between the broad osar of the Bridgton-Baldwin series and the adjacent till, or see it rejecting valleys of natural drainage in order to go up and over hills more than 200 feet higher than the ground to the north, without admitting the utter impossibility of accounting for such plains of sand and gravel in such situations by any freak of eolian, fluviatile,

lacustrine, or marine action. No way remains for accounting for these plains except dy the action of glacial streams confined between ice walls.

ALBANY-SACO RIVER SERIES.

Measured by the amount of assorted matter which it contains, this is one of the greatest gravel series or systems in the State.

The northern connections are obscure, and involve one of the most difficult questions relating to the drift of Maine, i. e., the determination of the true history of the sedimentary drift of the Androscoggin Valley from Bethel westward to the White Mountains. The pebbles, cobbles, and bowlderets of the central parts of this sedimentary drift of the Androscoggin are as well rounded as those in the kame plains, and usually more so than those in the beds of the White Mountain streams having a fall of 100 feet or more per mile. In places the alluvium of the main valley rises considerably above that of the lateral valleys. In a word, most of this drift presents all the external characters of the broad osar or plain. Also in some places reticulated ridges are common, and there are many kettleholes and some lakelets in the plain, thereby presenting the features of the plains of reticulated kames. At Bethel the character of the alluvium of the valley rapidly changes. Instead of the terraced plains of coarse matter, which are found from Gorham, New Hampshire, to Bethel, the drift of the valley from the last-named place eastward becomes finer, and consists almost wholly of clay and sand, except where the osar-plains crossed the valley, as at Rumford Point and in part of the valley from the Swift River to Canton. My explorations of this portion of the Androscoggin Valley were made before I had fully distinguished the osar-plain, and I was then chiefly occupied in studying the work done by the local glacier which, for a time after the general ice movement ceased, filled the valley as far east as West Bethel. I do not therefore assert positively that the plain of coarse alluvium that extends from the White Mountains east to a point about a half mile west of Bethel Village is chiefly glacial gravel, but all my later studies point to that conclusion. The relation of the earlier osar or osar-plain, if it existed, to the local glacier, will form an interesting subject for study, as will also the distinguishing of an osar-plain proper from frontal gravels deposited while the ice was retreating up the valley. The probable course of this glacial stream was down the

valley of the Androscoggin to near Bethel Village, where it turned south along the low valley in which was once surveyed a route for a canal from Bethel down the valley of Crooked River to Sebago Lake and thence to Portland. This valley lies a short distance west of Bethel Village, on the west side of the hill lying south of Bethel called Paradise Hill. There is considerable reason to suspect that there is an osar-plain of fine matter in the bottom of this valley, disguised by some valley drift. At one time there was an overflow of the Androscoggin south through this low pass, also down another valley which leads south from the broad Bethel intervale past the east base of Paradise Hill and joins the other valley just south of this hill. The intervale was then a lake 3 or more miles wide. The alluvial plains that fill these two valleys which lead south from near Bethel may possibly be wholly fluviatile drift, formed during this overflow of the Androscoggin southward, yet I provisionally mark a glacial stream as flowing down the Androscoggin to Bethel and thence southward. There may have been glacial overflows from the Sunday River and Bear River valleys. In Albany, near the top of the low pass that leads south from Bethel, gravel unmistakably glacial is found, and continues in the form of bars, ridges, and terraces down the valley of Crooked River to North Waterford. The gravels have been considerably eroded by the stream, and it is uncertain whether the original form of these deposits in northern Albany was that of a broad osar-plain extending across the valley or whether there were two or more distinct ridges. In the southern part of Albany and the northern part of Waterford there is a well-defined two-sided ridge of gravel and cobbles in the midst of the valley, and in a few places there are two such ridges, bordered by plains or terraces of rather fine sand and gravel having nearly horizontal stratification. These extend across the valley, which is near a half mile in width, at two places, but in most of its course is but little more than half that breadth.

The alluvial drift of the Crooked River Valley is of composite origin.

1. We have a broad deposit of glacial gravel taking the form of a broad osar, with some distant osar ridges in the midst of it.

2. There must have been considerable stream wash from the rather steep hills which border the valley, especially as there are few lakes and ponds in the region and the floods are rather violent. The drainage basin is rather small, however.

3. There were two overflows, each more than one-eighth of a mile wide, from the Androscoggin Valley in Bethel southward through Albany and down the Crooked River Valley. These took place after the ice had melted over the broad Bethel intervale, and apparently over the Crooked River Valley also. Their waters probably deposited most of their sediments before flowing over the col in Albany. As these Androscoggin waters rushed down the valley they would more or less wash away and reclassify the glacial gravel previously deposited.

It thus becomes specially difficult to determine whether the plain of finer sediments that borders the ridges which rise a few feet above the rest of the plain is osar-plain or valley drift or both. The ridges were without doubt deposited in narrow channels within ice walls. From general analogy it is probable that the original channel broadened and that an osar-plain was laid down in the broad channel, and that this was subsequently acted upon by river floods and covered by some valley drift.

At North Waterford the Crooked River turns abruptly eastward, and for several miles it is bordered by erosion terraces of gravel and well-rounded cobbles. Apparently a continuous plain one-eighth to more than one-fourth mile wide once extended across the whole valley. In the eastern part of Waterford the river again turns a right angle and flows southward. The valley here widens for 2 or 3 miles, but the gravel plain does not broaden correspondingly. It takes the form of a plain three-fourths of a mile wide and about twice as long, situated on the west side of the river. At the north it consists chiefly of coarse gravel, cobbles, and bowlderets, all very much rounded. Although rather level on the top, the plain incloses Papoose Pond and several kettleholes. Toward the south it becomes somewhat finer in composition, yet it ends in gravel which contains some cobbles and large pebbles. It can not, therefore, be a delta deposited in a large body of still water. Along the eastern side of this gravel plain and for several miles below this point the valley of Crooked River is covered by a plain of sand one-eighth to one-third of a mile wide. This is often very fine and silty, and sometimes contains a little angular gravel near the stream, the result of the erosion of the till. The contrast in shape between this gravel and that contained in the present bed of the stream as compared with the very round stones of the gravel plain that extends from North

Waterford to Papoose Pond is very great, and shows that the gravels of the osar-plain have been subjected to much more attrition. Going southward in the valley, the lower layer of the valley drift becomes clayey. It is overlain by sand containing some angular gravel—mere tillstones which are scarcely polished. The plain of valley drift rises 20 to 30 feet above the present bed of the river, which is bordered by two and sometimes three terraces of erosion. At Edes Falls, in Otisfield, the underclay is overlain by several feet of subangular gravel, sufficiently worn to suggest glacial origin. Perhaps there are local kames somewhere in the midst of the valley and part of the gravel was washed away by river floods and spread over the previously deposited underclay. No kames appeared near this place in the banks of the river, but they may be situated near by and are now hid by the valley drift. South of Edes Falls the plain of valley drift is in general from a half mile to more than a mile in breadth. The lower stratum is clay, while the upper is a thick layer of sand, which in many places has blown into low dunes. For several miles north of Sebago Lake the upper and lower layers of the valley alluvium have about the same composition, and both are a fine silty sand. As stated elsewhere, the river here has eroded a channel bordered by steep cliffs of silt, and there are no higher erosion terraces, i. e., the rates of erosion and deposition are here substantially equal. The upper end of the original basin of Sebago Lake has been silted up for 2 or 3 miles, and perhaps farther. The Crooked River unites with the outlet of Long Pond to form the Songo, which meanders back and forth in a remarkable manner. This stream has been celebrated by Longfellow in his song of "The Songo River."

We thus see that true osar-ridges extend from Albany down the Crooked River Valley to North Waterford. Then for several miles the valley contains a plain of gravel, with cobbles and bowlderets too large and too round to be a part of the valley drift, and ending in a broader plain showing some of the characteristics of a delta, but not such a delta as should form at the end of such a large glacial river as flowed through Albany to North Waterford. Then for many miles, to Sebago Lake, there is nothing in the valley that resembles the drift of the upper valley or that can be considered as glacial gravel proper, unless it be a short deposit near Edes Falls. That a large glacial river should end in that small plain at

Papoose Pond near East Waterford seemed so unusual that it demanded further investigation, although as yet I did not have even a hint of the true condition of things at North Waterford.

As stated already, the Crooked River turns abruptly east at North Waterford. From where the river turns east another valley leads southwest, so low that a dam of 50 or 75 feet would probably turn the Crooked River southwest into the Saco River. Kezar Brook originates in the Five Kezar Ponds, only about 2 miles from North Waterford, and flows southwestward in this valley.

DELTA BRANCH AT NORTH WATERFORD.

I have long since learned that glacial rivers bear careful watching. Their deceitfulness is well exhibited at North Waterford. At the time of my first visit to this region, in 1878, diverging or delta branchings of osar systems were unknown to me. I then went for about a mile down the river below North Waterford and found the gravel extending down the river. I inferred there was a Crooked River series, of which the gravel at Ede's Falls, which had been described to me, was a part. Several years later I explored the whole valley and discovered that the glacial gravel ends near East Waterford in the plain at Papoose Pond. A full investigation then followed. Two branches of the glacial river that came down from Albany diverged at North Waterford. The smaller one followed the Crooked River Valley a few miles to Papoose Pond. The larger one crossed a low col and followed the valley of Kezar Brook southwestward. For several miles gravel takes the form of a series of ridges and terraces of coarse osar material. Some of these ridges are more than 50 feet high and are very broad and massive. Approaching Lovell Village, the series takes the form of sand plains, having a gently rolling surface, as if the sand had been deposited in a broad channel upon gravel ridges which had previously been formed in narrower channels. The sand plain is here near a mile wide. The series here leaves the valley of Kezar Brook and turns abruptly southward over a rolling plain. It passes through Sweden, Fryeburg, and Denmark, and enters the Saco Valley about 2 miles east of East Brownfield. In all this part of its course it is a kind of osar-plain, not so level on the top as most osar-plains, and containing, at least on the top, much sand or

very fine gravel. It skirts the western base of Pleasant Mountain and the eastern side of Kezar Pond and two other small ponds in Fryeburg. The origin of these ponds is discussed elsewhere.

For 25 miles this great series is seldom less than one-fourth of a mile wide, and it often has three or four times that breadth. No central dominant ridge could be distinguished at the places examined. If such there was, it has been covered by the sediments which were brought down by the rush of the vast river which in later times swept down this broad thoroughfare of waters. The great volume of the sediments is strongly in favor of the hypothesis that there was an overflow from the Androscoggin Valley southward through Bethel and Albany before the melting of the ice.

It thus appears that at North Waterford there were two valleys widely diverging and that glacial gravels were deposited in each valley. The valley of Crooked River is not only a slope of natural drainage, but it is also more nearly parallel with the general direction of the ice movement in that region. Yet by far the larger overflow was southwest, along a route more transverse to the glaciation and over a low divide, rather than down the drainage slope. The breadth of the gravel plain along the Crooked River is as great as that of the Kezar Brook series. Both series were deposited in channels that were probably broad enough to carry off all the waters that came from the north without the aid of the other channel.

The history of the glacial gravels of this region is probably as follows: Originally a large glacial river flowed from Albany (and perhaps from Bethel and the Androscoggin Valley) south to North Waterford and along the valley of Kezar Brook southwestward to Lovell and thence south to the Saco River. At first this river flowed in a narrow channel within the ice. Subsequently other ridges were deposited in channels near the original one. By degrees these channels became confluent and the channel broadened, and an osar-plain was laid down in the broad channel. During this time the valley of Crooked River was blocked by ice, so that the glacial river easily flowed southwest over the divide. But the time came, toward the last of the Ice period, when the waters effected a passage from North Waterford eastward down the valley of Crooked River. At this time the melting had proceeded so far that the valley was bare of ice from Sebago Lake north to East Waterford. Hence glacial gravel was formed from North

Waterford only as far south as the plain near Papoose Pond, and below there the water flowed as an ordinary surface stream, and only fluviatile drift was deposited in that part of the valley; at least, if this glacial stream flowed in an ice channel south of East Waterford it was so narrow as not to deposit gravels, or else the glacial gravels are now covered by the valley drift.

Where the Albany series reached the Saco River, near East Brownfield, it can no longer be distinguished from the other series which cover a large part of southwestern Maine with a closely connected network of gravel plains. Above this point the drift of the Saco Valley is much finer in composition than the broad plain of gravel, cobbles, and bowlderets which extends from this point south and east along the valley for many miles. In the middle of the valley the stones of this plain are very much worn and rounded, but near the sides of the plain the material resembles till, which plainly has had the finest detritus washed out of it, but with hardly any attrition. I repeatedly saw stones and bowlders near the outer margin of the upper terrace that retained their till shapes with only very small modification. This appearance was especially noticeable at an excavation near Brownfield station of the Maine Central Railroad.

In Hiram, Baldwin, and northern Limington the gravel plain of the Saco is often uneven and ridged like the plains of reticulated kames. As we go southward the plain becomes more level and the material finer. The coarse gravel gives place to fine gravel and this passes by degrees into broad sand plains in Standish, southern Limington, and Hollis, where the sand ends in the marine clays. The plains showing reticulated ridges thus pass by degrees into the marine delta-plains. These deltas were deposited not far above 230 feet in the open sea, and are the largest in Maine.

While it is not easy, or at present possible, to separate the Albany-East Brownfield series from the other reticulating plains of sand and gravel near the Saco River in Brownfield, Hiram, Cornish, Limington, and Baldwin, yet the great size of the series toward the north makes it certain that this great glacial river contributed a large proportion of these plains. Most of the gravel series of southwestern Maine are remarkable for the height of the hills which they cross, but this series penetrates the high hills that lie east of the White Mountains along a route so level that one may travel from Gorham, New Hampshire, eastward to Bethel, and thence along the course

BROAD OSAR CROSSING COL; BROWNFIELD. LOOKING EAST.

House is situated on partially eroded osar plain. The glacial river, which for some miles skirted the north-south hill on left, turned abruptly eastward over low pass in center.

of this series, without having to rise over hills higher than 100 feet, measured on their northern slopes.

ALLUVIAL TERRACES OF THE SACO RIVER.

From the sea to near Bonny Eagle, in Standish, the Saco River is bordered by terraces of erosion in the marine beds. Near the river these marine sediments differ but little from those found at a distance from the river. If the ice had melted before the marine beds were laid down and the sea advanced, the river would have begun to flow before the deposition of the clays, and we should now find a plain of valley drift overlain by the marine beds. The fact that these beds are substantially the same near and far away from the river valleys shows that the rivers had not begun to flow at the time of their deposition, and that they were a rather deep-water formation.

Near Bonny Eagle the Saco enters the great marine deltas brought down by the glacial rivers, overlain by the delta of the river after the melting of the ice. That the glacial deltas were deposited in the open sea is proved by the fact that they are confluent and practically continuous over a broad area extending from Standish southwestward through Limington, Hollis, Lyman, Waterboro, Alfred, and Sanford, to North Berwick. For a few miles above Bonny Eagle the erosion terraces of the Saco are excavated in sand overlying clay. Then the gravel appears, and above Steep Falls coarse gravel, cobbles, bowlderets, and some bowlders form a large part of the river terraces. Where there are broad plains of porous gravel bordering the river there is usually more erosion than in the narrow parts of the valley. This is due largely to the action of subterranean waters in the manner elsewhere described.

North of Hiram lie a number of broad, rather level valleys opening southward. This would tend to converge the ice into the narrower valley of the Saco extending from this point south and east. Late in the Ice period as the ice retreated there would naturally be a local glacier in the valley, i e., one following the valley independently of the previous general movement. It is a difficult problem now to determine how much of the deep sheet of water-assorted matter that covers the Saco Valley from Hiram to Steep Falls was deposited during the general movement and how much was the work of the more local glacier. As the ice retreated up the

valley the terminal moraine of this supposed glacier would naturally fall into the subglacial rivers and be modified by water, thus helping to form an overwash or frontal plain in front of the ice as it receded.

Above Hiram the part of the valley covered by alluvium broadens into a plain, in Brownfield and Fryeburg, near 10 miles in diameter. The floods of valley drift in time covered the whole of this broad area, so that it would present the appearance of a lake. In this was deposited a broad fluvial delta extending from Conway, New Hampshire, east to Lovell and Brownfield. For many miles in this broad sedimentary plain the river winds very circuitously and is bordered by only a single bluff of erosion—that which forms its banks. This indicates that erosion and deposition are here going on at about the same rate. The alluvial plain narrows as we approach the New Hampshire line, and the drift becomes coarser and contains much rounded gravel. The erosion terraces along the Saco River vary from 10 to about 50 feet in height above the river.

THE GREAT COMPLEX OF NORTHWESTERN YORK AND SOUTHWESTERN OXFORD COUNTIES.

This is a series of plains closely connected by lateral series so as to cover as with a network the hilly country lying west and southwest of the Saco as far as the valley of the Mousam River. In this complex series it is difficult to distinguish tributary from delta branches. On the west these gravels are connected by three lines of gravel plains with the great kame system described by Mr. Warren Upham in the reports of the New Hampshire geological survey as extending from Conway, New Hampshire, southward to the valley of the Ossipee Lakes. Two of these plains (in the form of osar-plains about one-fourth of a mile wide) extend from Effingham, New Hampshire, into Parsonsfield, Maine, while a tract of reticulated ridges nearly 3 miles wide passes from Wakefield, New Hampshire, into Newfield and Acton, Maine.

The region between the Saco and the Mousam is diversified by numerous ranges of hills. If we start south from the broad hill-encircled plain of Fryeburg, which on a small scale much resembles in form the "parks" of the Rocky Mountains, we almost immediately enter the hilly country. In Porter, Brownfield, Parsonsfield, and Cornish many of the higher hills rise to 800 feet or higher, and the slopes are rather steep. Going southward, we find the valleys becoming broader and the hills lower and with gentler

slopes. Not far from the line of the Portland and Rochester Railroad we pass into a gently rolling plain, out of which rise a few granite knobs and other hills, like Bauneg Beg and Agamenticus. This plain extends to the sea. In the tract of country here described there is no single dominant range of hills. There are two systems of valleys, nearly at right angles to each other. The larger streams, such as the Great and Little Ossipee rivers, flow eastward into the Saco. The north-and-south valleys are occupied by numerous lateral tributaries of the principal streams. This arrangement of valleys will in part account for the somewhat rectangular shape of some of the reticulations of this complex series. The local rock of this region is chiefly granitic, and this rock in Maine always affords an abundance of till. In the more hilly country the glacial gravel is in general quite coarse, containing multitudes of much-rounded bowlderets and bowlders up to 4 feet in diameter. Broad sheets of rounded gravel, etc., frequently have numerous large till-shaped bowlders resting upon them, but these are mostly below 230 feet, and may have been deposited by ice floes. Numbers of short tributary branches come down the slopes of hills to join the main plains, and even these short hillside branches show large rounded bowlders. Along the principal lines of glacial overflow the stones are much worn and rounded, yet here and there they are subangular and differ in shape but little from those of the till. Such areas are usually on the borders of the plains.

The number and height of the hills which the gravels of this region cross are remarkable. Nowhere else in Maine is there anything equal to them. In Brownfield, Porter, and Hiram the glacial rivers flowed up and over these hills 200 or more feet higher than the valleys to the north of them, and in Parsonsfield and Cornish they crossed several more. In Limington, near the Cornish line, a gravel series goes up and over a pass in a narrow valley called "The Notch," at the western base of Strouts Mountain. The top of the pass is fully 300 feet above the northern base of the hill and about 400 feet above the same gravel series at the Saco River, 2 or 3 miles north of The Notch. These measurements were made with the aneroid barometer, but I have tried to make the figures here given under the truth rather than over it. Near the tops of the higher hills the gravel is scanty, and then for a half mile or more sometimes none will be found on the southern slopes. These branching series often reject valleys of

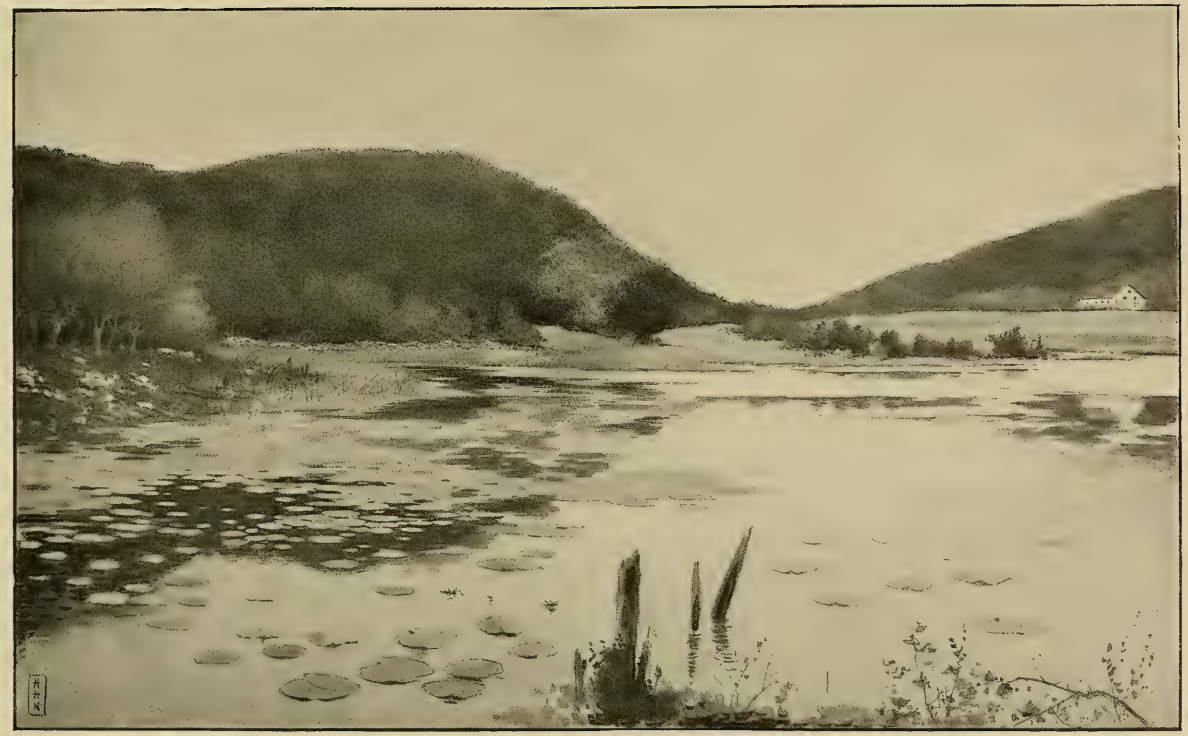
favorable slopes in order to climb hills, and are therefore difficult to map. Delta branches are liable at any point to diverge from the series one is exploring, and constant watchfulness is required.

The map shows the courses of these connected series more clearly than any verbal description, yet in the absence of maps showing the relief forms of the land it may be best briefly to describe the glacial gravels of three townships as a specimen of the whole region now under consideration.

Near the southern end of the Fryeburg Valley the glacial gravels begin, and extend southward along a low pass between the conical peaks

FIG. 24.—Broad osar penetrating narrow pass over hill 400 feet high; Limington.

known as Tibbitts and Peavys hills. The line of gravels then descends about 100 feet into the east-and-west valley of Pequawket Stream. It here divides into three delta branches. One series crosses the valley nearly at right angles and ascends the long hill which lies to the south along the south branch of Pequawket Stream to a height of fully 200 feet. Another branch turns east and follows the Pequawket Valley through Brownfield Village, when it soon expands into a broad plain reaching to East Brownfield, southeast of which place it becomes confluent with the gravels of the Albany-Saco River series. This plain shows the horizontal



THE NOTCH, HIRAM. LOOKING NORTH.

The lakelet is surrounded by plain of glacial gravel, coarse on the left. A large glacial river flowed from the north, through the lowest part of the narrow valley.

assortment of sediments characteristic of the delta-plain, and this broad and level valley near East Brownfield was at one time occupied by a lake, or a river so broad as to resemble a lake. The third diverging branch turns southwest and goes up the main Pequawket Valley for somewhat more than 2 miles, when it again parts into two series, one of which goes nearly south over a high hill and thence to Porter Village, while the other ascends a hill toward the southeast and, when near the top of a pass situated at the northern base of Pine Hill, unites with the series which follows the south branch of the Pequawket Stream. The united series now continues southeast through the pass and descends 180 feet into a valley opening eastward. By following down a rather steep slope in this valley the glacial river might, within 2 miles, reach the very large glacial river which flowed southwest from East Brownfield to Kezar Falls along the valley of Tenmile River and through the remarkable valley in the western part of Hiram called The Notch. Instead, it turned at a right angle southward and climbed a hill 180 feet high. On the top of this hill the river was in a situation interesting to study. Right in front of it is a valley leading southeast into The Notch, and by taking this route the glacial stream might, within 2 miles, have joined the glacial river just mentioned at a point 250 feet or more lower than its position on the hilltop. Instead of following this valley along a down slope, the glacial river turned southwest, and for an eighth of a mile flowed directly on the top of the ridge, and then crossed a north-and-south hill over a col 30 feet high. The gravels are somewhat discontinuous south of this point, but can readily be traced along the western slopes of this hill to Kezar Falls.

The above description applies to an area only about 10 miles long from north to south. A minute description of the branchings and reticulations and other developments of the Saco-Mousam network of gravel plains must be omitted.

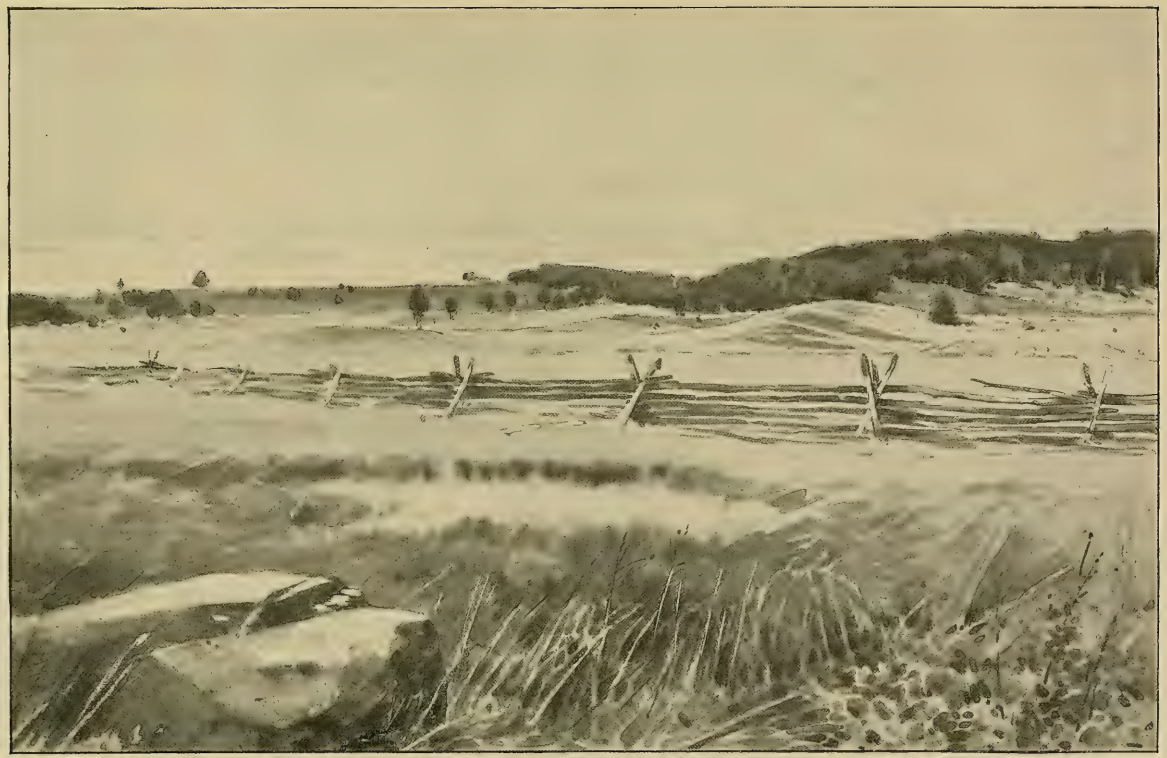
But there is one line of gravels that demands further notice. The Notch, in the western part of Hiram, is a very low valley with U-shaped cross section. The level portion at the bottom is usually not more than one-fourth of a mile in breadth, and at the highest part of the pass it is hardly an eighth of a mile wide. From this point two streams flow in opposite directions. One of them is a branch of Tenmile River, and flows northeastward into the Saco River; the other flows southwestward

into the Great Ossipee River near Kezar Falls. A line of glacial gravels extends from East Brownfield along The Notch to Kezar Falls. In the midst of The Notch are three ponds bordered by plains of glacial gravel rising up to 20 or more feet above the water. It is difficult to account for lake basins being excavated by boiling springs in a mass of coarse composition such as gravel, cobbles, and bowlderets. These lake basins must have been deposited in substantially their present shapes by the glacial river. This is an interesting divergence from the ordinary type of osar-plain. Here, as in numerous other places, we find the broad osar and the tracts of reticulated ridges passing into each other by degrees.

I shall sum up, briefly, some of the general features of the glacial gravels of this region.

Seldom, and then only for a short distance, do the gravels take the form of a single ridge with arched cross section, like the osars of eastern Maine. Toward the north these gravels usually take the form of a broad osar, i. e., a rather level-topped plain from a few rods up to one-fourth or, in a few cases, one-half mile wide. Farther south, at elevations below 600 and above 230 feet, the gravels expand into plains of reticulated kame ridges up to 3 or 4 miles in breadth. At about 230 feet the reticulated kames pass into the great level delta-plains. These show clearly the horizontal classification of sediments characteristic of deltas, and sand plains pass by degrees into marine clays. Here and there small delta plains are found in the courses of both osars and reticulated kame plains. Many of these are far above the contour of 230 feet and were probably deposited in glacial lakes.

One who studies the glacial gravels only on southern slopes where the rivers now flow in the same direction and in the same valleys as the glacial rivers, will find it difficult to distinguish between the sediments of the two kinds of rivers in such situations. He may come to attribute all the alluvium to the rivers of the so-called Champlain period, and may even doubt the existence of glacial rivers, at least as agents for depositing alluvium so much resembling fluviatile drift. Such skepticism will be permanently removed by a few days of exploration in the region now under consideration. Here he will see these long lines of sand, gravel, and coarser sediment go up and over the steep hills. Here can be seen how often they reject valleys of natural drainage and instead climb hills 200 feet or more



OSAR RIDGES AND HUMMOCKS SKIRTING HILLSIDES; NEWFIELD. LOOKING EAST.

Glacial river flowed from left to right.

high, leaving vast deposits of water-assorted matter on hillsides where there never could be any running water except rain-water rills (see Pl. XXII). Here these gravel plains divide into diverging series which after a time come together again. By the time the observer has seen all this he will be ready to admit that these gravels are wholly inexplicable as the result of fluviatile, lacustrine, or marine action. In the midst of these winding valleys bordered by high hills and covered by water-rounded cobbles, bowlderets, and bowlders, showing the action of swift currents from the north, and in presence of the meandering lines of gravel, wandering about on the tops of hills, the iceberg theory of the glacial drift of Maine utterly breaks down. These circuitous gravel systems bearing such curious topographical relations become of themselves one of the strongest proofs of the existence of the ice-sheet over Maine. Glacial ice accounts for the barriers necessary to force streams over hills and to prevent them from flowing downhill by the steepest slopes. No other known drift agency can do this. The critical student of the great northern drift should by all means visit this region.

On the map the glacial gravel of this region is marked as ending on the north a short distance southeast of Fryeburg Village. North of this point lies the large level basin of Fryeburg, Lovell, Stowe, and Stoneham, inclosed by high hills. To the west and northwest lie the White Mountains and their outlying ranges. During the last days of the ice this level valley would be filled by a sort of local glacier, replenished from the north and west along valleys where the flow of the ice could continue after the movement over and across the hills lying to the north had ceased. Here would be a local tongue of ice filling a valley about 25 miles long and from 3 to 5 miles broad. In all this valley I have not found a deposit of unmistakable glacial gravel. Cold River originates among the eastern spurs of the White Mountains and flows southeastward into the Saco River. Its valley would be a favorable place for a glacial stream, but the alluvium in the valley is very different from the gravel here described as glacial. The stones are subangular and the drift is clearly fluviatile. The apparent absence of glacial gravel from the level Fryeburg basin, while it is so abundant in the hilly country to the south, will be further discussed in a subsequent chapter.

South and east of the Portland and Rochester Railroad the country was wholly under the sea as far as the New Hampshire line, except a few

ranges of hills which then formed islands. A large part of the sands and gravels of this region were deposited in the sea, mostly in the open sea in front of the ice, but in part in broad channels opening on the sea-like bays inclosed at the sides by ice. In this region the gravels are somewhat discontinuous, and many of the smaller deposits are more or less covered by the marine clays; they are therefore difficult to trace. I have only partially explored the southern portion of York County.

ACTON-NORTH BERWICK SYSTEM.

This series of gravels is provisionally described as a distinct system, though this glacial river may have joined that which flowed down the Mousam Valley. If so, it was early in the Ice age, and late in that period these streams poured into the sea by widely separated mouths. The system begins about a mile north of South Acton, on the southern slope of a high hill. For about 2 miles it consists of two nearly parallel series situated about one-fourth of a mile apart. One of them is a series of short ridges and hummocks, forming a single line like the osars, with only a few outlying and reticulated ridges. These gravels run southeast across the valley of a stream which flows eastward into the Mousam River. It then penetrates a narrow pass through the hills southward over a divide not more than 50 feet high. In this pass a small stream soon appears, which flows southward past East Lebanon, and the gravel system follows the same valley, most of the way as a narrow osar-plain, now much eroded by the stream. It passes near Lebanon station of the Portland and Rochester Railroad and about a half mile west of Bauneg Beg Mountain, and continues south and east through North Berwick into Wells. As already stated, the system near South Acton is double. The more western gravels begin near the other series, but keep about 100 feet above it on the hillside. They take the form of a small two-sided ridge or osar with very steep lateral slopes and a very meandering course. The material is but little waterworn. Within about 2 miles it comes down the hill to near the other series in the valley, and is then lost. No doubt it was deposited by a small tributary of the main glacial river. This little osar-ridge is situated 400 feet or more above the sea, and the difference between its steep side slopes and the low arch of the ridges found below 230 feet is very noticeable.

From East Lebanon southward this system traverses a gently rolling

A. PLEXUS OF KAME RIDGES AND MOUNDS; NEAR NORTH ACTON.

B. TERMINAL MORAINE; WINSLOWS MILLS, WALDOBORO.

plain. Here and there are reaches of level osar-plain, but for most of this distance the gravel takes the form of a plain of reticulated kames one-eighth of a mile or more wide. The system passes not far west of Bauneg Beg Mountain, and expands into a marine delta not far north of North Berwick Village. South and east of this point are some discontinuous plains of sand and gravel, but their connections are obscure. Maryland Ridge, in Wells, is a large and broad ridge of glacial gravel having a southeast direction. I provisionally mark it as a part of this system, though possibly connected with the great series that extends from Conway and the Ossipee Lake region, in New Hampshire, down the Mousam Valley past Sanford.

LEBANON SYSTEM.

A series of somewhat discontinuous and plain-like gravels extends from near Wentworth or Northeast Pond, and in the northwestern part of Lebanon, southward through the central part of Lebanon, following a rather low pass and then the valley of a stream that passes near South Lebanon. Toward the south there are several narrow plains, which diverge in direction, as if delta branches of this system. These have been traced by me only a short distance into Berwick. I am indebted to Mr. J. H. Hammond, of Sanford, for much information regarding this portion of York County.

WEST LEBANON SYSTEM.

This gravel system begins on the east side of Salmon Falls River a mile or two north of East Rochester. It crosses into New Hampshire near East Rochester, and is said to extend to Dover, New Hampshire.

CHAPTER V

CLASSIFICATION AND GENESIS.

Although we need not now study the causes of such astonishing variations in climate as have taken place in post-Tertiary time, we must assume an ice-sheet covering all New England except perhaps a few of the highest peaks. For the present we must investigate the order of events. The higher questions involving the causes of geological climates must come later. As it is the first office of science to classify facts and discover their underlying principles, it remains for us to make a detailed examination of the known facts and, if possible, to reach a satisfactory classification and explanation of them. The moment we enter upon this inquiry, however, we confront the difficulty of isolating the glacial sediments from the other glacial deposits or from other forms of water transportation, and our subject at once broadens so as to include every form of superficial deposit.

Probably northern Greenland typifies more nearly than any other known country the condition of New England at the time it was covered by ice. It is known that the interior of that country is covered by a great continuous snow field that rises above all the hills and most of the mountains and is discharged into the sea by broad glaciers. During the greater part of the Ice age the glaciers of New England were practically confluent. The ice then extended far out into the present Gulf of Maine, and was there discharged into the ocean as icebergs or as melting waters. The drift which was at that time deposited near the ice front is now beneath the Atlantic. But the last part of the Glacial period saw the extremity of the retreating ice confronted by the sea along a very crooked line situated over what is now the dry land. The sea then stood at about 230 feet above its present level, and broad arms of salt water extended far into the interior of the State along the principal valleys. Our problem involves both the study

of the geological work of the ice on the land of that period and also the offshore drift then thrown into the ocean by the ice-sheet itself, by ice floes and icebergs, and by glacial rivers, the whole having since been more or less modified by the waves and currents of the sea. The subsequent retreat of the sea to its present position has exposed these deposits for convenient study, and thus has furnished a good example of the multiform work going on off an ice-bound coast. Our geological conceptions are thus enlarged by the same process that added the clay loams to the list of the soils of Maine. But the problem before us involves more. The final melting of the ice over the land left the waters free to follow the valleys of natural drainage. Rivers much larger than the present rivers then flowed into the sea from 30 to 100 miles above their present mouths and were depositing deltas in the sea not far from the coast line as it at that time existed. These deltas are now exposed for our study, and are to be distinguished from marine and glacial sediments. Moreover, before the ice had all melted, lakes gathered on the land, confined wholly or in part by ice. Thus the various kinds of drift of the glacier are to be distinguished in the midst of preglacial soils and lacustrine, fluviatile, and marine sediments, often since modified by the action of the wind and streams, or strewn by drift from floating ice, or eroded in part and carried away beyond our sight, or bodily misplaced by landslips. Everything which directly or indirectly produced a single one of the field phenomena must be of interest to us.

PREGLACIAL LAND SURFACE AND SOILS.

The longer a region has been above the sea the more nearly are the surface features due to upheaval and unequal elevation replaced by those due to subaerial erosion. The coming of the ice-sheet found Maine in that stage of development called geological "old age." The land had been deeply sculptured, here with a heavy stroke, there with a lighter touch, and the rock yielded in different degrees to the attack of the chisel. Only the ruins of the folds and cones produced by mountain-making forces remained. The outlines of these remnants of a primeval land were about like the present surface forms of the State, save that the hills were more rough and angular in outline. Steep cliffs of erosion abounded which were ragged with weather-rounded bowlders. The long conflict which for geological

eons had been going on between the elements and the living rock was testified to by the towers and buttresses with which the rock in vain strengthened its scarps of erosion. While the outlines of the hills were not so beautifully curved as at present, the drainage basins and the relative height of hill and valley were probably about the same.

It is uncertain to what depth the rock had become weathered in preglacial time. Over the driftless area of Wisconsin the residual earth has been found by Chamberlin and Salisbury to have a thickness of 4 feet. In a region of granitic rocks the residual earth represents but a small part of the rock which has become shattered and more or less disintegrated. In the Blue Ridge of Virginia I have repeatedly seen railroad cuts where the Archean schists were weathered and fractured to a depth of 20 to 30 feet. In Maine the roofing slates weather with such extreme slowness that the preglacial soil may have been on the average only a few inches thick, and the weakened rock only a few inches more. The sedimentary sandstones, etc., may have had only about the same depth as in the driftless area of Wisconsin, but the crystalline and schistose rocks must have been weathered to a much greater depth. Many of the feldspathic rocks have become weathered to a depth of several inches to several feet in postglacial time, and this indicates a deep preglacial sheet or surface layer of soil, subsoil, and bowlders of decomposition. Obviously the actual depth attained depends on the ratio between weathering and transportation. The till is much more abundant in the regions of schistose rocks than in those of slates and sandstones. This of itself is a proof of a greater depth of weakened rock, and in the granitic regions there was a still greater depth. Judging by the cliffs on the south side of Russell Mountain, elsewhere described, I do not think it an extravagant estimate that the rock in preglacial time had there become fractured into blocks removable by the ice to a depth of 50 feet. This was in granite, and not a very easily weathering variety. The depth of rock which had become fractured and more or less weathered in preglacial time may be estimated at from a few inches up to perhaps 50 feet.

Since the land had been for a long time above the sea, the larger valleys would have attained a base-level of erosion. Lakes occupying rock basins, if there had been any, would have been silted up or have been drained by the cutting down of their inclosing barriers, or in case of shallow

basins they may have been filled with peat. In the valleys there would be much stream wash—silts, sands, and gravels. I have never given up hope that somewhere portions of these preglacial soils, peats, or lake sediments were enabled to survive beneath the rough ridings of the ice-sheet in masses sufficiently large to contain characteristic fossils and be recognizable. So far as yet discovered, the only bodies of preglacial soil that failed to be incorporated with the drift of the ice-sheet were contained in small depressions of the rock. They consist mainly of rock weathered in situ, and plainly underlie the glacial drift. They are much the oldest of the superficial deposits of Maine. The largest of the depressions of this kind in which the primeval soils are preserved were in argillitic and quartzitic schists, and were less than 7 feet in diameter, unless certain narrow east-west ravines in sedimentary rock that open out from the gorge of the Seboois River not far from Mount Katahdin be also of this kind. The projecting tongues left by the unequal weathering of the fine-grained schists were thin and easily broken. Hence these rocks were reduced by the glacier to such an even or gently undulating surface that their glaciation may well be termed planing. The mica- and other coarse schists yield fewer areas of preglacial weathering, and these only from 1 to 3 feet in diameter. The laminæ are thicker and vary much in hardness. The glaciated rock often shows undulations a few inches wide and from 1 to 3 inches high, so that the surface has a ribbed appearance, as of corduroy. The projecting ribs are rather parallel to the strike of the laminæ of schists, and more often are transverse to the glaciation. Where the furrows between the ridges are very large they have sometimes been described as grooves gouged out of the rock by a single bowlder. Where they happen to be parallel with the glaciation it is difficult to decide the question of their origin; but where they are parallel with the lamination of the rock and transverse to the glaciation, as they usually are, they must be regarded as due to the condition of the weathered rock as the ice began to act upon it. The ridges are the projecting edges of the harder layers which the glacier was not able to plane off to a flat surface, although removing the weakened rock and leaving the surface of both the ridges and the hollows thoroughly polished. In other words, in these cases the signs of the surface of preglacial weathering were not entirely obliterated.

The granites and syenitic granites are glaciated in still more irregular

surfaces. They show greater numbers of rounded bosses, or roches moutonnées, and many small rock basins. These depressions are glaciated even to the bottom. I have not been able to find in granite areas surfaces of preglacial weathering, except at certain cliffs facing the south. For instance, at the southern brow of Russell Mountain, in Blanchard, there is a steep cliff several hundred feet in height. The upper portion has been shattered by the elements into a wall of bowlders of decomposition, most of them still occupying their original relative positions. Some of the largest of the upper tier of bowlders have been moved several feet southward, so as almost to cause them to fall down the cliffs. The top and northern slopes of the hill are intensely glaciated, and they so far bore the brunt of the attack that the ice only partially succeeded in pushing these bowlders from their places. Doubtless on that cliff in preglacial time there rested many a bowlder which the ice was afterwards able to push over the brink and carry away. The turrets and battlements of the castle as the glacier found it have been cut off, and perhaps the upper stories, but enough remains to remind us that the power of ice has some limit.

The condition of the surface of the glaciated rock in Maine proves that the behavior of a thin glacier, such as the extremities of those of Switzerland and Norway to-day, is very different from that of one a half mile or more in thickness. Under the deep ice of the time of maximum accumulation only here and there a small depression became filled by subglacial till or by embayed ice, so that the glacier flowed over it as if it had been solid rock. We have seen that the bottoms of most of the narrow furrows were glaciated even when transverse to the direction of the motion. It was very different during the last of the Glacial period, when the ice had become thin. Thus, at one of the lime quarries at Rockland, in a northeast and southwest valley, there is an earlier series of long, straight scratches bearing S. 31° W. Later scratches are found which in places have obliterated the earlier ones. They bear S. 51° W. The smooth, even surface of the limestone ledge gently inclines southwestward about 1 foot in 40. On this incline there is a steeper place where within 3 feet there is a fall of 3 or 4 inches. The later scratches come up to the northern edge of the steeper incline, when they disappear for about 3 feet, then begin again near the foot of the steep incline and continue southward. The steeper slope is beautifully glaciated, but the scratches were made during

the earlier glaciation. Here at the time the later scratches were made the ice could not bend downward so sharply as the small change in direction of slope. In other words, the ice traveled 3 feet horizontally, held up by its cohesion, before it would bend downward 3 inches. On the other hand, the earlier scratches changed instantly with the slope, and they themselves were a deflection from the general glaciation of the region in which they are found, and probably were not made at the time of greater thickness of ice. All over Maine the earlier scratches bend sharply (in vertical planes) around curves and some pretty sharp angles. Such facts prove that deductions drawn from the behavior of thin glaciers do not in all respects apply to thick ones. And yet if a thin glacier can not at once bend its course downward under the force of gravity, it is evident that the same causes, but operating under different circumstances, will limit the power of even a great ice-sheet to flow down into cavities and glaciate them. The ice, as shown elsewhere, must have been less than 200 feet thick at the time of the formation of the Waldoboro moraine. The pressure on its bed (neglecting the weight of moraine stuff) was less than 6 atmospheres. If the thickness of the ice over Maine was only half a mile, the pressure at the base was at least 84 atmospheres. Under this enormous pressure the power of the ice to flow down into hollows was very great, but not unlimited. Here and there a small portion of that ancient surface was protected by a curve of the rock.

GREENLAND SNOW AND ICE.

The only region sufficiently explored to enable us to identify its condition with that of northern New England in the time of the ice-sheet is Greenland. Most of what we know of the condition of the interior is due to the labors of the Danish geologists, of Torell, Nordenskjold, and Holst of Sweden, of Lieut R. E. Peary of the United States Navy, and others.

The principal facts relative to the ice and snow of Greenland likely to be of use to us in the interpretation of the facts as exhibited in Maine are the following:

The eastern coast is bordered by much shore ice. Near the southern extremity the country is mountainous, and numerous glaciers occupy the interior, but none reach the sea. Going north the inland ice descends lower and the principal fiords serve as the outlet of glaciers, which come down

to the sea level and end in cliffs near the heads of the fiords, where the ice breaks off as icebergs. Still farther north these glaciers extend out nearly to the mouths of the fiords, and they become broader. Finally the glaciers become confluent in great ice-sheets that confront the sea in a solid and continuous wall for a hundred miles or more. Part of this great breadth is due to the climate, part, perhaps, is due to the form of land surface. Going from the coast inland we find the ice surface rapidly rising. Near the shore the ice usually barely fills the valleys, leaving the mountains bare. Inland only a short distance, we find but few peaks (nunatakker) projecting above the ice. Within 30 or 50 miles we reach a region where even the highest peaks are wholly beneath a great continuous ice-and-snow field. In the interior no moraine stuff appears on the surface of the ice, though there is more or less dust, the kryokonite of Nordenskjold. Some morainal matter falls from the nunatakker onto the ice as we approach nearer the margin, but near the extremity many stones and bowlders appear on the surface. Many of these are in situations where they are supposed not to have fallen on the surface from nunatakker, but have got up into the ice from below, and were subsequently exposed by the melting of the ice or by movements within the ice. These are glaciated little or not at all. In several places the Danish geologists have seen a ground moraine, as, for instance, where a thin flow of ice takes place over the cols between two or more nunatakker while the deep mass divides and flows around them. The two main streams unite a short distance below the buried ridge. In lee of the buried ridge a moraine is formed, brought over by the thin sheet. The material of this moraine is intensely glaciated. In some cases a moraine profonde has been seen beneath the ice near its extremity.[1]

THE TILL.

While in general the unmodified glacial drift, or till, rests upon the preglacial soils and the glaciated rock, yet there are local exceptions where a later deposit rests on the rock in consequence of the absence of till or the occurrence of landslips. Indeed, landslips have been so common that it is unsafe to trust any inferences as to the chronological order of events

[1] This account is condensed from the above-mentioned authors, quoted by J. E. Marr in Geol. Mag., April, 1887.

Since the above was written a paper on Holst's observations in Greenland has been published in the American Naturalist (July and August, 1888), by Dr. J. Lindahl.

until it is clearly proved that there have been no slides at the places of observation.

A fundamental question regarding the till relates to its origin. The hypothesis of Torell—that part of the morainal matter of the ice-sheet was beneath the ice, while the upper portion was distributed through the lower part of the ice—has since 1877 appeared to me to explain satifactorily the facts as observed in Maine. The principal considerations bearing on the subject are the following:

We do not know how the age of ice began. Looking at it from the standpoint of our present climatic conditions, it would most naturally come on gradually. After a time local glaciers filled the mountain valleys. Above them rose cliffs that had been rent into loose blocks during the long ages preceding. Much of this cliff débris fell down upon the ice and formed moraines like those of the Alpine glaciers. But more snow continued to fall than melted, and the time came when this morainal matter and the hills were overtopped by the snow and ice. Unless the higher peaks of the White Mountains and Mount Katahdin be exceptions, all the territory was covered. The proof of this is conclusive, since the rocks on the hills are scored and afford drift bowlders transported from the north.

So, too, during the decadence of the ice-sheet the tops of the higher hills appeared above the ice long before the flow in the valleys ceased. The glacier had just swept over the cliffs and removed most of the talus and bowlders of decomposition; few therefore would fall upon the ice. The melting of the upper portions of the ice would leave many bowlders on the higher and steeper parts of the hills in such unstable equilibrium that now and then, as one was freed from the embrace of the ice, it would roll or slide down the slopes onto the ice that still remained in the lower parts of the valleys. At this time landslides of the freshly deposited material would naturally be frequent. In these ways it may be admitted as possible that morainal matter was at this period precipitated from above upon the ice, after the manner of ordinary valley glaciers. But if moraines were thus accumulated we ought now to find them, in the form of ridges and trains of bowlders, especially at the flanks of the high, steep hills. On the contrary, the bowlder trains are in lee of granite knobs, where a cliff was shattered beneath the ice and its bowlders pushed forward. While, then, we may grant a limited fall of débris from above onto the top of the

ice during the beginning and near the end of the existence of the ice-sheet, yet this supposed moraine stuff is not now so distinctly arranged in the form of medial or lateral moraines as to warrant the assertion that any considerable amount ever fell upon the ice from above. And it is therefore practically self-evident that during the time when all the country was covered with ice the morainal matter could get into the ice only from beneath.

MORAINAL DÉBRIS OF THE ICE-SHEET.

MORAINE STUFF IN THE LOWER PART OF THE ICE.

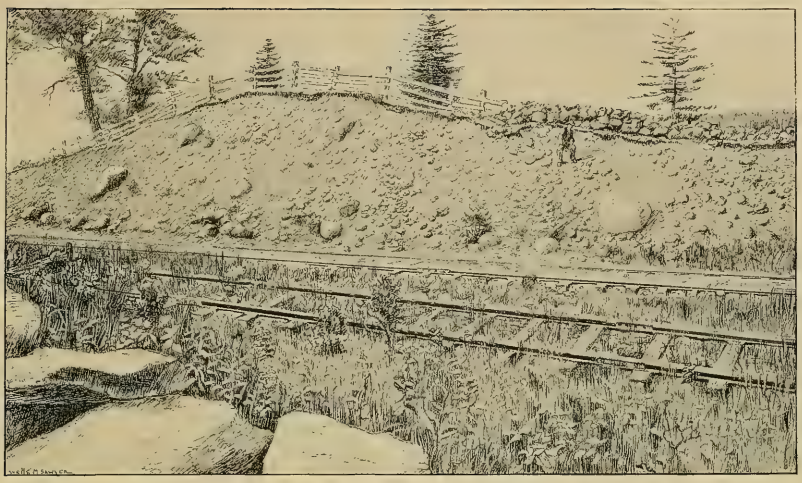
That till matter had in some way worked up into the lower part of the ice is conclusively proved by the presence of several terminal moraines.

WALDOBORO MORAINE.

The largest of these terminal moraines extends from near Winslows Mills, Waldoboro, for about 6 miles north and eastward. Its general appearance is that of a two-sided ridge, or sometimes of two or three roughly parallel ridges. It is composed of the same kind of matter as the upper layers of the till of the surrounding region, unless perhaps it has had a small proportion of the finest rock flour washed out of it by very gentle currents.

Regarding this moraine it may be said:

1. The moraine is not composed of matter torn up from the ground moraine or previously deposited till and pushed forward by the snout of an advancing glacier. As elsewhere recorded, a series of hummocks and short ridges of glacial gravel extends from Waldoboro northward along the Medomac Valley to a point more than a mile north of the moraine. One mound of this series directly underlies the more northern of the two ridges at Winslows Mills. If the ice during an advance had been able to push before it so large a ridge composed of till previously laid down on the bare earth, it ought to be able to push before it the heap of glacial gravel now found beneath the moraine, as well as all the other eskers situated north of this point. But no esker material appears in the moraine—only ordinary, slightly water-washed till. Also, the external forms of the eskers north of the moraine differ little if any from those situated south of it, so far as I could discover.



A. SECTION OF TERMINAL MORAINE.

B. TOP OF TERMINAL MORAINE.

2. During the gradual shrinking of a glacier no frontal morainal ridge can be formed. The morainal matter is left scattered promiscuously over the field of retreat.

3. When the rate of flow of the ice equals or nearly equals the rate of melting at the ice front, a rather steep ridge must form at the end of the glacier.

It thus appears reasonably certain that the Waldoboro moraine was not formed during an advance or recession of the extremity of the ice, but during a time when the rate of advance or flow of the ice at that point very nearly equaled its rate of melting. South of Winslows I have found no similar ridge. It is a fair inference that during the time previous to the period of this frontal moraine the ice had been melting faster than it was replenished by flowing ice from the north. Here for a time the two rates were nearly equal, allowing, however, for two or three little periods when the ice receded a few rods and then held its own again. Then the rate of melting gained on the rate of ice flow, and as the front retreated northward the country was covered with a diffused sheet of till.

To the north of this moraine lies a gently rolling plain for a few miles, and then we come to a range of round-topped hills rising 500 to 800 feet above the sea. This plain would be rather favorable to the flow of ice southward up to a very late date. The moraine crosses several hills. Its highest point is about 150 feet above tide water. At this point it crosses the northern spur of a hill which toward the south rises near a hundred feet higher than the moraine. If the ice had much exceeded 150 feet in thickness, it ought to have reached a higher point on the hill than it did.[1] If we assume a thickness of less than 200 feet of ice at the time of the formation of the moraine, we must admit that it is probable the higher hills of Washington and Liberty, situated north of this place, rose above the surface of the ice at that time. If moraines then formed on the ice from matter sliding down from the hills, we ought now to find lateral moraines bordering the valleys that lie between these hills, and thence extending south to the

[1] Observations in Greenland and by Russell in Alaska prove that when a rock or hill rises in the midst of a glacier the ice is driven far up the stoss side of the obstruction, sometimes to a height of several hundred feet. If this sort of action took place at the hill crossed by the moraine east of Winslows Mills, the thickness of the ice may have been even less than the above estimate. The ice did not reach so far south on the hillside by an eighth of a mile or more as it did in the valleys situated east and west of the hill. This, perhaps, may prove that the ice over the hill dragged behind the deeper ice of the valleys because it there bulged somewhat above the general level of the surface.

Waldoboro moraine. The phenomenon of crag and tail is very common in those parts, but I have discovered no lateral or medial moraines proper in any of the larger valleys, and I have crossed them all. The hills are not precipitous nor very steep, at least they do not prove so to the Maine farmer who has much of their surface under cultivation. These conditions make it improbable that any considerable amount of morainal matter got upon the ice by sliding from the hilltops at the time the hills were bare and glaciers still filled the valleys.

The argument, then, stands thus: The moraine is not composed of previously deposited till plowed up and pushed before it by the snout of the glacier. Neither can it contain much if any matter precipitated upon the ice from above. It is a fair inference that the moraine consists chiefly or wholly of matter which had previously got up into the lower part of the ice from below. A part of it may have been on the surface of the ice at the time the moraine was being formed, but if so it was because it had been laid bare by the melting of the ice above it. The composition of the moraine proves that débris of all degrees of fineness, from the finest clay and dust up to the largest bowlders, were contained in the lower part of the ice. True, the moraine at the excavations near Winslows Mills is somewhat more sandy than the average upper till of the locality, but this can be easily accounted for if we assume that it was deposited in the sea at the front of the ice, or became somewhat water washed by the terminal melting. Only a few of the stones of the moraine are distinctly scratched, in which respect they are like the stones of the upper part of the till. In a word, the material is the same as found in the upper portion of the till of that region. The structural difference consists in the fact that we have here piled in a single ridge material which during a gradual recession of the ice front would be scattered as a sheet over a zone a half mile, more or less, in breadth.

MORAINES OF ANDROSCOGGIN GLACIER.

The basal character of the drift is also seen at the terminal moraine of the local Androscoggin glacier. This glacier formed terminal moraines near the line between New Hampshire and Maine. Pl. XXV, *B*, shows the moraine on the north side of the river rising on the slopes of Hark Hill. If it carried surface moraines, the glacier ought to have deposited contemporaneously with this moraine a lateral moraine comparable with it in size.

A. TERMINAL MORAINE; ON ROAD FROM WALDOBORO TO NORTH WALDOBORO. LOOKING EAST.

Ice flow was from the left.

B. TERMINAL MORAINE OF LOCAL ANDROSCOGGIN GLACIER; GILEAD.

At various points on the hills that border the valley I found heaps of till of various shapes, but they have the forms of accumulations of englacial till. The only deposit having distinctly the form of a lateral moraine that I found in the valley is situated on the north side of the river and about a mile east of the Lead Mine bridge in Shelburne. This is one-third of a mile or less in length, and its origin is somewhat uncertain. The hills on each side rise often steeply to a height of 500 to 2,500 feet, and surface moraines were as likely to form in this valley as in any in New England except a few in the heart of the White Mountains.

At all the other terminal moraines found in Maine the absence of lateral moraines emphasizes the conclusion that there was but little morainal matter borne on the surface of the ice that was derived, like the moraines of glaciers of the Alpine type, from avalanches and débris sliding from above onto the ice.

Agassiz long ago reached the conclusion that the ice-sheet covered all the land, and hence the only way for morainal débris to get into the ice was from below. The above-stated facts prove that late in the ice epoch, after the time when the higher hills began to rise above the ice, not much débris fell from above onto the ice, even in valleys bordered by steep hills. Up to the very last the drift was almost wholly basal.

QUANTITY OF ENGLACIAL DÉBRIS.

The depth of the upper or englacial till does not necessarily give an estimate of the quantity of morainal matter contained in the ice at one time. If we conceive the ice-sheet suddenly divested of all motion, the scattered mass or sheet of englacial till left when the ice melted will represent the amount of débris in the ice at that time. But if the ice is in motion the case will be far different. Whenever the forward flow of the ice equals the terminal melting the ice front is stationary and a terminal moraine gathers as a frontal ridge. As the ice advances, the débris contained in a zone of ice perhaps a half mile or more in breadth is brought forward and dropped on the narrow moraine. In other words, the thickness of the moraine may represent the englacial matter not only of an area of ice equal to that of the moraine but many times this area. If now the melting comes to exceed the rate of advance, a series of parallel moraines

will be formed, and if the rate of recession is uniform, these successive moraines become confluent, as a sheet.

This I conceive to be the best interpretation of the upper or englacial till. Only where the ice was stagnant does it represent the quantity of débris in the ice at the final melting, and only locally was it stagnant. Where the ice was in motion the thickness of englacial till may several or many times exceed the quantity of englacial matter, comparing equal areas of ice and land.

There are numerous places where the rock is bare of till or the till is very thin. We here have proof that there were considerable areas of the ice that contained no glacial débris at the time of final melting. The interpretation of this fact is a matter of doubt. Many of the places bare of till are on the tops of hills that have deep sheets of subglacial till on their northern slopes. The situation suggests that possibly the ice had been robbed of its englacial material while passing up the northern slopes of the hills. We may here have a glimpse of a general scantiness of englacial matter when the ice had become thin and ready to disappear, or we may assume only local deficiency.

The terminal moraines are from 10 up to 100 feet high. How many years' accumulation they represent is now unknown. The least possible time we could allow is a single season, and an advance of the ice=0. This would give as the utmost admissible thickness of englacial matter 5 to 50 feet. But if the ice was stationary, during the subsequent recession a sheet of the same thickness or thereabout ought to have been formed, and it was not so formed. This proves that the hypothesis of stationary ice is inadmissible. Structurally the moraines, at least those of Maine, can not be explained unless the ice was in motion. The retreatal moraines of the Muir glacier may possibly be a type of some of the moraines of the Androscoggin glacier, but not of any others. The proof is irresistible that the moraines represent the débris of an area of ice much broader than their bases. The sheet of englacial till that covers most of the land is a more doubtful subject of interpretation. In a given place it may or may not represent terminal accumulations.

Without venturing on very definite figures, and allowing for great local inequalities, I assume that the ice in Maine at a given place contained simultaneously only a few feet of morainal matter, perhaps a maximum of 20

feet, and over most of the State very much less; in the slate regions often only a foot or two and from that down to 0.

GROUND MORAINE.

Excavations at the bases of the terminal moraines ought to exhibit well the differences between the englacial and the subglacial till. The moment we assume that the moraines were of englacial origin we are logically driven to look for a different origin for the lower layers of the till. For the matter of the moraines (englacial matter) shows little glaciation, while that of the lower part of the till is intensely glaciated. It is just what should be expected if it is a moraine profonde. Accumulations of it have a curved, flowing outline, quite unlike the heaps into which the englacial till was often thrown. These are the two fundamental arguments for the existence of a ground moraine. Expanded they are as follows: A moraine profonde consists of débris that has been between moving ice and the underlying rock. A rock fragment can not be in such a situation without being subjected to great attrition against the rock or against other fragments if the ice preserves the known rigidity of ice under ordinary conditions. It has often been assumed that under extremely great pressure ice becomes much more fluent or plastic than at ordinary pressures. If this be so, what bearing has the fact on the nature of the glaciation?

Whatever theory of the origin of the lower or intensely glaciated till we adopt we must make it consistent with two facts: First, all the known excavations that penetrate to the bottom of the till reveal glaciated rock. Either, then, the whole mass of the lower till was rolled or dragged bodily beneath the ice, or each place overrun by the ice was first an area of erosion and subsequently one of deposition. Second, the depth of the rock scorings, their straightness and length, require a vast force to produce them. The immense amount of débris that has been fractured or ground to rock flour or scratched and polished is the ample counterpart of the very great abrasion of the rock. No theories of the superior fluidity of ice under enormous pressures or under any other conditions can be allowed to obscure the fact that at the time the rocks were scored the stones that did the work were moving under great pressures and with wonderful steadiness of movement. The increase in plasticity, if such there was, was not sufficient to impair seriously the rigidity of the ice. If the stones that were ground

against the solid rock were held embedded in the ice, it was solid enough to deserve the name of ice. If they were rolled or dragged beneath it, only solid ice could furnish the necessary friction. No matter what theories we indulge as to basal melting or semifluidity under sufficient pressure, or as to the conditions prevailing at any given point when it was a place of deposition of stationary ground moraine, we must admit that over the area of erosion at any period in the history of the ice-sheet there was a body of ice beneath which, under the enormous pressure extended, terranes were turned to dust. The marks of this tremendous conflict are conspicuously shown by the lower till and not by the upper. Plainly they are what should be expected of material that has been beneath the ice.

Again, the deeper accumulations, such as the drumlins and the sublenticular sheets on the hillsides, have a rounded outline. Under the action of water waves a sand or gravel bar assumes the form most favorable to its stability, and a mass of débris ought to assume a corresponding form while ice flowed over it. The drumlins often show beautiful curves and billows, and the type of ground-moraine scenery is very different from that of moraines either of surface or englacial débris. The latter show more variety of form and gradient of slope and have a more or less heaped appearance.

It is perhaps now impossible for us to form an accurate picture of the relations of the englacial and subglacial morainal matter to each other and to the subjacent rock. We know that the englacial till is but little glaciated, and hence must have entered the ice before being rolled or dragged between the ice and the rock. We do not know in detail the manner of its entrance into the ice, though that must have occurred soon after the flow was established, or possibly even before the flow of consolidated ice began. We do not know the relation of this assumption of englacial matter to the history of the adjacent regions. We do not know certainly whether the stones and particles of the ground moraine were from the first and constantly beneath the ice, or whether each particle was at one time within the ice and was subsequently torn from its grasp, or whether both kinds of matter are now a part of the subglacial till, though there is a strong probability that the last-stated hypothesis is the true one. How much of the ground moraine was stationary during the time of the accumulation? We do not know the height in the ice attained by the englacial débris, nor its vertical and horizontal distribution. In a general way we know that it got

into the ice before it had been much overridden and glaciated; that the region of chief deposition of the subglacial till was near the front of the ice-sheet, where the ice was thinner; that back of this region there was another zone, perhaps found not very far below the distal margin of the névé, where pressure and velocity of motion united to produce great erosion of the rock and transportation of subglacial débris, while under the névé transportation was less active, whether because of the depth, or the structural condition of the snow and ice, or other causes, is unknown. But while the details are thus uncertain, the fact of the existence of the ground moraine is satisfactorily established.

In the foregoing discussion it has been assumed that the ground moraine was wholly formed between the ice and the rock, and that the flowing outlines of accumulations were carved by the ice flowing over them. There is a possible alternative theory that perhaps ought to be noticed. No matter whether we consider the flow of the ice as plastic or viscous, we can conceive of a mass whose internal friction is so great—forming, as it were, a mass of till infiltrated with films and threads of ice—that it could remain embayed while the purer ice flowed over or around it. Such an embayed mass (half-till, half-ice) would be carved into the lenticular form as the glacier flowed over it, just as if it were a mass of true subglacial moraine.

In reply to this it may be said that if débris scattered through the lower part of the ice were reached by heat rays from the sun or other source of heat external to itself it would absorb the heat and, by melting the ice in contact with it, might increase the fluency (or plasticity) even more than the friction of the stones diminished it. Certain bowlders in the Alps have been supposed to rise upward in the ice in consequence of the absorption of solar heat by their upper surfaces.[1] The instances where thin glaciers have been observed to flow over bowlders without pushing them

[1] It has been contended that rocks warmed from above naturally rise in the ice. This is doubtful as a general proposition. The ice melts with contraction of volume, leaving a small cavity above the water. Molecular heat could then no longer produce melting except where the ice was in contact with the water. The upward melting could proceed from radiant heat alone, while the radiant molecular heat communicated to the water would be largely transferred to the bottom of the cavity, the water of 39° seeking the bottom. Whether as a net result the melting would be most rapid upward or downward would depend on the size of the fragments, their shape, etc. If it be contended that the ice from beneath would push the stone upward fast enough to fill the cavity of melting, we must demand the proof of such action against the force of gravity. This note applies only to the supposed rising of débris in the ice owing to heat from above. Whether vertical ice movements could raise the débris is a very different question.

forward (Niles[1] and Spencer[2]), also over sand and gravel without disturbing the stratification (Chamberlin[3]), may be due in part to radiant heat absorbed by the bowlders or communicated directly to the ice. It is uncertain to what depth solar heat penetrates the ice, yet during the decay of the ice-sheet a time must have come when the sun could penetrate the thin ice to the moraine stuff scattered through it.

In attempting to sum up this controversy I find too much hypothesis and too little fact. It is important to study in the field, if possible, the effect of a large amount of englacial matter on the rate of flow. In the present state of the case it must be considered doubtful if any large accumulations of till have been made in this way. If there were such masses of ice embayed because of the contained till, the till would be upper rather than lower till, or at least a transition between them. The matter of the lenticular hills has been thoroughly glaciated, and it remains to be proved that the mutual friction of till fragments in a mass of partially stagnant ice could simulate the greater attrition which must inevitably mark those which have been ground against the solid rock or against each other at the bottom of the ice.

Some other questions demand attention.

DRUMLINS.

1. Were the drumlins accumulated at the ice front during the retreat of the ice at unequal rates, so that they are a form of terminal moraine? It can be confidently answered that their shapes and materials are wholly unlike those of the terminal moraines of Maine.

2. During the final melting of the ice the surface would melt unequally, since the larger bowlders and deeper masses of till would partially protect the ice beneath them from melting. There would be much lateral sliding of till into the depressions thus formed on the surface, as seen by Prof. G. F. Wright on the Muir glacier of Alaska, and this process would originate trains of bowlders, and ridges and mounds of various

[1] Upon the relative agency of glaciers and subglacial streams in the erosion of valleys, Am. Jour. Sci., 3d series, vol. 16, pp. 366–370, 1878.

[2] Notes on the erosive power of glaciers as seen in Norway, Geol. Mag., new ser., Dec. III, vol. 4, pp. 167–173, 1887.

[3] Observations on the recent glacial drift of the Alps, Trans. Wisconsin Acad. Sci., Arts, and Letters, vol. 5, pp. 258–270, 1877–81.

shapes, and they would be composed of upper till, not the intensely glaciated lower till, unless first eroded and then rebuilt by the glacier. It is difficult to conceive how smoothly rounded hills in such large numbers and of such great size could result from this process. Moreover, some of the masses of thoroughly glaciated matter are long ridges parallel with the glaciation. These are still more difficult of explanation as being due to accumulations in surface hollows of the ice. Osars or sandy ridges would result, not masses of till containing much rock flour.

3. Are the deep masses of till remains of a former sheet of till of which the greater part has been eroded by the sea waves, as suggested by Prof. N. S. Shaler?[1] This can not have been the case in Maine, for the following reasons:

First. These deep masses of till are sometimes 1 mile or more from any other similar mass. The amount of erosion required is enormous.

Second. The presence of continuous beaches from high level down to the sea, shown on Monhegan Island and other exposed coasts, proves that if great masses of till had been eroded most of the larger stones would now remain as broad sheets in the valleys or as terraces on the hillsides. On the other hand, the beach gravels of Maine are relatively scanty and bear no relation to the positions of the drumlins.

Third. The coast region, where the lenticular hills are most numerous, is largely covered by marine sands and clays. If the till was eroded in the manner supposed, the erosion must have occurred before the deposition of these marine beds. These beds would preserve the beach gravels beneath them from erosion. No such rolled gravels now exist beneath the clays.

Fourth. If we suppose that there has been such an erosion of the till, we must account for the fact that the kames and marine deltas deposited in the sea by the glacial rivers have escaped in such good state of preservation.

Fifth. The lenticular sheets of till on the northern slopes of hills must have substantially the same origin as the drumlins themselves. They lie inclined against the hills and reach upward on the slopes for several hundred feet. The erosion required to carve away the surrounding portions of a former deep sheet of till to such great heights must certainly have left its mark. Yet there are multitudes of these hillside lenses in regions

[1] Illustrations of the earth's surface: Glaciers, by Shaler and Davis, p. 63, Boston, James R. Osgood & Co., 1881, 4°.

where all the vigilance of road overseers and selectmen exercised for years has not succeeded in finding a wagon load of genuine water-washed gravel.

4. Are the drumlins remains of a former sheet of till irregularly eroded by the glacier? I do not know how a glacier can deposit till and not at the same time also deposit glacial gravel. Glacial streams are inseparable from a glacier. The work of the latest ice-sheet is a fair sample of what former ice-sheets did, differing only as they have differed in size or time of continuance. Now the latest Ice period has left hundreds of square miles covered with well-rounded stones and bowlders distributed over a large part of this State, as well as of New England generally. If at any future time Maine is again glaciated, those rounded stones will be incorporated in the till or pushed bodily out into the Gulf of Maine, being more or less changed in shape during the process, but still being quite different in form from angular stones of fracture. It is possible to conceive of glaciation so severe as to remove all the glacial gravels from Maine into the sea, but farther west, where the outer terminal moraines are deposited on the land, the water-rounded stones of the last ice-sheet would appear in the moraines. If any one claims that the lenticular hills are remains of the till of a former Ice period that failed to be eroded by the latest invasion of the ice, on him rests the burden of proving that the till and terminal moraines of southern New England contain a sufficient number of once rounded stones and bowlders to account for the glacial gravels of such supposed more ancient ice-sheet and which the later ice incorporated into its own deposits. Of course it is assumed that if a sheet of till can be eroded by ice, masses of sediments would sooner be eroded. For the present the theory under examination can not be insisted on.

RELATION TO MARINE GRAVELS.

The relation of the lower till to the beach gravel deserves notice in this connection.

A good place for study of the subject is at Matinicus Island. A lenticular mass of till 10 to 50 feet deep covers the western portion of the island, as is proved by the cliff of erosion at the present beach and by wells. The till is everywhere covered by a few feet of beach gravel. The till is very fine in composition, is very compact and intensely glaciated, has a dark-blue color, and is typical lower till, very different from the matter of

the Waldoboro moraine. At the time the sea stood at its highest level the water would be about 150 feet deep over the top of the island. Here then is a good place to observe the effect of the sea waves on the ice and its contained till as the ice front retreated northward. If this lenticular mass of till was contained in an embayed mass of ice rendered viscous by the amount of solid matter distributed through it, or if it was cast out at the ice front as any kind of frontal moraine, then we ought to find the till more or less assorted by water unless the ice had melted with extraordinary quietness before the elevation of the sea. A multitude of facts furnished both by the terminal moraines and by the deltas deposited by glacial rivers in the sea, as well as by the valley drift of the river valleys, point to the conclusion that the sea stood at high level during all the later part of glacial time. On Munjoy Hill, Portland, are a number of small irregular masses of sand, filling pockets in the clayey till. They are found only near the surface. In the lower part of the deep masses of till I have found no water-classified matter. The presence of signs of water, either glacial streams or marine waves, in the upper portion of the till only makes their absence in the lower till still more suggestive.

The relations of the beach gravels to the deep masses of till are not only perfectly consistent with the subglacial origin of the lower till, but distinctly favor this hypothesis.

On the whole, we may affirm that whether we regard the composition of the lowest portion of till, or its relations to the terminal moraines or to the glacial gravels on the marine deposits, all find their simplest explanation in the hypothesis of a ground moraine.

It is not asserted that a ground moraine covered all of Maine. It is well known that many places are bare of till where there has been no erosion by the sea or streams. There are places where probably only subglacial till is present, and others where the till was all englacial, or nearly so. Neither is the line of demarcation between these two deposits always sharply defined. Indeed, they graduate one into the other so as often to render it difficult to make out the line of separation. Probably the lower the point in the ice where morainal fragments occurred, the more glaciated they would be—a sufficient cause of gradations in glaciation between the upper and the lower till.

BOWLDER FIELDS AND TRAINS.

Many details as to the till are here omitted, as not bearing on the subject of the glacial gravels. One phenomenon must, however, be noted—the bowlder fields. In a certain sense the whole of the granitic regions might be considered as bowlder fields. But the fields referred to are different. They lie in regions of coarse slates. The whole surface is so covered by slabs, up to 6 or 8 feet long, that one can travel a half mile by stepping from bowlder to bowlder. The only soil is found 2 to 5 feet below the surface. The babbling of invisible streams is heard as they make their way among the bowlders. Raspberry bushes peer up through the rifts between them. One of these bowlder fields is found about a mile south of Tomah station of the Maine Central Railroad. This is situated near the junction of two large glacial rivers, and the finer parts of the till may have been washed away by the waters. I observed a still larger bowlder field in T. 7, R. 4, Aroostook County. It is situated 2 miles from any known osar, and its cause is obscure.

In the wilderness between Aurora and Deblois a train of huge granite bowlders, which is parallel with the glacial scratches of the region, is intersected obliquely by the Katahdin osar. The bowlders are piled one above another so as to form a ridge, and some of them overlie the gravel. The bowlder trains bear a relation to outcrops of granite rocks, but are not lateral to valleys. The appearances indicate that they were not medial or lateral surface moraines, but either distinctly subglacial or stranded basal matter, so that in their ridge-like development they are drumlins of coarser material than the ordinary.

WAS THERE MORE THAN ONE GLACIATION OF MAINE?

The observations of White, Winchell, Upham, Chamberlin, Salisbury, McGee, and others in the Upper Mississippi Valley prove that there were at least two principal advances of the ice, separated by a rather long interval. It has since been a special object of search to Eastern geologists to find similar advances in the Northeast. At one time it appeared probable that I had found traces of two tills that might belong to different periods. The dam of the Penobscot River where it flows out of South Twin Lake had broken a short time before my visit to the place. The water had escaped

around the end of the wooden part of the dam and eroded a channel in the earth, thus affording a fresh section down to the solid rock. At the bottom were several feet of a hard, tough, clayey till that resisted erosion wonderfully and broke up into blocks 2 to 3 feet in diameter.

Above this was a lighter-colored and less compact till forming a north-and-south ridge or elongated drumlin. The material was indistinctly arranged in layers, yet was not an osar composed of water-transported matter, but was true unmodified till. The great contrast between the tough under stratum and the more siliceous overlying layer made me suspect that here were the ground moraines of two different ice-sheets. Subsequent observations in many parts of the State have convinced me that this phenomenon, which is a very common one, is probably due to the overlap of till derived from two different kinds of rock. Thus at South Twin Lake the local rocks are slates and other fine-grained schists. The lowest (blue) stratum of the till is derived from the local rocks, while the overlying ridge (also a part of the ground moraine) is composed of matter transported from the granitic region about Mount Katahdin, situated not far to the north. This overlapping of till having different characters is found wherever the ice passed from one kind of rock into an area of another kind. We do not need to postulate two glacial periods in order to account for it, although that is certainly possible. It is just what should be expected in the case of an ice-sheet moving over areas of different kinds of rock, provided the ground moraine was not all formed simultaneously, but each region was first an area of denudation and subsequently of accumulation. During the first period of denudation the scratching was produced. The first of the embayed ground moraine would be composed chiefly of local matter, which would subsequently be overlain with far-traveled matter.

All parts of the State have been examined without finding peats or soils within the till, or anything indicating an interglacial period in Maine.

The relation of the marine clays to the till deserves special study. I could find no fresh exposures showing the relations of the Waldoboro moraine to the marine clay. On the surface the clay overlay the moraine, but the base was not seen. At Sabatis Village the marine clays also overlay the terminal moraine, to a depth of 8 feet, but the base of the moraine was not exposed. It is thus uncertain whether at the base the terminal moraines cover the marine clays or not.

Since 1861 Prof. C. H. Hitchcock has repeatedly expressed the belief that two advances of the ice are proved by the relations of the upper till to the fossiliferous marine clays at Portland.[1] The same opinion has been expressed in the geological reports of New Hampshire. Professor Hitchcock's latest conclusions are contained in his report as a member of the American Committee of the International Congress of Geologists:[2]

* * * Very clear evidence of the relations of the fossiliferous beds to both tills is found at Portland, Maine. Here clays and sands rise about 100 feet above the sea and hold 121 species of organisms, all of living forms. They rest upon typical lower till, and are overlain by as much as 50 feet thickness of upper till. At the time the reporter described these facts the prevalent doctrine of the triple nature of the glacial period had not been established; but it seems clear that two seasons of ice presence are indicated at this locality. * * *

The meaning of the terms "interglacial," as well as "upper" and "lower" till, must be made definite when used in this connection. The use of the term interglacial as of world-wide application can not be warranted until the facts are all in; for the present it can only be admitted to express the facts in particular regions explored, e. g., the Mississippi Valley, large parts of Europe, etc. At the great terminal moraines there may have been many advances and retreats of the ice, and one studying the till there might come to the conclusion that there had been many glacial and interglacial periods, and so there would have been at his place of study and from his standpoint; yet all these advances of the ice might be comprised within what another would consider as a single invasion of the ice, mere minor accidents of a larger movement. So, too, the term "upper" till may mean englacial till, or, where there are tills deposited during two distinct advances of the ice separated by a warmer climate, it may mean the later of these tills. The use of the term by Professor Hitchcock in connection with the reference to the triple nature of the Glacial period seems to indicate that he considers the two seasons of ice presence at Portland as the correlative of the two glacial epochs of the interior.

Let us review the points brought out by Professor Hitchcock:

1. The locality cited is situated at the western end of Portland, where there have been extensive landslips, and it is difficult to determine what was the original order of deposition. The proof of so important an event as an

[1] Thus, in the Preliminary Report upon the Natural History and Geology of the State of Maine, 1861, p. 275: "We have recently noticed that in Portland these clays underlie a coarse deposit, which has always been referred to the unmodified drift," etc.

[2] Am. Geol., vol. 2, p. 302.

interglacial period ought to rest in observations made in more places than one, and in places where there can be no suspicion of landslips.

2. I have examined the place since reading Professor Hitchcock's publications, also after he has kindly written me descriptions. Near the same locality Dr. William Wood and Mr. C. B. Fuller, of the Portland Society of Natural History, have recently exhumed a skeleton of a walrus in sandy clays. I have examined several excavations in that vicinity (all that are now open), and can not be sure that I have seen the exposures referred to by Professor Hitchcock. I have found masses of rounded cobbles and bowlderets overlying the fossiliferous marine beds, also small masses of more till-like appearance. Both were in material that had slipped down from the hill above; but not to insist on this, let it be assumed that both kinds of deposit can there be found overlying the marine beds in situ.

If the "upper till" referred to by Professor Hitchcock is composed of the rounded gravel and bowlderets, we have a case here of transportation by water as well as by ice. The great glacial river which reached from the upper Androscoggin Lakes to Portland could transport bowlderets beyond the front of the ice into the sea, especially in the time of summer floods. It is a possible interpretation that the ice was confronting the sea, and if so it might often happen that matter brought down by glacial rivers would be dropped on marine beds previously laid down. The presence of such water-rounded matter is not of itself a proof of a readvance of the ice over the fossiliferous clays.

But if this "upper till" was transported not by water, but by ice, we have at Portland substantially the same problem as the supposed one at the Waldoboro moraine overlying the marine clay. The problem is to determine whether here are two presences of the ice such as warrant the correlation of the Maine deposits with those of the Interior.

3. During the latest glacial period in the Northwest there were deposited the great kettle moraine and broad sheets of morainal drift (up to a breadth of several hundred miles), varying in depth up to 400 or 500 feet or more. The amount of till overlying a supposed interglacial clay at Portland, and perhaps at Waldoboro, is inconsiderable compared with the great sheets and moraines of the Northwest. We can not correlate them unless it can be proved that in Maine the ice carried less morainal matter, so that smaller moraines represent a greater relative time of deposition.

4. The glaciation of the country south of the Waldoboro moraine differs in no respect that I can discover from that of the country north of it, and the same is true of Portland. There is no sign of the subaerial erosion that would result if the ice only advanced to these places after a retreat at all comparable in time to the interglacial epoch of the West, supposing the land to have been above the sea. On the other hand, if it was beneath the sea during all or even a part of the interglacial period, we ought to find a different development of the marine beds south of those places (the supposed line of ice front during the second advance of the ice) from that north of this line. I do not recognize any difference except the general change we discover everywhere as we go to greater elevations up to 230 feet.

5. If the supposed readvance of the ice at Portland over marine beds is correlative to the second glacial advance over the Northwest, we ought to find everywhere along the coast a series of terminal moraines or morainal sheets overlying the marine beds. Only a few places have been found where this can be admitted as even remotely probable. The few scattered bowlders in the marine clays can better be accounted for as due to ice floes and small bergs.

6. Existing glaciers are known to advance and retreat alternately, or for a time remain stationary. Analogy requires us to postulate similar behavior of the great ice-sheet. It is not necessary to correlate the time of such temporary halts of the extremity of the ice, or of its readvances, with the interglacial period of the Northwest. They may have been only for a few years at most; not a geological epoch. The small terminal moraines and supposed readvances of the ice in Maine correspond generically to the smaller retreatal moraines of southern New England and the Northwest. At the time of their formation the doom of the last ice-sheet had been pronounced. The algebraic sum of the secular accumulation and waste of ice had the minus sign, though particular elements might be plus.

7. It is granted that a thin body of ice might advance over marine sediments without eroding them, just as happened with the soils of the Upper Mississippi Valley. But if the flow were to continue long enough to equal the second advance of ice over the Northwest, a considerable body of till, both subglacial and englacial, ought to be left overlying the clays. The finding of only small masses of till or a thin sheet of scattered bowl-

ders may mark an advance of thin ice, but only a temporary one. If there shall be found in Maine unmistakable subglacial till in situ overlying the marine clays, it will indicate a much longer period of advance than any interpretation now allowable.

8. If the sea rose while the ice still remained, so that the waves beat upon a shore of ice, pieces of ice would from time to time be detached, partly as floating bergs, but in case of ice containing englacial matter it might often happen that the pieces would not float because of the morainal matter contained, and when the ice melted such fragments would form a deposit similar to true glacial-transported till. Such might often be lodged in the marine beds or glacial gravels. I have not sufficient facts to discuss the hypothesis at present, yet this question must be considered before the significance of small till masses on or in marine sediments can be regarded as definitely determined.

The floating bergs would naturally drop fragments upon the sea bottom, and perhaps sometimes quite deep masses. These deposits must be distinguished from matter brought to the place of deposition by glacier ice.

9. It is agreed that the fossiliferous sands and clays of Portland overlie a fine blue clayey till, apparently subglacial. But on the upper slopes of the hills I found fossiliferous sand overlying glacial gravel. This I regard as beach sand and gravel, composed of the material washed down from the top of the hill by the waves of the sea. Glacial sand and gravel were originally deposited on the tops of the hills. Part of this deposit and perhaps some till were subsequently eroded by the sea and strewn on the hillsides. The alternative hypothesis would be that the fossils grew in the sediments of the glacial streams as they were poured out from ice channels into the sea.

10. In determining whether in a given region there have been two ice periods, we have to compare the shapes of the stones of the till of the supposed two ages. As elsewhere noted, a system of glacial streams is inseparable from a glacier, and these waters leave a system of glacial sediments. If ice subsequently advanced, the rounded stones of this glacial gravel would either be overridden by the later glacier or be partly or wholly eroded and pushed forward by it, and in either case they would be found in either the earlier or later till, perhaps at the terminal moraines. They might be somewhat planed or modified in shape in the process, yet

where there were large numbers of them they could hardly fail to betray the fact that they were once rounded by water movements and were not fragments of fracture and cleavage. In Maine there are places near the White Mountains where I found till containing numerous water-rolled stones, but in general such matter is very small in amount as compared with what was once angular gravel or talus matter. I find in the till no adequate representation of the water-rounded stones of a more ancient glacier. In the terminal moraine near Waldoboro there are few it any such; none were observed.

11. The Waldoboro terminal moraine is 6 miles long, and is much larger than anything of the kind at Portland. So far as I have yet discovered, it does not prove a readvance of the ice, but can equally well be assumed to have been formed at the ice front during a pause in the retreat. There is still stronger reason for this conclusion in the case of the Portland deposits; yet if it shall be hereafter proved that there was an advance of the ice immediately preceding the time of the formation of this moraine, we still have the small size of these deposits to account for before correlating them with the great kettle moraine, or with a retreat and readvance of the ice for hundreds of miles, such as took place in the Northwest.

Summary.—Two lines of reasoning point toward two possible glaciations of Maine. The first is based upon the finding of two different layers of the till, possibly the till of two different ice periods. No sedimentary or fossiliferous beds have been found between them, and a better interpretation is that they are derived from two different kinds of rock—one local, the other from a distance. The second refers to the finding of till or glacial gravel overlying fossiliferous marine beds. It is certain that the marine beds in Maine overlie a stratum of till most or all of which was subglacial. They therefore were deposited late in the Ice period of that coast, when the ice had receded far back from its extreme limit. Waiving all doubts as to the Portland beds having been caused by landslips, and assuming the most favorable construction, i. e., that there are terminal moraines and other glacial deposits overlying marine sediments, we must consider the significance of this assumed fact. My interpretation of the facts is that there is no proof that these supposed advances of the ice were for any but very limited times and distances, as is proved by the small size of the deposits and the fact that the glaciation and development of the marine beds vary

but little when we study them north and south of these moraines. Local advances and retreats of the ice might be expected during the decay of the ice-sheet, but they are to be regarded as minor incidents of one Glacial period rather than distinct periods worthy of a place in geological chronology. The moraines that correspond to the outer terminal moraines of the second ice-sheet of the Northwest are to be sought for in the Gulf of Maine, not along the present coast. The so-called interglacial period of the Northwest was longer than the intervals between the retreats and readvances of the ice in Maine, so far as the known facts warrant conclusions.

The significance and explanation of the fact, if such it be, that there was but one glaciation are left for future investigation.

GLACIAL SEDIMENTS.

Under the term "till," as here used, is included all matter transported to its present position by glacier ice. The term "glacial sediments" denotes all matter transported to its present position by streams of water from the melting ice. No doubt ice movements contributed to the transportation of kame matter. Yet clearly we have in case of the glacial sediments a form of transportation that the till did not undergo. While the till is glacier drift simply, the former are glacial drift plus water drift.

RELATION OF WATER TO THE GLACIER.

Energy reaches the glacier in various forms. Radiant energy comes to it from the sun and other bodies. Part is reflected, part is radiated and lost, and part is absorbed, which is but another way of saying that it is transmuted into molecular motion and is expended in doing work within the ice, such as melting it, raising its temperature, or aiding its flow. Molecular heat is communicated to the ice from surrounding bodies and performs the same kinds of work as radiant energy. Most of the radiant heat comes from the sun, most of the molecular heat from the air and the summer rains or from the earth beneath the ice. The chief sources of heat act from above, and there the most of the melting and other direct action of heat takes place. The glacier is one form of heat engine. From the time that heat aids in cementing the separate snow crystals into clear blue ice up to the time that it resolves the ice back again into granules and

crystals and melts them, heat is inseparably connected with all the work of the glacier. Water is the heat transport of this heat engine. The waters derived from the melting ice flow along the surface or gather in pools until they find a crevasse down which they can escape. In passing from the surface to the bottom of the ice they carry heat with them. The phenomena of both subglacial and superglacial streams are largely determined by the behavior of water with respect to radiant and molecular heat. The most important of these relations are the following:

1. Water is a poor conductor of molecular heat, but a good absorber of radiant energy.

2. Water, like all fluids, readily transmits and distributes molecular heat by means of the convection currents so easily set in motion within it.

3. The temperature of water at its greatest density is 39.1° F.

4. The temperature both of melting ice and of freezing water (under ordinary conditions) is 32° F.

5. The specific heat of water is very great.

As a result of these properties of water, we have water above and below the ice, and perhaps in some cases distributed everywhere through it The glacial streams erode their banks and walls in a manner peculiarly their own. Water is employed in the hydration of the clay which is formed beneath the glacier. Glaciers have their drainage systems as truly as does the land, and no other form of stream erosion is so complex. In a word, we can not conceive of a glacier without its system of waters. The glacial sediments are as important a matter of investigation as glaciated stones themselves, if we are to detect former glacial periods.

SIZES OF THE GLACIAL RIVERS OF MAINE.

Many considerations prove that the precipitation over a large part of North America was very great during glacial times. The occurrence of Lakes Bonneville and Lahontan in the Great Basin and the observations of Professor Whitney in California unite with the facts as observed in many other parts of the country to establish the general conclusion.

Mr. Walter Wells, in his report on the water power of Maine,[1] pointed out many circumstances favorable to a large average precipitation in the

[1] Provisional Report upon the Water Power of Maine, by Walter Wells, Secretary of the Hydrographic Survey, Augusta, 327 pp., 1868, 8°.

State He computed the annual discharge of the present rivers of Maine at 1,229,200,000,000 cubic feet, or 3,368,000,000 cubic feet daily. This represents a precipitation of about 3½ feet per annum.

Obviously in glacial times that portion of Maine which was within the area of accumulation or névé had less water discharge than the precipitation, the surplus being pushed forward as flowing ice into the zone of melting. The position of the névé line would determine the ratio, at any given time, of water discharge to the total precipitation over the area now under consideration. The location of the névé line during the time of thickest ice is uncertain. The glaciation of the islands off the coast proves that at one time the ice advanced out into the Gulf of Maine. Later, at a time when the ice had retreated before the rising sea nearly or quite to its coast, great glacial rivers were pouring into the sea and were depositing in open tide water the largest marine deltas in the State. Here and there we find marine deltas south of this line, proving that the glacial rivers had previously to this time been pouring into the sea at various points in the course of the retreat of the ice. At the time the ice front had receded as far north as the present coast line the whole coast region of Maine to a breadth of 100 miles must have been in the zone of wastage, and either at this time or later the whole State was in this zone.

The melting of the great body of ice that covered the land and was continually renewed by flow from the north would of itself give a large melting-water discharge over the zone of wastage. To this must be added the precipitation over the zone itself. During part, perhaps all, of the period after the ice had retreated to the present coast line, the land stood at less elevation in Maine than at present. This would tend to lessen the precipitation, but only in small degree. On the other hand, during a part, at least, of this period the sea advanced so far up the St. Lawrence and Champlain valleys that New England was a peninsula or island unusually accessible to moisture from the ocean.

Whether we look, then, at the great quantity of the glacial gravels, or at the large size of the stones and bowlders transported, or at the broad plains of valley drift which were often deposited while ice still lingered to the northward, or at the local geographical conditions, or at the climate prevailing at or about this time in various parts of the country, we find that everywhere the field phenomena require a large supply of water. The

precipitation here near the sea must have been large, even if diminished from what it had been during the time of maximum glaciation.

For these and other reasons we postulate a larger water discharge in Maine in late glacial times than the present. The glacial rivers exceeded the present rivers in number and had correspondingly smaller drainage basins. This tended to diminish the size of the individual rivers, yet some of them have left level plains one-eighth to one-half mile wide, and appear to have equaled or surpassed the discharge of the larger rivers of the present time.

ZONES OF THE MAINE ICE-SHEET.

According to the accounts of the explorers named above, the interior of Greenland is covered with snow fields. At the highest elevations if there is any melting it is limited, since Nordenskjold's Laps found the surface dry and powdery. At lower elevations the melting becomes more abundant and the surface waters slowly ooze through a zone of slush. Then we find pits filled with water, and, by degrees, the waters uniting to form surface streams. Some of these have been traced for several miles and are from 4 to 10 feet wide. Still descending, we find crevasses appearing, sometimes near the nunataks, at other times where none are visible but where the ice is probably flowing over a buried ridge. Into the crevasses the surface streams pour and disappear, escaping as subglacial or englacial streams. Sometimes they pour with a loud roar into small lakes within the ice. Some of the crevasses are very wide as well as deep, one observed by Lieutenant Peary being 50 feet wide. As we approach the outer margin the surface becomes indescribably rough with blocks, hummocks, and ridges. Here the water derived from surface melting need flow only a few feet or rods before plunging into the depths.

These observations give us a general conception of an ice-sheet with respect to its waters of surface melting. Over all the region broken by crevasses we have an elaborate system of subglacial and englacial streams which receive the waters of the short surface streamlets. Above this zone is another, of superficial streams, then the area where the snow absorbs all the water of surface melting, which becomes progressively less as we go upward.

Applying these principles to Maine, we note that the average slope of the land southward is only from 3 to 10 feet per mile, much less than is

found in much of Greenland. This would favor a low surface gradient of the ice-sheet. The slope being southward would favor a higher gradient. It is probable that on a uniform slope the gradient is chiefly determined by the ratio between snow precipitation and waste. During the advance and retreat of an ice-sheet over transverse hills and valleys the surface gradient must often change with some corresponding change in the positions of the crevasses and in the boundaries of the zones of superficial and subglacial waters.

The ice flowed over Mount Desert Island to an unknown depth. From there to Mount Katahdin the distance is approximately 110 miles, and they are nearly in the same lines of glacial motion. Prof. C. H. Hitchcock, in his report on the geology of Maine, estimated that the top of Mount Katahdin rose above the ice surface. I visited the mountain in 1870 and found fossiliferous drift fragments to within a few hundred feet of the summit, just as Professor Hitchcock did, but there has been so much surface weathering and sliding toward the top that drift débris would long since have disappeared, even if it had once been there. However, without insisting on the doubt, if we assume the highest limit of the ice at 4,500 feet at Katahdin and 1,500 feet at Green Mountain, Mount Desert, we have a surface gradient of 27 feet per mile. If the gradient was as moderate as this, or near it, we have reason to estimate the zone of subglacial waters as pretty broad.

The western part of Maine must have been overflowed by the ice from the St. Lawrence Valley and Hudson Bay. How far east this northern ice overflowed Maine is at present uncertain. Without assuming the correctness of Mr. Chalmers's hypothesis of a divergent flow in eastern Quebec and New Brunswick as applying to Maine, we must at least consider it a possibility. Obviously the breadth of the zone of subglacial waters of an ice-sheet fed from the far North will be much greater than of a local ice-sheet covering the peninsula south of the lower river and Gulf of St. Lawrence. Until the doubt as to the condition of northeastern Maine is removed it will be unsafe to attempt an estimate of the position of the névé line at any stage of the glaciation.

ENGLACIAL STREAMS.

Recent observations of the Alaskan glaciers warrant the belief that englacial streams are sometimes of geological importance, or perhaps it might be better stated that the englacial portions of streams that are subglacial or superglacial for the rest of their course have helped in the development of the glacial sediments.[1]

It is evident that any conditions that prevent the formation of crevasses in the lower part of the ice will hinder, if not prevent, the formation of subglacial tunnels, at least as conduits for waters of surface melting. Where crevasses reach only part of the distance down to the bottom of the ice, the superficial water would often form an englacial channel along the bottom of the crevasses. The collapse or blocking of a subglacial tunnel would cause the water to rise and escape superglacially, or in case of crevasses it would form a new channel either at the bottom of the ice or above it englacially. In a shrinking glacier the melting of the ice forming the roof of an englacial tunnel would leave it as a superglacial stream. The stream reported by Russell as rising on the Lucia glacier where it flows past a nunatak would appear to have formerly had an englacial channel at this place, now become superficial by melting. The situation suggests that the course of glacial rivers in such relations may have been determined by the fact that the ice of the deep valley at the sides of the nunatak was so compressed laterally as it parted and flowed around the hill that the basal ice was little broken by crevasses. Crevasses would naturally form over the top or higher flanks of the hill, but would not reach below some point on the hillside. These shallow crevasses were utilized by the stream as part of its channel.

Englacial streams and channels of the ice-sheet may have performed two different offices.

First, they may have amassed glacial sediments directly from the ice. Whether we consider them of importance as gatherers of glacial sediments will largely depend on our conception of the distribution of the débris in the ice. The only way such streams could directly collect glacial sediments would be by melting the ice around the débris and transporting it. The

[1] Prof. I. C. Russell, Nat. Geog. Mag., vol. 3, pp. 106, 107, May, 1891. Am. Jour. Sci., 3d series, vol. 43, p. 180, March, 1892. Also Prof. G. F. Wright, Ice Age in North America, p. 63, 1889.

higher the englacial débris rose in the ice the more would the superficial and englacial streams be able to collect. Those who believe the englacial matter to have been strictly basal will not admit that either class of streams would be able to gather much sediment until their beds sank nearly to the ground.

Second, the englacial channels were often simple conduits for streams otherwise subglacial. As such, their mission may have been simply to protect the ground moraine from erosion, or glacial gravels may have been deposited in them. In the last case the stratification of the sediments would be generally obliterated by the melting of the subjacent ice.

In Maine I have discovered numerous places in the line of long glacial rivers where the ground moraine is less eroded than in the case of some of the short hillside eskers, as, for instance, at The Notch, in Garland. Both to the north and south the stratification, etc., are consistent with the hypothesis that these were subglacial rivers through most of their course. How can we account for so little erosion of the ground moraine? At one time I considered these places strong evidence that the osar rivers were superficial as a whole, but it must now be admitted that they may imply only an englacial or superficial course of a subglacial river for a short portion of its length. Thus in the jaws of the narrow pass of The Notch, Garland, the basal ice may have been so solid that for a mile or more a subglacial river was forced to rise into or on the ice. In 1888 I suggested that such accidents might not be uncommon, but without observational basis for the idea. Without insisting on close analogies between the Alaskan glaciers and the ice-sheet, we must at least consider englacial streams as one of the forms of a glacial water action, and probably an important one.

DIRECTIONS OF SUBGLACIAL AND ENGLACIAL STREAMS UNDER EXISTING GLACIERS.

The recorded observations bearing on this subject are too few to permit generalization. The courses of only a few of the subglacial rivers are more than approximately known. At the terminal enlargement of the glacier of the Rhone, the courses of the subglacial streams have been mapped, and it is known that some of them flow transversely to the direction of ice flow. But this takes place longitudinally and where the

water would find unusual facilities for flowing in almost any direction by zigzagging along crevases. We can not therefore consider this case typical of the behavior of the subglacial waters under thicker and less broken glaciers.

We know that the subglacial streams of ordinary valley glaciers must flow approximately parallel to the ice, for the very obvious reason that they are confined between the sides of the valleys and can not wander out of them. But such a statement adds nothing to our knowledge of glacial conditions and can not satisfy us. We wish to know more of the laws that govern the formation and maintenance of subglacial channels. For instance, in the case of glaciers flowing in meandering valleys, it is well known that the line of swiftest ice flow is a curve more crooked than the axis of the glacier. Are there conditions under which a corresponding deflection of the subglacial rivers takes place along the lines of swiftest motion, or do they follow a less crooked course than the axis of the glacier? This and many similar questions need to be answered observationally before we can understand the drainage systems of existing glaciers, still less of extinct ice-sheets.

We may form two very different conceptions of the relation of the ice of the glacier to its waters.

First, we may consider the ice as static, like the stationary land. The waters falling on the earth cut into it valleys and canyons, as do the superficial streams on the ice. They penetrate its pores and crevices, as glacial waters do the snow and ice. They enlarge the subterranean passages into watercourses like the subglacial and englacial channels, and in both land and glacier these internal channels often overflow on the surface as fountains. In short, the waters falling on the land, though often employing different forces, yet in the end achieve substantially the same results as the superficial waters of the glacier. But in all this the land is stationary; it is simply obstructive, holding back the water or modifying its flow by friction or direct pressure. So also glacial ice as static is nothing but an obstruction to its waters. But for the ice the waters would follow the drainage slopes of the land; whereas the ice, by simply standing in the way, often forces the water to follow crevasses or other channels along lines very different from the land slopes. In fact, on this conception the ice is simply regarded as a rock and its internal water system a part of the subterranean drainage.

But second, we may consider the ice of glaciers as in motion. While portions of the land are being upheaved the rising terranes are brought under the sharper rasp of swifter streams, the earth by its internal movements thus guiding the development of the erosion. In like manner we may view the glacier as in motion, a sort of organism having its internal motion so far determined by its environments that it has a systematic development, and each part of the ice must be considered not alone with respect to the forces now acting on it, but as having a history, and as often retaining the forms or structures it obtained long before. This is obviously true of the banded structure and other features visible on the surface, and ought equally to be true of unseen parts Thus if the basal ice is hollowed out by the water that falls down a crevasse at a moulin, the forward motion of the ice will cause each successive portion of the ice as it advances to that place to be also hollowed—the mechanical equivalent of a forward prolongation of a series of hollows that together make a tunnel but are subsequently modified by the tendency of the stream to enlarge the channel and of the antagonistic upward flow of the ice to cause its collapse. Now if the ice, having thus, so to speak, gotten the stream in its power, shall continue to carry it along the same tunnel prolonged by the ice movement, we must consider the ice as having more than obstructive power. By virtue of its motion it so exerts its obstructive power in the direction or along the line of its motion, that it can be said to have a constructive power to help build its own tunnels and determine their courses and development. The moving ice tends to the maintenance of all subglacial and englacial tunnels parallel to its flow, while the water with equal pertinacity strives to follow the slopes of the underlying land. When the movement pushes the tunneled ice over rising ground the water bides its time, and at the first eligible transverse crevasse it steals off sidewise toward the lower ground. The ice moves onward and prolongs the now unused tunnel until it becomes filled by subglacial till or disappears by the collapse of its sides and roof. On this conception the actual course of a subglacial or englacial river is the resultant of two forces which may or may not be antagonistic, viz, the movement prolonging the tunnel in its own direction, and the water tending to follow the slopes of the underlying land wherever practicable. In this discussion we assume the tunnels; we do not account for their origination.

It is a matter of observation that even small surface streams generally find no difficulty in flowing into crevasses and finding exit by subglacial or englacial channels, whereas waters flowing against the sides of glaciers are usually dammed by the ice until glacial lakes accumulate. One of the best known of such lakes is the Märjelen See in Switzerland, found where the Great Aletsch glacier flows past the mouth of a small lateral valley. The lake is about a mile long and one-fourth as wide, its longer axis being at right angles to the glacier. The water of the lake is warmed by the sun, and also receives the water of several small streams which, during several months of the year, have been warmed on land bare of ice. Many small icebergs fall from the glacier into the water and float about the lake. Obviously the water of 39° must sink to the bottom, below the reach of the smaller bergs, and it will slowly melt away the side of the glacier. The fall of the berglets is probably due to the melting of the ice beneath them. But although the side of the glacier is thus undermined as it flows past the lake, it is not melted away sufficiently to prolong a channel down the valley between the ice and the mountain. It is only after several years that, to use Lyell's language, owing to "changes in the internal structure of the glacier," "rents or crevasses in the ice open and give passage to the waters." The pressure is so great that the discharge takes place with a loud roaring rush of waters along the central parts of the glacier. That it is along the channel of a subglacial river is proved by the fact that toward the lower end of the glacier a great quantity of water spouts upward through the crevasses and escapes down the steep slope on the surface of the ice. It is evident that at the time of the discharge there is a large opening into the permanent waterways of the glacier, but for some reason the inflowing streams, though in summer warmed on land bare of ice, are not able to maintain the channel. It soon closes, perhaps by being pushed past the mouth of the lateral valley, and the lake is not able again to force an outlet till after the lapse of several years. In the Alps, in Alaska, and in most mountainous countries now glaciated, are many similar lakes formed in valleys lateral to glaciers, and the Parallel Roads of Glenroy, Scotland, and many similar raised beaches found in Sweden and Norway mark the sites of ancient but now extinct glacial lakes of this class.

The inference follows that streams flowing transversely against the sides of glaciers do not readily form subglacial outlets beneath them. The

exceptions to this rule are near the distal extremities of glaciers where the ice is much shattered.

Various physical causes can be assigned for the discharge of lateral glacial lakes. Thus in the course of climatic changes or cycles it may happen from time to time that crevasses open in new places, or they may open wider and extend farther than usual toward the side of the glacier, or there may be a larger supply of warm water in the lake to enable it to melt its way farther into the glacier till an opening is made into a crevasse connecting with a subglacial or englacial tunnel. So, too, by reason of its greater specific gravity the water tends to float the ice in contact with it, the buoyancy of the water being resisted not only by the weight of the ice next the lake, but also by all the ice cohering to it. Again, the pressure of the water is directly tending to rupture the ice. While these and other physical agencies are operative in the discharge of glacial lakes, obviously it is only by test and observation that we can determine the causes in any particular case.

While, then, the existence of so many lakes lateral to glaciers is proof that waters can not find basal passage under glaciers in all directions except under the most favorable conditions, yet the fact of occasional discharge beneath the ice can be cited in favor of the hypothesis that subglacial rivers can under some conditions flow transversely to the ice of even thick glaciers as well as the waters from glacial lakes.

While the conclusions that can at present be drawn from existing glaciers are rather meager and demand further investigation as to the courses of the internal streams, yet incidentally they fall in line with many other indications as to the streams of the ice-sheet. The osars of Maine are often for considerable distances more or less transverse to the existing glacial scratches, as well as to the bowlder trains and elongated drumlins, and therefore probably transverse to the direction of glacial motion. The known instances of the subglacial flow of water transversely to the ice flow, admitting the least allowable weight to analogies, indicate that the transverse direction of the osars can not be held incompatible with their having been subglacial.

INTERNAL TEMPERATURES OF ICE-SHEETS.

Surface rocks and soils experience great changes in temperatures, but as we descend into the earth we pass beyond the influence of the seasons and reach a point of invariable temperature. It has been computed that in temperate zones this point lies at an average depth of about 50 feet, varying greatly according to the local conditions. In far northern countries where there is little snow the earth is permanently frozen after we reach a depth of a few feet.

Without assuming the causes of the ice epoch we can at least assume practically Arctic conditions as then prevailing over the region overrun by the ice-sheet. It is important to know, if possible, what temperatures prevailed within that vast body of snow and ice. Was that 4,000 feet or more of ice a rock which, like other rocks, had beneath its surface a level of invariable temperature? If so, at what depths, and what was the temperature? Where did the isogeotherm of 32° lie in winter and in summer?

The only tests made of the temperature of glaciers have been made near their distal extremities, where both the ice and glacial waters are reported to have a nearly constant temperature of 32°. No observations appear to have been made of the interior temperatures of the névé, and we can arrive at only an approximate estimate by reasoning from some known facts. In such an investigation we have to depend chiefly on the following physical properties of water and ice:

1. Water has a very high specific heat.

2. Water and ice are poor conductors of molecular heat, especially ice in the form of snow.

3. Water freezes without change of temperature at the surface of freezing so long as any water remains unfrozen, the latent heat of liquidity being given up in the act of solidifying.

4. Ice melts with contraction of volume and without change of temperature at the surface of melting so long as any portion remains unmelted.

These properties account for the remarkable power the glacier has of regulating its own temperatures. The heat of summer or of the day first raises the mass to 32°, and then the surplus is expended in melting some of the ice, without change of temperature. In winter or at night the surface temperature of dry ice falls like that of other surface rocks, except that the

waste is probably slower, owing to its low conducting power and high specific heat. The point in the interior where we first reach an invariable temperature lies nearer the surface of ice than in other rocks. In addition to these properties which make changes of temperature of the ice mass take place slowly, the glacier has at its command another most important means of maintaining and regulating its temperature. It is known that there is a large amount of surface melting over much or all of the névé, and progressively more as we approach the distal extremity. A large amount of water is during the day and summer stored up in the snow of the névé and in that contained in crevasses; water is always found in the larger subglacial channels, often also in surface pools and crevasses without outlet beneath into the tunnels, and in internal cavities in the granulated ice near the surface. The moment the temperature at any wet place tends to fall below 32°, some of this water is frozen and the temperature maintained. The glacial waters thus serve an important purpose in storing up heat when there is an excess above 32° and in giving it out again when there is a deficiency. Those parts of glaciers at a distance from water must fall in temperature during the cold of night and of the winter, just like other rocks.

The net result is that the wet parts of the glacier, i. e., all the region of surface melting extending from the distal extremities well up into the névé, have the nearly constant temperature of 32°. In summer the isogeotherm of 32° rises to the top of the glacier in all this region, or rather, the isogeothermal stratum of 32° includes the whole glacier from the bottom to the top. In winter the upper limit of this stratum sinks beneath the surface an undetermined and varying distance.

As we go above the zone of wastage into that of accumulation it becomes uncertain what are the internal temperatures of the snow fields. The addition of new layers of snow is constantly pressing down into the interior of the mass the older layers, many of which would have had a temperature far below zero when covered, and must abstract a great amount of heat from the interior of the névé. The heat of summer could not directly penetrate dry granular snow so far as it could clear solid ice. Above the limit of appreciable surface melting it is doubtful if the heat that comes from above can pass in large quantity far down into the snow. Where the snowfall was very great during the intense cold of winter and at high elevations, it might happen that the heat of summer could not pass

down to the bottom of the previous winter's snow so as to raise it all to 32°. If so, this very cold snow, sinking down toward the ground beneath the pressure of later snows, would cause a temperature below 32° to prevail downward to some unknown depth, where the heat of the earth would just suffice to overcome it and cause a temperature of 32°. The isogeotherm of 32° might here lie not far above the ground, or even beneath it.

It has sometimes been assumed that because the surface portions of the highest parts of the névé were found dry and powdery there is no melting in that region. I am satisfied that inferences founded on observation of only the surface of snow are to be received with caution. I have seen several places in the Rocky Mountains where water of surface melting filtered down through the snow, leaving the surface dry and powdery and with no sign of surface melting, or with only a thin crust which the wind soon blew away. In one such case a drift about 20 feet deep had formed on the frozen ground. Soon after a warm wind melted considerable snow, and then followed two weeks of very cold weather, when the mercury stood at or below zero most of the time. The temperature of the air was still below the freezing point when an excavation accidentally revealed the fact that the lower part of the drift to a depth of 4 feet was moist and part of it was almost slush. No stream or spring was here and the earth beneath was frozen. It was evident that the moisture was due to water of surface melting that had seeped down through the snow, leaving no sign of its former presence to the eye of an unguarded observer. No limit can be set to the distance that water will pass into snow as into sand, provided it does not reach a stratum having a temperature below the freezing point.

Summary.—All those parts of glaciers where there is enough melting to furnish water and store more of it in summer than freezes in winter have the constant temperature of melting ice irrespective of season. Over all the zone of waste the glacier has the internal temperature of 32°, while the temperature of the dry surface ice varies with the seasons, but can never rise above 32°. Under this part of an ice-sheet the bottom of the ice is never frozen to the ground, but is bathed by at least a molecular film of water. The ground and the subglacial till are here unfrozen. As we go above into the area of accumulation the internal and basal temperatures are variable and uncertain.

BASAL WATERS OF ICE-SHEETS.

Ice-sheets covering all the land obviously receive beneath them no water from adjoining land bare of ice.

The waters found beneath ice-sheets are due to various causes, as follows:

1. Water of surface melting that has gotten beneath the ice through crevasses. This is by far the largest source of subglacial waters.

2. Basal melting due to the internal heat of the earth. This normally occurs under all the parts of the glacier and névé having a basal temperature of 32°. Assuming the correctness of Taine's estimate of the internal heat, the annual basal melting equals a stratum having a thickness of 0.36 inch covering an area equal to that of the ice. This might be modified by the circulation of subterranean waters.

The fact that the subglacial rivers continue to flow during the winter has sometimes been urged as a proof of basal melting. But it is known that in winter the larger crevasses become filled with a large amount of snow, even down to the distal extremity of the glacier. This snow partly melts, partly sinks into the depths, where it is only slowly consolidated to ice. So also in the zone of surface slush there is a large quantity of snow capable of holding water like a sponge. It is certain that there is a large amount of unconsolidated snow on all large glaciers or within their wounds that is saturated with water at the end of summer. These granular masses act, like the soils and other porous strata, as reservoirs to moderate the flow, and thus they hold back the water till long after surface melting has ceased for the season. Waters of springs issuing from the earth would continue to flow during the winter. We can thus account for large streams continuing to flow from glaciers during the winter irrespective of basal melting from the internal heat of the earth. Such melting in winter must be proved by other evidence than the mere presence of water beneath the glacier at that season.

3. Basal melting caused by friction of the ice against its bed.

In connection with the friction of the ice against the underlying rocks and till, we may also consider the friction of débris held in the ice against the bed or of one piece against another. When we consider the great amount of rock that was planed off beneath the ice-sheet and reduced to rock flour or broken into fragments, we must conclude that the doing of so great an

amount of mechanical work was inevitably accompanied by a considerable development of heat from friction. Its quantity would depend on many variables, such as the coefficient of friction of the ice against different kinds of rock, the pressure and rate of motion of the ice, the amount of englacial matter, etc. It is well known that beneath landslides and avalanches considerable frictional heat is developed. Whether the heat generated by the slower motion of the snow and ice will cause basal melting depends on the basal temperature of the mass. Where available for melting, heat from this cause might considerably augment the basal waters, but the quantity is unknown.

4. Basal melting due to heat transmitted from above through the ice.

Croll's theory of glacial motion seems to involve the hypothesis that heat can be transmitted from a particle of water to a particle of ice without a difference of temperature to act like the electromotive force to drive it. Without involving ourselves in dynamical questions, we can for the time consider the ice as static, and assume that the passage of molecular heat in it is from particle to particle by the process of conduction from where there is a higher to a lower temperature. It follows, since all the lower portions of glaciers have the temperature of 32°, that the heat contained in the ice can not, unless pressure changes the melting point, pass out of one part of the ice to produce melting of another part of the same body of ice. Omitting from the present discussion the questions involved in the varying melting point of ice under varying pressures, we are justified in the conclusion that molecular heat from the surface will be conducted downward until the temperature of all the mass is at 32°, and then no more can pass, for the tension, to use the electrical term, is then equally high in every part. But in the form of ether vibrations energy can penetrate the ice irrespective of temperature. The rougher and more granular condition of the ice near the surface indicates that most of the radiant heat is absorbed soon after passing into the ice—i. e., is converted into molecular heat and causes melting at a multitude of places. The reflections from the surfaces of these cavities containing water causes the opaque and granular appearance of surface ice. But it is well known that the words "transparent" and "opaque" are relative terms, referring only to visual rays, not to all the waves of ether energy. It seems probable that the rays capable of producing photographic effects on silver salts, and all the rays visual to the eye, are absorbed by water

and ice before reaching a depth of many hundred feet. But there are abyssal animals in the sea far below those depths, and they have eyes, proving that even at such great depths ether waves of low refrangibility are not absorbed by the water. The passage of radiant energy from the sun and stars into the ice will be affected in considerable degree by the condition of the ice surface. The rougher and more broken the surface ice, the larger the proportion that will be refracted and reflected and radiated outward and lost or absorbed in the surface ice. A residue remains of rays not absorbable by the ice or absorbed only after traveling a long distance in it, which may be transmitted through it till they come to englacial débris or to the ground. Here, being absorbed in part, they become changed to molecular heat and melt the adjacent ice. While the passage of stellar and solar radiations to considerable depths in the ice is probable, the quantity is unknown and has not been proved by observation. If we could prove that any considerable amount of heat was thus transmitted through the ice, it would greatly help to account for the accumulation of drumlins and the glacial gravels and the dropping of englacial matter to become part of the subglacial till, it would account for a part of the glacial waters and for the maintenance of the internal temperature, and it would perhaps help to answer the question, What effect did the pressure of surface waters, streams, pools, and shallow lakes have on the development of the subglacial till beneath them? For surface waters would somewhat help to make the ice more transparent, like a piece of ground glass flowed with water, and we know that the larger superglacial streams remove the granular ice and reveal only the clear solid ice in their beds. Such an hypothesis, if proved, would be a welcome addition to our knowledge of glacial conditions, if for no other reason than to account for the fact that the ice, after having taken the englacial débris into its grasp where it is thicker, lets go of it again subglacially where the ice is thinner.

5. Subterranean waters issuing as springs beneath the ice. The rocks beneath glaciers become charged with water, just as they do elsewhere, and probably discharge it under the ice in many cases. Such waters would disturb the distribution of the internal heat of the earth. In their subterranean courses they would absorb some of the internal heat and transfer it to their place of issuance. If this was beneath the ice, the heat would be available for melting or maintaining temperature.

6. There is another possible, though hardly probable, source of subglacial waters, which we admit into our list simply as a subject for investigation. Possibly it depends for its basis wholly on our ignorance of the structure of the névé. It has often been observed that at the margin of the snow fields the solid ice extends under the snow. In the Mount St. Elias region Russell has seen it to a depth of 100 to 200 feet beneath the snow. But the snow there does not melt at elevations above 13,000 feet, but comes down as avalanches upon the névé. These conditions can not be typical of ice-sheets, for though the latter may perhaps sometimes rise above surface melting, there are no avalanches to compact the ice, nor any crevasses to admit water from rocks nearly bare of snow. Both Russell and Chamberlin regard it as probable that even in such a supposed ice-sheet the dry névé grows more compact as we go downward, and finally becomes solid ice. A hole bored to the bottom of the Greenland névé would answer all these questions of fact, but in the absence of observations it must be considered as possible that there are conditions under which the coarse granular snow or partially consolidated ice extends beneath the zone of surface melting, so as to become charged with seeping water, and near enough to the ground to permit its contained water to escape to the bottom of the ice without the aid of crevasses as the grains are slowly pressed together to form consolidated ice. This could happen only under snow fields unbroken by crevasses. If this ever happens, the granular zone would form the fountain head of subglacial streams.

BASAL FURROWS AS STREAM TUNNELS.

As the glacier flows over an obstruction a furrow is formed in the base of the ice. Though viscous to a certain extent under ordinary pressures, the ice can not at once fit itself to the lee side of the obstruction. This is proved not only by the general laws of the flow of fluids but also by field phenomena, such as the subglacial till that has been seen to gather beneath the ice of a tongue that crossed a low part of a hill in Greenland, the phenomenon of crag and tail, the existence of hollows in the rock that were glaciated not at all or only imperfectly, etc. The ice does not always change its direction and bend downward when the rock surface does so, and thus small caves may exist beneath the ice. This is proved by the facts elsewhere recorded as observed at Rockland. It is to be noted that

this happened only while the latest scratches were being made. An earlier series of scratches went up and over and down the slope of the rock without distinguishable break of continuity. These scratches do not date from the time when ice was deepest, but are themselves deflected from the direction of general glaciation, yet at the time they were made the ice could flow down into depressions without leaving caves beneath it. The scratches on the tops of the highest hills date from the time the ice was deepest, and scratches parallel to this direction are remarkable for the depth of the depressions they go down into and the abruptness of the slopes they are able to follow. A fair inference is that the furrows or hollows left beneath the ice while passing over uneven ground, bowlders, and other obstacles are a feature of thin glaciers. Many observers have seen such furrows in the lower surface of the ice where it flowed over bowlders, but their observations were necessarily made in the crevassed portions of glaciers near the extremities. Such furrows must fill up by inward flow of the ice, and the rate would depend on pressure, etc.

The hypothesis that basal furrows and lee cavities have helped to form subglacial stream tunnels has some quasi support from certain field phenomena. Thus in the coast region the gravels are often found on the tops of low hills, but in such places it is probable that crevasses would be formed, and these might aid in the formation of tunnels far more than the basal cavities. None of the hillside eskers have been seen to originate from bowlders or sharp peaks of rock, or to have such in their courses. The bosses of rock that are sometimes found in the course of an osar river are so low and broad that only very short cavities would form in their lee. And since such cavities were largest near the extremity of the ice, where crevasses were most numerous and sufficed to carry off the waters, we must infer that basal furrows and caves were of little use in establishing stream tunnels.

Another conceivable sort of basal cavity attracts attention as a possibility. Under unbroken ice the water of basal melting would be pressed sidewise from where there is greater pressure to where there is less pressure, and collect beneath the ice. Since water is practically incompressible, such a water-filled cavity can not collapse in one part without a corresponding expansion in another. It would in some respects be the analogue of the air bubble in water, though not owing its shape to surface tension, and, like

the bubble, could be pushed forward, to be discharged into the first crevasse or cavity formed in lee of an obstruction. By some such process the basal waters are able to maintain a precarious and much-interrupted passage beneath the ice.

At North Dixmont and elsewhere osars that are somewhat transverse to the glaciation are stratified monoclinally, the dip being toward the lee side, as if the advance of the ice continually closed up the stoss side of the enlarging channel and left a corresponding opening on the lee side.

GENESIS AND MAINTENANCE OF SUBGLACIAL AND ENGLACIAL CHANNELS.

Of this intricate subject our definite knowledge is phenomenal and general rather than causal and detailed. Rivers are known to flow within or beneath the ice. The surface waters plunge down crevasses and disappear. These facts are well known. But as to the parts of the work wrought respectively by the ice and the water, these and many similar questions can be argued, but not determined by direct observation.

No other means than crevasses for the passage of superficial waters beneath a sheet of ice covering all the land has been discovered. If interstitial water reaches the ground through granular snow and consolidating ice, or if surface pools melt their way to the bottom, these processes would hardly merit naming as exceptions to the foregoing rule, since they could supply so small an amount of water. We have, then, to consider the ice-sheet as one of the rocks which surface waters penetrate, as they do other rocks, along a system of joints and crevices of wonderful complexity till they reach the earth or the bottom of the crevices. Thus in the first instance the ice itself provides the means for the descent of the waters. It is at the escape of the waters horizontally that difficulties begin. Generally the streams are longitudinal, while the greater part of the crevasses are transverse. The transverse crevasses break up the glacier into parallel blocks or prismoidal slices, each of which, judging from surface appearances, is capable of acting as a dam to hold back the waters above it. Where the ice is broken longitudinally or, as not infrequently happens, alike transversely, longitudinally, and obliquely, the waters find no difficulty in making their way by zigzags through the labyrinth of crevasses. But it is known that surface streams often sink into the ice far above the greatly shattered portions of the ice-sheet. There must be subglacial or

englacial channels under long reaches of ice unbroken at the surface, and it is not admissible that they were formed along longitudinal or any other crevasses. The problem is solved so far as the much-crevassed ice is concerned. It now remains to inquire how we can account for the existence of longitudinal channels within or under parts of the ice solid on the surface, or if broken, not longitudinally, but transversely into long prismoids attached at the ends to unbroken ice, so that apparently they ought to dam the subglacial waters.

At the outset we are confronted by another query: How nearly do the surface crevasses represent those of the bottom? Except at precipices, crevasses form at right angles to the tension, or nearly perpendicular to the ice surface. Usually they are not planes, but more or less curved and irregular; but even when approximately plane when first made, they become greatly distorted by the unequal flow of the ice. Also, since the upper ice moves much faster than the lower, the successive fractures divide the ice into blocks that are much wider, lengthwise of the glacier, at the top than at the bottom. When the ice has great depth and rapid motion and crevasses form at short surface intervals, the bases of the prismoidal slabs must often be narrow, and it may even happen that the crevasses meet at the ground or above it. We must admit, therefore, that the basal ice is broken by crevasses nearer together than at the surface, and also that by the intersection of curved and irregular crevasses it may not seldom happen that transverse slabs of ice that appear on the surface to be capable of acting as dams to the subglacial waters are broken through in the depths. After making a most liberal allowance for cases where there are no apparent longitudinal crevasses but yet the transverse crevasses connect, we still have a residue of apparently unbroken ice penetrated by longitudinal subglacial streams.

Into all crevasses the surface waters pass. Part of the crevasses do not reach to the ground; part open into subglacial channels and part do not. Those crevasses down which the waters succeed in forcing a passage are soon enlarged into the shaft or well of a moulin. This enlargement is significant and must be accounted for. At the instant of melting, the surface water has the temperature of 32°, but under sunlight it absorbs heat and rises in temperature. The water in contact with the ice then gives up its surplus heat to melt a portion of the adjacent ice. This is a slow

process, since water is a poor conductor of molecular heat, while the absorption of radiant energy is practically instantaneous. Volumes are as the cubes of the diameters, and surfaces as the squares of the diameters; hence the larger superficial streams contain a larger proportion of water warmed above 32° as they pour into the ice. This heat melts the ice of the crevasse as it descends and enlarges the passage into a shaft, and continues the work after it is beneath the ice in the enlargement of even the narrowest crevasses into tunnels. Water at 32° would find its way through the crevasses as do the subterranean waters through the joints of the insoluble rocks, without enlarging the natural joints except to a limited extent by mechanical erosion. Surface waters of the ice never become heated very much above 32°, and their melting power is much more feeble than waters warmed on the land.

Crevasses not opening into established subglacial or englacial channels may become filled with water in which convective currents soon begin to carry heat to the bottom, since water at 39.1° sinks and forces that of 32° to rise. But crevasses are so deep in proportion to their width that only a sluggish circulation can be kept up in them, and rarely, unless in exceptional cases, will stationary water be able to melt for itself a subglacial outlet. The flow of a surface stream over the mouth of the crevasse aids the melting by furnishing a constant supply of warmed water.

When a superficial stream pours down a crevasse, an enlargement of the base of its shaft is formed, where the water, falling at a high velocity to the ground, rebounds outward in all directions. A new crevasse soon opens at a short distance above the last one, and in the course of time the stream opens a new shaft in this and abandons the old one. As the ice flows past the place where the crevasses form, each part is in succession hollowed out at the base of the waterfall, and thus a large continuous tunnel is prolonged by the forward movement of the glacier. It is not meant to imply that the water acts only at the base of the waterfall, but it acts there most energetically. Given, then, a waterfall or any other conditions whereby warmed waters can melt a passage underneath each successive block between the crevasses, and the glacier itself will prolong a tunnel distally.

Let us take the case of a moulin supposed to be formed at the proximal end of a subglacial stream—the successive transverse crevasses not opening

into one another but separated by a solid slab of ice. When a new crevasse forms, it becomes filled with water, but it is narrow, and melting by convection currents is very slow. Under a pressure of thousands of feet the water searches out every point of weakness. It acts by its pressure to rupture the ice, also to penetrate between the ice and the underlying rock, and also by its superior weight to raise bodily the ice in contact with it. The last can not be done without fracturing ice of great thickness, and this the flotation is not able to do. The line of contact between the ice and the rock is that of weakness, since the adhesion of the ice and rock is less than the cohesion of the ice, and probably of the ground moraine, where there is one. If the ice has been held above the rock by a film of basal water, or there is a basal furrow in the bottom of the ice, the water immediately penetrates between the ice and the rock, and soon enlarges the smallest chink to the capacity of the stream. Moreover, the ice must flow down into each scratch of the rock or the trickle will begin and all the rest follow. Whether ice held under great pressure in fair contact at all points with the rock could prevent the passage of the waters is a matter of conjecture. It is possible that continued pressure might cause a minute flow of the ice, so as slowly to raise in arch form the central parts of the block forming the dam, and thus permit the water to escape. Only the minutest opening would be required to initiate the flow, and the melting would do the rest.

It is known that ice can flow over deeply buried ridges without being crevassed at the surface. If the motion continues while the thickness diminishes, the time will come when the ridge will cause an increasing bulging of the ice surface, and finally crevasses. In many cases of retreating glaciers surface waters are seen to pour down crevasses that would not exist when there was considerably deeper ice, and in these cases the waters must have established subglacial or englacial channels for themselves not very long ago. At the moulin, where the water in the new crevasse is separated from a large tunnel by at most only a few feet of ice, it is not so wonderful that it finds a passage. The difficulty is to show how a channel is for the first time established beneath or within the ice, often underneath long reaches of ice unbroken at the surface. It is constantly being done on the glacier longitudinally, yet the large Märjelen See can not keep open a permanent channel transverse to the ice flow. We seem to be driven to

the conclusion that the motion of the ice not only indirectly establishes the subglacial drainage by furnishing the necessary crevasses, but also directly aids in the formation of the channels in the direction of motion. This it does because the modifications of the base of the ice that are made as the ice passes a given point are carried forward by the motion. As one of the possible combinations, let us postulate a new crevasse appearing far from any others, opening into the basal cavity formed in the lee of the obstruction causing the crevasse, and where no previous water channel exists. When the crevasse fills with water, its outward pressure, owing to the higher specific gravity of water, somewhat exceeds the pressure due to the weight of the superincumbent ice. The inward flow of the ice to fill the cavity in lee of the obstruction is resisted by the viscosity of the ice and the antagonistic pressure of the water. In the absence of specially great pressure, such as would be caused by converging ice flow owing to lateral pressure of obstructions, it might happen that the pressure of the water filling the crevasse and basal cavity could resist the collapse of the latter, or make it very slow. If so, as the lower ice moved forward, the water would fill the lengthening furrow which would extend from the base of the crevasse backward to the obstruction. When a new crevasse was formed at the proximal end of the same cavity, the water pressure would still be maintained, and would continue while the base of that crevasse was in turn pushed forward. Under favorable conditions the basal furrow might thus be prevented from collapsing until its forward end had been brought to where it opens into other basal cavities or into a crevasse. In this analysis we have avoided a comparison of the pressure exerted by the inward flow with that due to the weight of the ice. Without insisting on details where so much remains unknown, we may in a general way safely affirm that the motion of the ice greatly assists in the formation of subglacial tunnels in other ways than simply by the formation of crevasses. Probably a mass of motionless ice would have only a surface drainage.

How are the channels of subglacial streams maintained transversely to the movement? Where transverse crevasses form a part of such a channel it is easy to account for the maintenance of the channel. As new crevasses opened, the stream would occupy them in turn for a time, and then abandon them, as it did old moulin shafts. This implies that the stream is pushed onward, whatever distance intervenes between the successive crevasses, and

then returns to its old position in the latest crevasse. Probably all subglacial tunnels wander, but the transverse ones more than the longitudinal. A transverse channel could be stationary in two ways: by the melting of the ice as fast as it advanced, or by becoming filled with sufficient gravel to force the ice to flow over it. The stratified osars date from a time when the channels were approximately stationary, due probably to both the above-cited conditions, aided perhaps by a sluggish ice movement.

The same causes which enlarge crevices into tunnels maintain the tunnels against a slow inward movement of the ice. An instance is seen on the Malespina glacier, where the subsidence of the roof of a glacier river has resulted in the formation of scarps of depression on the upper surface of the glacier. That glacial rivers do not succeed in eroding so broad canyons and tunnels in the ice as they would in rock is due partly to the gradual collapse of the walls and partly to the fact that the glacier is ever being renewed.

While we postulate some inward flow, the assumption must be so held as to allow the formation of crevasses, which we can not account for if we assume very much fluency or plasticity.

In case of a decaying ice-sheet having its névé and higher ice unbroken, the thinning of the ice over the hills would from time to time cause the appearance of crevasses at places before free from them. New subglacial tunnels would soon be formed, if surface waters flowed into them. Thus, in Maine, as the névé retreated northward, there would be a corresponding advance of the subglacial rivers, so far as they serve to carry off superficial waters. The advance would take place into a region previously drained by superficial streams. The thinning of the ice would cause a multitude of crevasses to appear in new places, but many of these would be of no significance. To use a biological phrase, there would be a natural selection of the crevasses, only those intersecting the established superficial streams having the power to determine the courses of the larger subglacial rivers to that place. In this manner the superficial drainage systems of the ice-sheet may have had an important influence in determining the number and courses of the subglacial rivers.

It is difficult now to ascertain the causes of the dividing of the ice-sheet into superficial drainage systems or how far it was determined by the underlying hills. There may be parts of the slush zone that are so flat

that the courses of the surface streams are determined by the accidents of the winter snow drifts. Many observers report seeing domes and rounded ridges on the ice, presumably formed by some buried obstruction.[1] Instrumental surveys might reveal shallow anticlines or synclines where to the eye there was a plain. Where ice flows over a ridge that is parallel to its motion there will be a bulging at the stoss end of the ridge, and probably then to leeward there would be a shallow valley on the top of the ridge for a considerable distance, caused by the retardation of the flow at the bulging. But in Maine the hills were mostly transverse, and the transverse billows of the ice-sheet would be more numerous and higher than the longitudinal ones. It is certain that the osar rivers penetrated the higher hills by low cols and passes. In many cases, especially in western Maine, they must have been subglacial rivers. It is as yet uncertain whether we are to attribute the courses of these subglacial rivers wholly to conditions existing within or beneath the ice, or whether we can trace additional links in the chain of causation and can declare that the courses of the subglacial were in part determined by those of the superficial streams, and that these in turn were determined to the low passes by the undulations of the surface ice as it flowed over the adjacent hills. Such an investigation could not proceed far without the aid of a topographical map. The facts in the field certainly seem in numerous cases to favor the hypothesis. The topic will be referred to later.

FORMS OF GLACIAL CHANNELS.

Observation proves that the subglacial and many of the englacial channels have arched roofs. This is chiefly due to the fact that the waters are always in contact with the lateral walls, but only in time of flood can they reach to the roofs to melt them, and partly because water of 39.1° tends to sink to the bottom. In case of a roaring stream this would have little effect, but it might be an important element in case of a quieter flow, as when a stream enters an enlargement of its channel or goes up and over a hill. That the melting is most rapid near the bottom of a cavity that con-

[1] Lieutenant Peary, Bull. Am. Geog. Soc., vol. 19, p. 287, 1887, says: "As to the features of the interior beyond the coast-line, the surface of the 'ice blink' near the margin is a succession of rounded hummocks, steepest and highest on their landward sides, which are sometimes precipitous. Farther in, these hummocks merge into long flat swells, which in turn decrease in height toward the interior, until at last a flat, gently rising plain is reached, which doubtless becomes ultimately level."

See also Prof. I. C. Russell, Nat. Geog. Mag., vol. 3, pp. 106, 107, 132, May 29, 1891.

tains water warmed above 32° is proved by the overhang at the margin of glacial lakes and by the enlargement at the bottoms of glacial pools and lakelets. On Hagues Peak, Colorado, is an ice field that is sliding, if not flowing, and the walls of the subglacial outlet of a small lake overhang at an angle of 45° or more in a curve convex downward.

In case of superficial and englacial channels the bottom as well as the sides is more or less melted and eroded by the glacial waters; hence the base does not enlarge laterally so much as when the bed is composed of rock, and such streams generally form more canyon-like channels. But if they succeed in melting their beds down to the ground the channels then begin to enlarge at the base, and the walls to overhang, like those of a subglacial stream. Gravel deposited in such a channel would be a ridge with arched cross section, like that found in a subglacial tunnel.

FIG. 25.—Ideal sections across channels of superficial glacial streams. *a*, before reaching the base; *b*, after reaching the base.

The accompanying cut (fig. 25) was drawn in 1888, and can be compared by the critical reader with the more recently published photographs of the Malespina glacier by Russell.

EXTRAORDINARY ENLARGEMENTS OF THE GLACIAL RIVER CHANNELS.

When we follow one of the ordinary osars for 50 miles, we become greatly impressed by the narrowness and steepness of the ridge. Some of the hillside and smaller osars are, toward their northern ends, only 5 to 15 feet wide at the base. Their material here is very little worn and rounded, and the streams that deposited them were brooks. The height of the osar proper usually exceeds one-eighth, and sometimes locally reaches to one-fourth or one-third, of its base. That rivers capable of transporting so great a quantity of sediment should occupy so narrow channels is truly wonderful when we consider the softness of ice as compared with the hardness of the débris transported and its consequent liability to mechanical erosion, also that it was liable to melting, a process which has its analogue in the action of subterranean waters or calcareous rocks, and might be expected to result in the formation of subglacial and englacial channels comparable to the great limestone caves. That the glacial rivers do not ordinarily succeed in doing this is due, I conceive, chiefly to the

constant renewal of the living glacier. Canyons cut in rock exhibit the cumulative effects of erosion on a fixed bed. But the ice-sheet of to-day is not that of the last century. Pressing onward from age to age, just as new generations of men rise to do the world's work, the worn, rounded, and wasted glacier loses itself at the glance of the sun, before its streams have time to enlarge their channels very greatly, and is replaced by a new and unbroken, youthful glacier, eager to run its race. The slow inward flow of the ice also assists in preventing enlargement of the channels of the streams.

In addition to the small narrow ridges we find others broadening to an eighth of a mile or more, with corresponding height, or expanding into massive ridges or mounds one-half to three-fourths of a mile in breadth and a mile or more in length, with a height of 100 to 150 feet. We find hundreds of miles of osar terraces one-eighth to one-half a mile in breadth, level in cross section or with a central ridge rising above the rest of the plain, going up and over hills or skirting hillsides as terraces in a way to prove they were at the time of deposition confined on one or both sides by ice. We find cones, domes, mounds, and ridges of very small as well as large size, but all in situations such that they must have been deposited in channels or basins in the ice. We find osar border clay deposited in the broadened channel of an osar river, which is in some cases probably marine—i. e., an osar channel became a fiord in the ice. We find channels of the ice one-fourth mile to a mile wide filled with deltas which at their distal ends are marine. From a diminutive osar like one of the ridges near South Acton or the little gravel hummocks near the Head of the Tide, Belfast, up to the Whalesback, Aurora, or the so-called "mountains" of Greenbush, or the broad osar terraces of York and Oxford counties, the distance is immense. Before the final disappearance of the ice-sheet it was gashed and pierced and sliced by a complex system of channels, most of the time of large size and irregular shapes. Is this self-destructive? If so, it is no more suicidal than the behavior of a glacier could be expected to be that was forced to supply water for its own destruction. The drainage waters of ordinary Alpine glaciers immediately escape, but this ice-sheet went over many transverse hills, and to the north of the hills there were large permanent bodies of water which toward the last were eating out its vitals. To complete its misfortunes the sea rose, and by the greater subsidence to the northwest it found itself on a bed sloping against it over

large areas. In the time of its strength the ice-sheet could so far strangle its rivers that only a little sediment was left in their channels, but the sediment was poured out in front of the ice where the sea now is. But in its decay, when the flow became sluggish and even the ground turned against it and increasing quantities of solar heat were transmitted through the ice, the gravel was left far back of the ice front. In the Rocky Mountains substantially all the glacial gravels were frontal or overwash plains, and the same was true of large portions of the northwestern Interior. In Maine the marine deltas and a large part of the reticulated kames were deposited in front of the ice, also much of the valley drift; but in addition to these there is a very great development of gravels that were deposited within the area then covered by the ice. For the great enlargement of the glacial stream channels we need invoke only the same causes that first established them as tunnels. Mechanical erosion, melting by warmed waters, and heat transmitted through the ice, are sufficient to do the work when acting through thin ice whose motion was sluggish or in places almost arrested, aided by the rising sea, the bodies of water lying to the north of the hills, the increasing quantities of water warmed under the sunlight either by the melting of the roofs of their tunnels or their being forced up onto the ice by the clogging of their channels, etc. Toward the last probably most of the water in the channels of the broad osars or osar terraces was exposed to the sunlight. If the narrowness of the early osars is remarkable, the broadness of the later ones is equally remarkable.

These extraordinary enlargements of the stream channels were made in the last days of the ice at the place of enlargement, all the other conditions being favorable. Mechanical erosion was active, but still more effective was that insinuating, ever alert agent, heat, whose transformations within the decaying ice-sheet were varied and powerful.

DIRECTIONS OF GLACIAL RIVERS COMPARED WITH THE FLOW OF THE ICE.

Our definite knowledge of the courses of the rivers of the ice-sheet is derived from the sediments they have left behind them and the excavations they made in the till and the solid rock. When we map the gravels, we map only those portions of their channels in which sediment was deposited. In large portions of their courses the flow must have been too swift to permit the deposition of sediment. While it is impossible now to reconstruct

the map of all the streams of the ice-sheet, enough is known to enable us to mark out the courses of the larger rivers. In some cases the gravel is residual rather than transported—that is, the streams had barely power to carry off the finer matter of the till, leaving the larger fragments with but little, if any, water transportation from the place where the ice brought them. In a multitude of cases no doubt small trickles and brooklets carried off some of the finer matter of the till, leaving it a little more sandy than the usual till, but such we can hardly trace. In a number of places glacial streams formed potholes, but have left no gravels. In places we find the ground moraine eroded and glacial gravel left at some point southward.

Although the general or average directions of the rivers were roughly parallel to the direction of ice flow, there are many important divergences. Most of the shorter meanderings are plainly transverse to the scratches on the rocks, and so are some of the larger zigzags of 5 to 30 miles. The maps show that a number of the osar rivers had tributary branches like those of ordinary rivers, and at their places of junction I have found no proof from the scratches that there was a similar convergence of the ice movements. In like manner, where the delta branches diverge, there is no corresponding divergence of the scratches. They diverge or converge at large angles up to a right angle, and it is difficult to conceive causes for such ice movements. It is true that the latest ice movements were recorded by shallow scratches on rocks bare of ground moraine, and from which the glaciated surface has now generally weathered, aided by forest fires or by those made in clearing the land. But after making the largest admissible allowance for the imperfections of the record it is still difficult to assign causes for such a converging flow as must have taken place near the head of Penobscot Bay (the reader is referred to the map, Pl. XXXI, for explanation), or in Greenbush, or near Tomah station of the Maine Central Railroad. As elsewhere noted, there is a convergence of glacial rivers toward Columbia and Jonesport. The scratches also converge toward the same region, but not so much as the rivers. The Coast Survey charts give the soundings for a few miles off the coast, and I fail to find any deep valley in the sea floor, or other topographical reason for such a converging flow of the ice; and there is just as little topographical reason for the flow of the rivers for 30 miles or more transversely to the ice movement, as testified both by

scratches and bowlder trains. I see no admissible interpretation but this: Osars for long distances are transverse to the recorded glacial movements, and probably even the latest ice movements were not parallel with them. In the coast region, as near Belfast, there are usually one or more systems of glacial scratches that diverge progressively more and more from those that mark the time of deepest ice, the latter being parallel to the scratches found on the tops of the highest hills. Here we find the systems of discontinuous gravels approximately parallel to the scratches last made, and convergent like them, to Belfast Bay.

The great divergence of the glacial rivers, both for short and long distances, from the recorded movements of the ice suggest many questions as to the causes that determined the courses of the rivers. The subject is briefly treated in the following chapter.

RELATIONS OF GLACIAL RIVERS TO RELIEF FORMS OF THE LAND.

The general facts as to the topographical relations of the osar rivers have already been stated. These rivers often flowed over the lower hills, but not over hills higher than 200 feet except in western Maine, where many gravel series go over hills a little more than 200 feet, and over one hill 400 feet, above the ground on the north.

A question of detail arises whether the glacial streams were determined to the low passes before the hills adjoining the passes emerged from the ice, premising that it is only rarely in Maine that ridges are parallel with the direction of ice movement. Almost always they are transverse.

The phenomena of delta branches proves that a single glacial river sometimes either used too widely diverging channels simultaneously or abandoned one of the channels for another. This phenomenon is very common in southwestern Maine and over most of the State. But these delta branches go over no higher hills than the tributary branches or main osars, and they throw no light on the time the glacial rivers were established in the low passes.

The hills adjoining the low passes penetrated by the glacial rivers rise to a height of 100 to 1,000 or more feet above the passes. If at or near the time that the ice melted over the transverse hills bordering the passes, glacial streams crossed them, we ought under certain conditions to find traces of such streams.

1. If subglacial, they ought to have left channels of erosion in the till or deposits of glacial gravel, at least on the south sides of the hills, like the hillside eskers.

2. If superficial, there would come a time when the top of the thinning ice did not rise so far above the hills but that the channels would cut down through the ice to the till. Erosion of the till would follow until the hill emerged from the ice. The eroded matter would be left somewhere as glacial gravel. Or if the surface streams disappeared down crevasses at the tops of the hills, they ought, while escaping as subglacial streams, to erode the till and leave gravels.

3. The lowering of the ice to the top of a hill would necessarily deflect to some neighboring pass any stream previously crossing the hill. The deflection might take place in various ways. It might happen some miles to the north, or a pool might be formed on the north slope of the hill which would in fact so far check the force of the stream that it would deposit only scanty sediments that might since have been wholly or partly eroded. But we can at least conceive of a stream thus deflected leaving gravel terraces to mark its new channel along the northern slope of the hill or at some point north. One such case would be very significant. As elsewhere recorded, there are cases on the north sides of hills of lateral deflection from the general course of large glacial rivers, as at South Albion and in Montville and elsewhere, but no gravels on the hills marking more ancient channels than those in which the osars proper were deposited.

The Greenland and Alaskan glaciers show prominent bulging on their surface, presumably due to passing over hidden hills. Such bulgings must appear while the tops of the obstacles are a considerable distance beneath the ice. Whenever bulging of the surface is accompanied by deep crevasses it would be possible for surface streams here to escape beneath the ice as subglacial streams, but it must often have happened that the raising of the ice over the hills would cause the surface water to gather in the lower parts of the ice surface, i. e., over the low passes of the underlying hills. How far such bulging over transverse hills helped establish the courses of the rivers through the passes is uncertain.

Numbers of the hillside kames are situated on the south slopes of hills higher than 200 feet above the ground on the north. The small size of the gravel deposits does not call for large streams or long-continued flow. In

some cases it appears probable that the local drainage of the hillside would furnish all the water required to deposit the gravel. But there are other cases (as that found near Wilton, elsewhere described) where the stream was of good size at the top of the hill. In such cases the streams must have had a gathering ground to the north. Of course such streams ceased to flow when the hills rose to the surface of the ice, but thus far I have found no traces of deflection channels into which they turned after their original channel was interrupted.

Summary.—Some of the streams that deposited the hillside kames appear to be instances of glacial streams whose career was cut short by the lowering of the ice to the tops of transverse hills. Thus far I can not identify them with any of the long rivers, nor trace any channels they abandoned for others. In the case of delta branches the glacial rivers may have abandoned one channel for another, but such branches obey the same law respecting low passes as the main rivers. In case of the larger rivers penetrating low passes, there is as yet no field proof that the rivers even flowed anywhere except where the osars were deposited. The general inference follows that the courses of the great glacial rivers were determined to the low passes before the osars were deposited or the adjoining hills were bare of ice.

SEDIMENTATION IN PLACES FAVORABLE OR UNFAVORABLE TO THE FORMATION OF CREVASSES.

The discontinuous gravel deposits found near the coast region often form on a lenticular hill or drumlin, as near Belfast, or on the tops of low hills, as near Portland. Both the Kennebec and the Penobscot rivers for many miles are flanked by osars, somewhat discontinuous, that are for the most of the distance found at the flanks of the valleys or near the top of the steep bank 50 to 100 feet above the rivers, just where crevasses would naturally form. Near Lewiston the Androscoggin River shows the same peculiarity for a few miles.

On the other hand, some of the discontinuous gravels are in the bottoms of valleys or on level ground where there appears to be no inequality of the ground to cause crevasses. So, also, the long osars love to zigzag over broad plains, often through swamps, where the land is very level and even and there is no apparent cause for crevasses. They often follow the

axis of a valley or zigzag from one side to the other in a way that shows no connection with the inequalities of the land.

Thus far I have been able to make no generalization, but certainly the determination of the positions of the crevasses is a difficult matter, and perhaps often impossible. Many details in regard to particular places will be found in the descriptions of the gravel systems.

GLACIAL RIVERS OF MAINE: SUMMARY.

In the preceding pages we have spoken of the great length and volume of the glacial rivers of Maine as attested by the gravels they deposited. Care has been taken to avoid naming them either subglacial or superficial. From whatever point of view we look, the difficulties are immense in accounting for the branchings of the rivers of the ice-sheet, their directions and their relations to the relief forms of the land, the nature of their sediments, etc., on the theory that we are dealing with subglacial streams alone. To insist that the glacial gravels are wholly due to subglacial streams, or wholly to superficial streams, appears to me to be dangerously like the dispute between the followers of Hutton and those of Werner as to whether the earth had come to its present condition by the action of water or fire. Both sides of that controversy were partly right and partly wrong, and probably this is the case in the controversy as to the glacial streams. Those who study the question near the great terminal moraines will everywhere see signs of subglacial streams only. Those who study in northern New England will also see phenomena that are consistent with the hypothesis of superficial streams. It is too early for anyone to settle finally the moot question of glacial streams. In the following interpretations I have endeavored to correlate the facts in Maine, so far as I have observed them, with those of Greenland. The best interpretation will prevail.

GLACIAL POTHOLES.

The process of pothole making has long been well understood in the form in which it appears in the beds of surface streams of the land. If we go to some place where a rapid stream passes over a series of waterfalls and rapids, especially over granite rocks, we can see potholes in all stages of formation An accessible locality is the falls of the Androscoggin River

at Brunswick. Here and there the water can be seen flowing over an angular depression in the rock, where a portion of the granite has broken away under the action of frost, ice gorges, the force of the water, etc. In process of time the surface is sand carved and hollowed out into bowl shape. The water falls into the cavity, rebounds in a curve, and swiftly shoots up the other side. Up to this time the sand grains and stones of various sizes used by the stream in this process are driven almost immediately out of the cavity, along with the upward rebound of the water. By degrees the cavity deepens, until some day a stone falls into the bowl of such size that the water can not roll it up the steepened slopes. The stream now sets this stone to rolling, at first with considerable vertical motion, but more and more, as the hole deepens, the horizontal whirling prevails. The grinding now proceeds with multiplied rapidity.

The conditions for the formation of a pothole are the following: (1) A rapid stream. (2) A rock firm enough to withstand the direct impact of the water. Thus potholes are more frequently found in granites, sandstones, and indurated slates than in schists and shales easily weathered or split and broken under the action of the water. (3) The formation of such a cavity as to permit a vortical motion of the water. (4) A moderate quantity of stones for the stream to whirl around in the hole. If there is a large quantity of sediment swept along by the stream, the cavity will soon be filled or partly filled with stones and the process of excavation will be stopped. Sooner or later most potholes are filled in this way.

It is important to note that the direct impact of the running water bears a very subordinate part in pothole erosion. The principal agency is the friction of the rolled stones and bowlders. It makes little difference whether the water falls into the cavity from above or is shot horizontally, or nearly so, across the mouth of the opening, provided the water is kept whirling.

The best-known glacial potholes in Maine are situated near Riggs Landing, on the island of Georgetown. They were examined and measured by me in 1879. The region has since been explored by Mr. P. C. Manning, of Portland, whose observations were presented in a paper read before the Portland Society of Natural History. He found similar potholes in several other of the islands situated east and southeast of Bath. Some of these were called to his attention by Mr. Alexander Johnston, of Wiscasset. Several times archeologists have asserted that these potholes were

excavated by the Indians. That they are glacial potholes is proved by the following facts:

One of the potholes near Riggsville is situated about 1½ miles southward from that place, on the shore of Robin Hoods Cove. The pothole is covered by about 1 foot of water at time of ordinary high tide. It is near 10 feet in depth; its average diameter is 4 feet at the top and 6 feet at the bottom. It is excavated in a little shelf of rock on the side of a rather steep ledgy hill, about 40 feet high. Within a few rods this hill slopes in the opposite direction from the shore, down to the valley of a small brook which enters the cove about one-eighth of a mile north of the pothole. The ground slopes down from the hill in all directions, so that the only surface drainage that ever could reach this pothole must have come from a slope only a few rods long. The rock is a compact gneiss, with no veins or dikes at this place and no fault or fracture. I could find no other sign of running water in the vicinity. There were stones in the bottom of the hole that could be moved around by an oar, but I had no means of getting them out, and it was impossible to see more than 2 feet into the black water. Robin Hoods Cove is here near one-fourth of a mile wide, and contains no islands or rocks to cause a tidal race. About one-eighth of a mile north of Riggs Landing are two potholes at an elevation of about 60 feet above the sea. The one situated at the southwest is about 4 feet in diameter and 5 feet deep. The other is about 6 feet in diameter and 10 feet deep. Both are nearly round, and the walls are quite smooth. The layers of gneiss, tilted up at high angle, are continuous, except where interrupted by the holes. The same layers can be readily traced on opposite sides of the holes. There is no sign of veins or fractures. In the potholes were rounded pebbles and bowlders, one of them 3 feet in diameter, well rounded at the edges and angles. Some of the rounded stones had been taken out by previous explorers. The holes are situated on the southern slope of a hill of gneiss that rises 150 feet (by aneroid) above the sea. The hillside shows much bare rock and is broken by numerous hillocks and small valleys. We reach the top within about one-fourth of a mile from the shore. All the surface drainage that ever could have reached the holes came from this hillside, and that, too, on an irregular surface where no single valley exists to direct the flow of water to these holes.

About one-half mile north of Riggs Landing there is a pothole on the

shore situated a foot or two above high tide. It is 2 feet in diameter and 4 feet deep. About 4 feet west of this hole is a shallow bowl with very smooth inner surface, an incipient pothole. There are several masses of water-rounded gravel near here, which at the time of my visit I supposed to be esker gravel, probably deposited by the same glacial stream that formed the potholes. I am now uncertain whether it is esker or beach gravel.

No one familiar with potholes could fail to recognize as potholes these round wells with smoothly polished inner surface, even if he did not find within some of them the round cobbles and smoothed bowlders used in grinding out the cavity. All are found on short slopes. There is hardly a grass field in Maine that would not contain potholes if these were produced by land waters. The potholes are manifestly in places where no ordinary streams can ever have flowed, and must be due to the action of glacial streams. These potholes are found in a region where there is a larger proportion of bare rock than in any other part of the Maine coast. They are situated a few miles east of the Kennebec River. At the time the sea stood at the 225–230-foot level the whole region was deeply under water and exposed to the force of the Atlantic. The rocks are gneissoid and schistose, which rocks usually produced more till than is seen in this region. The scarcity of till is in part due to marine erosion and in part to the subglacial streams. If other regions were as bare of till as this, it is possible we might find glacial potholes everywhere along the coast. It is incredible that Indians excavated holes such as these.

In the interior of the State the only potholes known to me are found in the beds of streams, with a single exception. This is situated in the town of Paris, about one-half mile west of Snows Falls. It was first pointed out to me by Mr. N. H. Perry, mineralogist, of South Paris. By aneroid it is 240 feet above Snows Falls. Above these falls the valley of the Little Androscoggin widens into a triangular basin 3 miles in diameter. The pothole is situated near the top of a hill lying directly south of this broad open valley, and if the valley were filled by a glacier the ice would naturally abut against this hill. From the highest point of the hill (about 300 feet above the river) a ridge extends northeastward down the slope. At one place this ridge is cut across at right angles by a ravine 100 feet wide, bordered on each side by steep rocks rising about 20 feet. On the

northeast side of the ravine there is a narrow step or shelf situated about halfway between the top and the bottom of the wall. Its position is shown in the accompanying diagram. The hole is nearly round. It is 21 inches in diameter, 16 inches deep on the lower side, and 2 feet on the upper. The upper part of the interior is somewhat weathered and rough. The lower part, which is generally filled with water, is very smoothly polished. The bottom is almost hemispherical. The granite of the region weathers rough. These facts prove it to be a pothole, not a freak of weathering. Its situation halfway up the side of a cliff and within a few rods of the highest part of the ridge, whence the water flows in several different directions, conclusively proves that it can not have been formed by any stream of surface drainage. A glacier moving from the north would naturally be broken by crevasses as it flowed over the cliff. This would be a favorable place for a stream flowing on the surface of the ice to plunge to the bottom and escape as a subglacial stream. I could find no glacial gravel in the vicinity. A subglacial stream flowing from this point southward would fall more than 200 feet within a mile, and might be expected to sweep its channel clear of sediment. If a subglacial stream from the north flowed up the long hill and over the cliff it probably ought to have left sediment or other sign on an up slope that rises at least 200 feet within a mile. The north slope of the hill is covered deeply with the ordinary granitic till of the region, without glacial gravel or erosion channel or any other sign of a glacial stream. The only admissible interpretation of these facts that occurs to me is that a superficial stream here tumbled down a crevasse that formed as the ice passed up the cliffs.

Fig. 26.—Section of cliff and pothole; Paris.

Can potholes be formed at the foot of a moulin shaft? Professor Dana has suggested that the change in position of the waterfall due to the advance of the ice would produce an elongated rather than a round cavity.

It is a fact that as each crevasse moves onward a new crevasse is produced in the rear of the former, and a new well is soon excavated down the crevasse last formed. It will naturally result that the water will not continually fall in the same place, but over an area as long as the distance between the successive shafts. In other words, each shaft begins at a certain place and moves on, subjecting all the rock over which it passes to the

direct impact of the water, until it is superseded by the next crevasse, which then repeats the process. But there must be an enlargement at the base of the shaft, varying in size according to the size of the stream, the depth of ice, and the amount of warmed water. This may in many cases permit the water to scatter, so that it will not strike the rock in a round definite stream. But be this as it may, the direct mechanical impact of the water against the rock has very little to do with eroding potholes except to start the process. It is chiefly the stones rolled round and round by the water that do the work. Were the rock so soft that mechanical erosion by the water exceeded the attrition of the whirling stones, we should have, not a smooth-walled pothole, but a canyon of erosion with irregular surface. When once a cavity is found or made which is deep enough to prevent the stones swept along by the stream from being prematurely washed away, the erosion by the rolling stones would, in case of hard rocks, so far exceed the mechanical erosion of the water that the shape of the well would be that due to the attrition of the stones, with hardly a trace of direct water erosion. All that is needed is that the water in the pothole be kept whirling. When a nearly vertical cascade strikes the rock, the water must shoot swiftly outward on all sides in nearly a horizontal plane. If a pothole were within reach of these out-rushing waters, the water within it would be kept whirling as well as if a vertical stream fell into it. Whether, then, the water at a glacier mill falls directly into a pothole or anywhere near it, it will continue to whirl the water in the hole. And the hole would be as round as one formed by any other stream, unless the nature of the rock permitted it to be easily eroded by the direct impact of the water.

Regarding glacial potholes, my conclusions are as follows:

1. They may be formed by subglacial streams.

2. They may be formed at the foot of the waterfall where a superficial stream pours down a crevasse.

3. They form only where the stream carries but little sediment or is swift enough to keep its channel clear of sediment, or nearly so. If a stream begins to drop its sediment an incipient pothole would soon fill up and ultimately would be covered by a mass of glacial gravel.

4. The velocity of subglacial streams is so great, since they are urged by a great pressure from behind, that they might be able to form potholes at a considerable depth beneath the sea or a lake into which they might

flow. A superficial stream falling down a crevasse could also whirl the water at a considerable depth, if it was of large size. The glacial waterfalls are often many hundred feet high, and the water attains a high velocity in falling. How deep beneath the water potholes could thus be formed is uncertain. In any particular case we should, in order even to guess, have to know the size of the streams and the thickness of ice.

5. The existence of glacial potholes in places remote from any recognizable glacial gravels is proof that not every glacial stream left sediments. Only the larger masses of the drift of these streams have thus far been mapped. The smaller masses are buried beneath the englacial (upper) till or the marine clays of the coast region. So also are the potholes and erosion channels excavated by the subglacial rivers in the solid rock. I have not found any of the latter in Maine which are of geological importance, but Professor Dana showed me one of this kind near New Haven.

FORMATION OF KAMES AND OSARS.

Ridges, domes, and plains rising 50 to 150 feet above the surrounding till testify that a very large amount of work has been expended in bringing so great masses together. They usually rise to a greater height and show greater thickness than equal areas of till in the same regions. On the average they are areas of unusual accumulation. They can not have been derived from the local subglacial till supplemented by the englacial till contained in a body of ice of such length and breadth as at the given place deposited an area of till equal to that covered by the gravel. A supply must have been brought from abroad. And since a large amount of the finer detritus of the till is washed away in the process of making glacial gravel, this foreign supply must have been large. Such local accumulations might be caused in various ways.

1. In case of the longer glacial rivers, flowing as they did up and over hills, we might expect areas of till erosion on steep down slopes or near the tops of passes, where the swift streams carried all before them, alternating with areas of accumulation. In places all the till, both subglacial and englacial, has disappeared, and often all but the coarsest of the water-rolled matter. In other places (as at The Notch, Garland), the osar river did not succeed in eroding all the till over which it flowed. This erosion of the till in the course of osar rivers sometimes took place along a definite channel

of erosion bordered by rather steep walls (as north of Hogback Mountain, Montville), but more often the erosion is diffused. We see that till is absent, but we find no bank or margin which can be said to mark the limit reached by erosion. A characteristic form is shown in Pl. XXVI, *A*. The discontinuous osars lie in regions so covered by marine clays that we do not know what forms the erosion takes.

2. It is evident that during the last days of the ice-sheet the englacial morainal matter would appear on the surface in consequence of the melting of the ice above it. There would form on the ice a multitude of small superficial streams and seeps which would carry off much of the finer part of the exposed till and precipitate it into the main channels. The larger of these lateral tributaries formed the short tributaries of the osar rivers elsewhere recorded. No matter whether the longer ridges were deposited by subglacial or superglacial streams, in either case there must have been a multitude of superficial tributaries that have left little or no gravel. Indeed, their work was almost wholly erosive, not constructive. Their slopes were probably steep. They simply carried away such of the till of the region they drained as they could lift, and cast it into the main river channels, where it either went to make up the osar-ridges or was carried into lakes or the sea to form a part of the glacial deltas. The larger stones over which these brooks flowed would be left in place and be but little polished. Being in the upper part of the till the signs of water wash and wear would in most cases long since have disappeared by weathering. The diffused erosion of the englacial till could be accounted for by the action of a multitude of these lateral streams. A diffused erosion of the subglacial till is more difficult to explain, unless by the wandering of the streams.

3. The flow of the ice no doubt often helped to bring osar matter together.

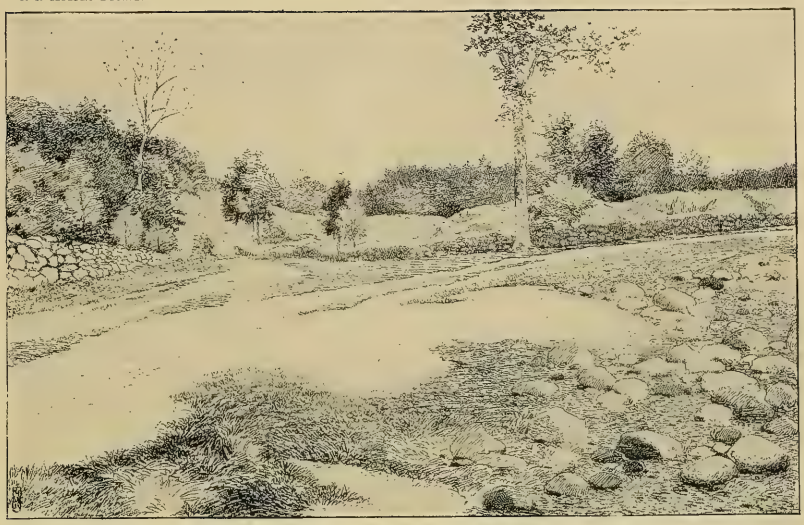
(*a*) At the end or front of moving ice. In this case the flow of the ice constantly brings moraine matter to the front and throws it down for the subglacial streams to act upon as they swiftly emerge from their tunnels. In such a case the sediments deposited in front of the ice would consist partly of worn matter transported from a distance by the subglacial streams (or superficial, if such there should be), and partly of matter which would otherwise form part of the amorphous terminal moraine and which happened to be dropped into the streams very near

the end of the ice. Such matter would be less rolled. Where the ice met the sea a marine delta would be formed in front of it. Where the ice front was above the sea, as was probably the case for a time in the valleys of the Carrabassett and several other streams at about the same distance from the coast, plains of gravel were formed in the valleys in front of the ice. With respect to the glacial streams and the ice front, these may be termed frontal deltas or overwash aprons. They are the correlative of the sediments formed in front of all glaciers ending on the land. Such a series of frontal plains were found south of the great terminal moraines of the ice-sheet for a considerable part of their length. At the south end of Sebago Lake a very deep mass of glacial gravel accumulated, and, as elsewhere explained, ice movements probably contributed to bring this great mass together, although it must be admitted that glacial streams can transport sediments long distances.

(*b*) When the flow of a subglacial stream was transverse to that of the ice. The great size of the stones and bowlders contained in the gravels of the hilly country west of the Saco River, and other facts, favor the hypothesis that they were deposited in large part by subglacial streams. If so, the eskers must often have been deposited in such subglacial channels transversely to the flow of ice, for the ridges of those reticulated series of kames trend in every direction. In this case either (1) the ice pushed the channel with its contained sediments bodily forward, or (2) the ice flowed over the gravel, or (3) the ice was melted and eroded by the stream as fast as it advanced, or (4) the ice may sometimes have been stationary. The truth probably combines the second and third hypotheses, and in both cases some morainal matter would be dropped into the channel as the ice passed over it.

(*c*) When the channel was parallel with the direction of ice flow. In this case it is certain that there would, especially in case of deep ice, be more or less flow of the ice inward from the sides. That the channel did not then collapse, like an unused moulin shaft, must be due to the antagonistic action of the stream enlarging its channel. Some till would be contained within the ice melted and eroded as it flowed inward, and thus some esker matter would be brought together.

(*d*) In most glaciers the swiftest flow is found near the glacial river. This must in part be due to the fact that the ice is there generally the



A. BARE LEDGES IN CHANNEL OF GLACIAL RIVER; PARSONSFIELD. LOOKING SOUTHEAST.

Most of the bowlders in sight have been water-rolled.

B. OSAR SPRINKLED WITH TILL BOWLDERS; PROSPECT.

Flanks of ridge partly covered with marine clay; bowlders attributed to floes of sea ice.

thickest; yet it is also possible that the presence of abundant subglacial waters facilitates the flow of ice in some degree. Both causes would produce an oblique flow inward toward the line of swiftest motion. Such a movement would bring till matter to the stream, or nearer to it.

So far as movements of the ice brought the matter of the kames and osars together, they distinctly resemble the medial, lateral, or terminal moraines of ordinary valley glaciers. Converging glacial striæ are elsewhere recorded.

BOWLDERS OF THE GLACIAL GRAVELS.

When bowlders are found on the surface of masses of glacial sediments, it is important to determine whether they have been worn and polished by water action. This often requires considerable excavation, since it is only beneath the earth, where it has been protected from the action of the weather, that we can expect the polished surface to have been preserved. Many bowlders of coarse granite have so far weathered and fallen to pieces since the glacial epoch that even beneath the ground it is now impossible to know with certainty whether they were once polished or not. Omitting, then, some undetermined cases, the bowlders of the glacial sediments may be classed as follows:

1. Below the highest level of the sea are many bowlders not smoothed by running water which overlie both the fossiliferous marine clays and the coarser glacial sediments, also the osar border clays. They have the shapes and rough surfaces characteristic of bowlders of the upper (englacial) till. They are scattered here and there at intervals, generally one in a place, but sometimes, especially on the north sides of hills, in heaps and sheets. They are most abundant on slopes favorable to the grounding of floes of shore ice. The deposits are so discontinuous and helter-skelter in their distribution and so unlike a sheet of till in composition and structure that I attribute them to floes of shore ice or small bergs. Two theories suggest themselves: that there was a readvance of the ice over the marine clays, the ice containing but little drift, or that the bowlders tumbled down from the ice upon clays formed in front of the ice during its retreat before the sea.

2. Bowlders are sometimes found in the till beneath the glacial gravel and projecting upward into the gravel. In some cases the parts projecting above the till were distinctly water-polished. This is a very common occurrence at the marine glacial deltas.

Instances are elsewhere recorded (see p. 161) where streams and springs have eroded portions of the glacial marine deltas and exposed till strewn with bowlders just like the ordinary till of the locality, or where the delta is thin the tops of the larger bowlders project above the gravel.

3. Bowlders having rounded and polished surfaces are found within or partly within the glacial gravels. These must be as truly a part of the formation as the finer sediments. There are multitudes of them in the gravels of southwesterm Maine of all sizes up to 6 feet in diameter.

4. Elsewhere are described certain large bowlders found in the northern part of Baldwin. They are situated on a northern slope in the midst of medium sand, and have little or no water polish. The sand is horizontally terraced in such a way as to suggest that the bowlders were deposited by floating ice in a broad osar channel which contained a lake-like body of water confined between the ice on the north, east, and west and the hill situated to the south. An alternative hypothesis is that the broad osar channels were overarched by ice resting upon the water that collected north of the hills.

5. In the case of the larger ice channels, especially the superficial ones, floating ice would often transport stones and bowlders like any other river ice. I do not know how in all cases to distinguish whether a bowlder not polished and rounded was dropped from the ice into the bed of the glacial river, or was transported by floating ice, or was driven along by ice gorges. We know that ice dams to-day are efficient means of transporting large bowlders. Not many years ago in Howland an ice gorge of the Piscataquis River forced upward a very large bowlder 10 feet out of the bed of the river and left it on the silty flood plain several rods back from the channel of the river. The ice gorges of the osar channels must have been efficient means of transporting bowlders and leaving them in the midst of fine sediment.

6. Bowlders not water-polished are found here and there on the surface of the osar border clay, i. e., the clay deposited in a very much broadened osar channel. These broad channels were from one-eighth to near three-fourths of a mile wide, and it is extremely improbable that they were subglacial. The few stones and bowlders they here and there contain were almost certainly dropped by floating ice. If arched by ice for so great a width, it was probably sustained by flotation on the underlying water.

7. There are considerable numbers of bowlders not waterworn, which

quite certainly slid down into the channel of the glacial river from the ice overhead or the walls at the sides. Such are the bowlders overlying the osar at the south end of the Grand Lake of the St. Croix. (See p. 75.) In the wilderness a few miles southeast of Aurora the gravel of the great Katahdin osar is found in an interesting relation to a train of granite bowlders. The place is situated in the valley of Leighton Brook, a tributary of the Middle Branch of the Union River. The course of the train is nearly north and south, and parallel with the ice flow. The train consists of bowlders piled one above another so as to make a moraine-like ridge 10 to 30 feet high, and some of the bowlders are 10 to 20 feet in diameter. The osar here forms a broad ridge of sand, gravel, and cobbles transverse to the bowlder train. The train comes up to the edge of the osar, and several of its bowlders overlie the gravel. Near the same place the osar crosses another similar ridge of till, and its flanks are overlain by the bowlders.

An important and difficult question arises concerning the proper interpretation of the facts as to the presence of large water-rolled bowlders as an integral part of the kame or osar gravel. Several facts should be noted.

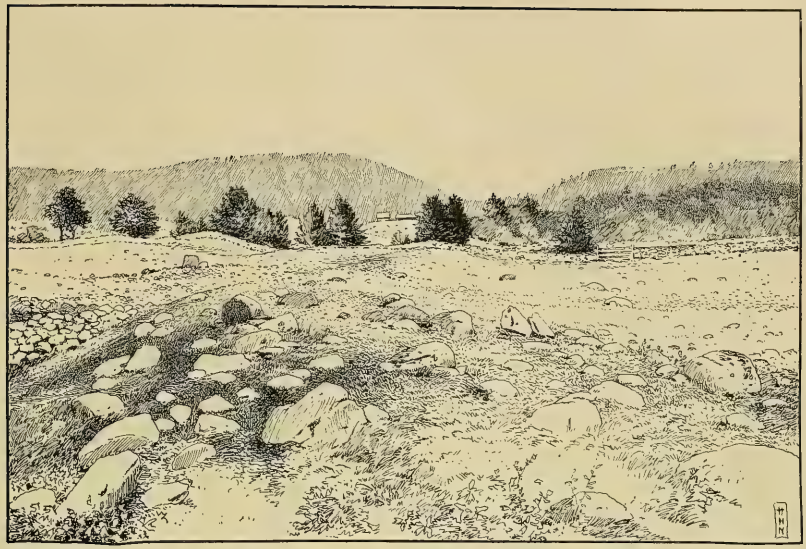
1. In many places, especially in western Maine, the large bowlders are more abundant in the kames and osars than in the same amount of the average till of the region. (See Pl. XXVII, *A*.) This is due to the finer part of the till having been washed away, leaving the coarser residue.

2. Almost universally the largest bowlders of the till are most abundant at the surface. In the glacial gravels the larger bowlders are as often, perhaps more often, contained in the lower part of the gravel. The two arrangements so alternate in the glacial gravels as to make the interpretation doubtful. Most of the large bowlders in the glacial gravel are found in the granite areas, sometimes underlying and sometimes overlying finer sediments.

In this connection we must also consider what has become of the bowlders that were contained in the ice that was melted and eroded during the formation and maintenance of the channel in which the glacial sediment was deposited. This ice must have contained its average proportion of bowlders, yet over large areas only fine matter appears on the surface of the osars and osar-plains. As elsewhere noted, we have reason to believe that the osars are, on the average, areas of accumulation. With material

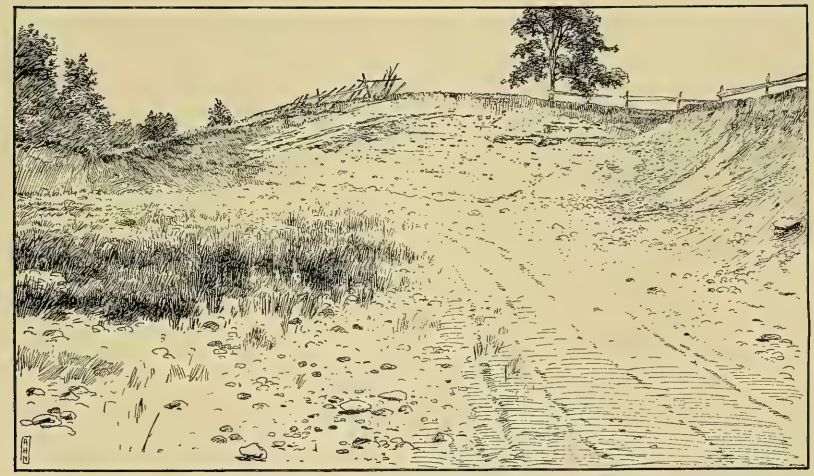
that may be termed indigenous—because, in order to become a part of the glacial gravel, it only needed to be laid bare by the melting and erosion of the ice around it—there is mixed much matter derived from the subglacial till or the adjacent regions. The indigenous matter, as it was released from the ice, necessarily fell into the channel and became mixed with the foreign drift. The details of osar transportation are very complex, and the interpretation in case of individual bowlders is doubtful, in view of the many alternative fates that might happen to any particular stone or bowlder. When a polished bowlder overlies finer sediment, we know the order of deposition, but we do not know whether the bowlder fell from the roof of an ice vault, or slid down from the overhanging walls of a canyon, or was transported to the place by moving water, or by floating ice, or by an ice gorge. Unfortunately the presence of large water-rolled bowlders does not give us a conclusive answer to the question whether they were transported by subglacial or superficial streams. Yet where they overlie finer sediments, the larger the number of such bowlders the greater is the probability that they were dropped from the roof of a subglacial vault. This is a sufficient dynamical cause for large bowlders being lifted above finer sediments, and it is a constant and inevitable feature of the marginal part of an ice-sheet. Certainly a less number of bowlders will be contained in the ice of the overhanging walls of an open channel than in the whole roof of an arch. Besides, the other modes of transportation named are agencies that would naturally be occasional rather than constant methods of the glacial river.

Summary.—In case of a superficial river, the melting and erosion of the ice in the channel would proceed from above downward to the ground, and then laterally outward. The disposition of the larger bowlders of the till indicates that, on the average, the large bowlders were as high in the ice as the finer materials were, or probably higher than they were. If so, these large bowlders would first be laid bare in the bottom of the deepening superficial channel. Subsequently deposited sediments would be laid on top of them or at their sides. The only large bowlders dropped from the ice into the osar channel would be from the overhanging lateral walls. We thus see that in case of a superficial canyon most of the bowlders of the upper till contained within the ice melted or eroded to form the channel ought to be beneath the gravel. The argument is complicated by the



A. RETICULATED RIDGES OF COARSE WATER-ROLLED GRAVEL; PARSONSFIELD. LOOKING NORTH.

Glacial river flowed through low pass in distance down the hill to the foreground.



B. STRATIFICATION OF GLACIAL MARINE DELTA; MONROE.

fact that we have no proof that the whole length of an open canyon would be simultaneously an area of deposition. On the contrary, the analogies all favor the hypothesis that as the ice retreated northward the more northern portion of superficial channels would be areas of denudation, their drift being swept southward and deposited nearer the margin of the ice-sheet. If so, we would have at each place the ice all melted in the bottoms of the channels before sediments began to be deposited, and this would result in all the bowlders first being freed from ice and left on the bed of the canyon, to be afterwards covered with finer drift. This would well account for the long reaches of osars and osar-plains containing few or no large bowlders on the surface.

In case of a subglacial river, the enlargement proceeded from below upward and laterally. The bowlders contained in the ice forming the roof of the vault would from time to time drop into the channel as it became enlarged and they were released from the ice. If the bowlders were high up in the ice, they would be last to fall. Yet if at this place the velocity were such as to sweep all the finer matter from the channel, these bowlders might be left on the bed of the subglacial stream. Then as the ice became thinner a time might come when fine matter would be deposited at this place, and now be found overlying the large bowlders. So also the local land slopes must be considered, i. e., whether the place of observation was on up or down slopes.

Thus the large bowlders do not form a crucial test between the subglacial and superglacial streams. Yet we are warranted in affirming that the presence of very large quantities of fine sedimentary matter overlying the till bowlders is consistent with the hypothesis of a superficial stream, and the presence of a large number of rolled bowlders in the upper parts of the glacial gravels can be considered as probable evidence of a subglacial stream. The fewer the number of such bowlders in the one case and the greater the number in the other, the greater becomes the degree of probability. And the matter is still further complicated by the great difference in the size of the bowlders furnished by the different kinds of rock. In slate regions there might be found only one bowlder to a square rod, while in granite regions there might be ten or twenty. A superficial channel would show very different deposits in the two cases, yet they would be formed in the same manner; and so of a subglacial stream.

REMARKS ON THE GLACIATION OF THE ROCKY MOUNTAINS.

The glaciation of the Rocky Mountains throws some light on the glaciation of Maine, and therefore a few of the principal valleys are here briefly described. Questions pertaining to the problems of two or more glaciations of the mountains and the water drift of Tertiary time are omitted as not having a direct bearing on the questions arising in Maine.

LA PLATA MOUNTAINS.

These mountains are situated in southwestern Colorado (north latitude 37° 25′), and rise above 13,000 feet. They lie to the west of the San Juan Mountains, and are the first high mountains encountered by the warm southwest winds that bring moisture from the Pacific Ocean. To the west and southwest lies the great plain of Arizona and southern Utah, out of which rise here and there volcanic peaks and ranges of hills. The precipitation in the form of snow is heavy in these mountains. Snowslides frequently rush down the lateral ravines into the main valleys in such masses that often they do not entirely melt during the summer, although situated so far south.

The mountains consist of a mass of upheaval due to igneous eruptions through sedimentary beds which have been somewhat metamorphosed. This makes it easy to recognize matter from the mountains as compared with the unaltered sediments of the adjacent plains. The mass of upheaval has been deeply dissected by a radiating system of streams, so that the mountains now consist of centrally connected ridges separated by profound canyons ending above in rather narrow cirques, the ridges being only a few feet wide on their tops and having their lateral slopes steep as talus will lie, and often precipitous. Many of these slopes are so steep that lateral moraines must have slid down the mountain sides as fast as the glaciers melted, but here and there are broader parts of the ridges, or shelves on their sides, or gutter slopes, where morainal matter could lodge.

The evidence is conclusive that these valleys were once filled by extensive glaciers.

Glacial scratches.—Although the local rocks resist chemical decomposition very well, they fracture readily. Hence, only here and there does the exposed rock in place preserve the glacial scratches. Many places are covered with a talus which shows slabs up to 4 feet in length that are well

glaciated on one side. Fresh exposures from beneath the soil reveal glaciated rock up to near the top of the secondary ridges.

Moraines.—On the steeper lateral slopes of the valleys there is no moraine stuff. On gentler slopes there is a thin sheet or scattering of erratics. No distinct ridges or terraces were observed, except one on a shelf of the mountainside situated in the valley of the East Mancos River about 3 miles from its head, and 250 feet above the valley; also two at Helmet Peak. This peak is the highest peak of a high ridge which separates the East Mancos and West Mancos valleys. To the west (in lee of) this peak, and perhaps 50 feet below the summit, are two moraines, one lateral to each valley. Most of the material is rather fine and well glaciated. The upper surface of the moraines conforms to the slopes of the mountain, here quite gentle. These terraces are shown to be moraines, not only by the glaciation of the stones, but also by the fact that the local rock is igneous (hornblendic trachyte of Hayden) while most of the glaciated stones are of quartzite and other erratic material. The upper part of the peak is so weathered and shattered that I can not be sure whether it was ever glaciated or not; hence it is uncertain whether these moraines were pushed out laterally at the surface of the ice or were formed subglacially as tail to the peak as crag, at a time when the ice in the two valleys rose above the ridge that divides them. This is about 600 feet above the valley of the East Mancos.

In the upper 3 miles of the valley of East Mancos River there are a number of small retreatal or terminal moraines in the bottom of the valley, which here is U-shaped, but becomes V-shaped nearer the plains. After entering the plains the stream flows in a valley of erosion in sedimentary beds. This valley grows wider and wider up to near a mile in breadth at Mancos.

Lateral and terminal moraines would naturally form where the stream emerges from the mountains, but the slope here is very steep, and most of the moraine stuff appears to have become a part of the glacial gravel or has been left much scattered. The upper valley of La Plata River is considerably broader than that of the East Mancos. It contained a much larger glacier, which has left moraines arranged about like those of the valley already described.

Glacial gravels.—Large overwash or frontal aprons of water-rounded gravel,

cobbles, bowlderets, and bowlders up to 5 feet in diameter begin 2 to 4 miles from the head of these streams and extend 15 or more miles down the valleys. The size of the stones grows smaller as we go below the principal terminal moraines. There is a large terrace in the valley of La Plata River a little below where it emerges from the mountains, which is composed in large part of very coarse matter and appears like a water-washed terminal moraine. The bowlders were probably rounded by the waves of a Tertiary lake.

In the narrower part of the East Mancos Valley the plain of water-rounded matter is 50 to 150 feet wide and 3 to 8 feet deep. While the stones of the moraines show unequal wear into subangular forms, and some faces with little wear, these are polished quite equally on all sides and have much rounder shapes. Some parts of the valley have been worked as gold placers, and thus it has been revealed that underneath the gravel is glaciated rock, hollowed out into numerous rather shallow potholes. The miners affirm that most of the gold, which is quite coarse, is found in coarse gravel near the bed rock, and not in the bottoms of the potholes and hollows, but on level rock between them. This proves that the currents were swiftest where the potholes and basins now are. The gravels are most easily interpreted as due to swift subglacial streams, either beneath the ice or in front of the ice as they rushed from the mouths of their tunnels. The stream has eroded a portion of the original gravel deposit and rearranged a portion as a new flood-plain.

Summary.—The principal valleys of La Plata Mountains were filled by glaciers 600 or more feet deep. A very large proportion of the transported matter was acted upon by the subglacial streams, with the result that for many miles the valleys are strewn with frontal plains of glacial sediments, though mixed probably with considerable stream wash. The moraines are of less size than the ordinary for glaciers of such length. Hayden's Atlas of Colorado shows no moraines among La Plata Mountains. My exploration of the mountains was confined to two valleys.

LAS ANIMAS VALLEY.

Las Animas River rises in the heart of the San Juan Mountains and flows southward into New Mexico, where it joins the San Juan River, which it is the principal tributary. Its head waters occupy a radiating

system of deep valleys bordered by mountains rising to elevations of from 11,000 to 14,000 feet. Over the upper part of this valley, covering 500 square miles, the precipitation is probably greater than over any other equal area in Colorado. Every cirque and lateral valley contained its glacier, which was tributary to that of a main valley.

The rocks of this region are largely volcanic, and in general weather easily, either by chemical decomposition or by fracture. Glacial scorings are seldom found on exposed rock surfaces. Excavations made in constructing roads over the mountain passes and to the mines show that in the larger cirques and passes the rock is glaciated up to about 12,000 feet. Mining excavations have been made at higher elevations, but none of them visited by me are in such situations that we could expect them to show the glaciated rock. Hence, while it is probable that the glaciers extended nearly or quite to the tops of the higher basins, I have as yet no glacial scratches to prove it.

The scratches in the lateral valleys are parallel with these valleys, but as we descend them we come to where the scratches are parallel with the main valleys and transverse to the lateral. Obviously if we can determine the height above the main valleys that these scratches parallel with them reach, we shall know the depth of the great valley glaciers. Such scratches I have from time to time observed, and by degrees the upper limit was raised, till now it is proved that the main Las Animas glacier was more than 1,000 feet deep at Silverton and at least 1,500 feet at a point 5 miles south of Silverton. This was the main outlet of the ice of this region. The tributary glaciers reached to the tops of cols 12,000 feet high, and perhaps higher. Thus at Stony Pass, a pass from the Rio Grande over the Continental Divide to Las Animas Valley via Cunningham Gulch, I found well-glaciated rock within 100 feet horizontally from the top of the pass, and on both slopes. On each side were peaks of the range rising 1,000 feet or more above the pass. It is thus proved that the flow took place from the very top of the ridge down two valleys in opposite directions. The supply probably came laterally from the adjacent peaks.

Nowhere in these steep mountains have I found prominent lateral moraines in the form of ridges or terraces. Many of the slopes are so steep that no moraine stuff could remain perched on them. The volcanic rocks have often weathered and formed slides of talus 1,000 to 2,000 feet high.

On the gentler slopes there is a body of drift that forms a complex problem. Near the underlying rock almost all the stones show considerable attrition, the original forms due to weathering and fracture having been somewhat changed by a subsequent process of polishing. The coarser stones are mixed with some fine matter, thus forming a mass somewhat resembling the till of New England. Approaching the surface, we find an increasing proportion of rain wash and talus. Some of the worn stones are distinctly glaciated. On steep slopes where there has been much sliding and soil-cap movement, the stones are subject to some wear, and thus the interpretation of the sheets of drift on the wooded slopes of these mountains is difficult. In many places there are bowlders in this drift that have plainly come from a distance; hence, in part at least, it is of glacial origin. Naturally where the snow covered the mountains almost to their summits there would be much matter borne onward in the lower part of the ice. I leave it as an open question how far the drift sheets of the gentler slopes of these mountains were deposited subglacially and how far they are a lateral moraine, left at the margin of the ice as it melted and sank to lower levels.

The two forks of Mineral Creek come together at right angles. The valley of the South Fork is the larger. At a time when the ice had retreated from Las Animas Valley, also from the North Fork of Mineral Creek, a glacier still continued to flow in the valley of the South Fork. It flowed across the valley of the North Fork and abutted against Red Mountain, where it deposited a terminal moraine 100 feet high near the railroad from Silverton to Ironton. Above Silverton there are a number of terminal (retreatal) moraines, more or less water-washed. All are small.

About a mile north of the city of Durango a terminal moraine extends across the valley of Las Animas River, here about one-third of a mile wide. It forms a low ridge rising 10 to 30 feet above the sedimentary matter that covers its flanks. It is thus proved that at one time the ice flowed to or beyond Durango at an elevation of about 6,000 feet. I have not explored the valley below that point sufficiently to know the extreme limit of the ice. From Durango to Silverton it is 45 miles, and to the head of the Las Animas 65 to 70 miles. Assuming that the ice surface was at the top of the mesa near Durango and rose 1,500 feet above Silverton, we have an average surface gradient of about 120 feet per mile.

From where Las Animas River emerges from the mountains it flows in

a valley 1 to 2 miles wide which extends for 12 miles and then suddenly narrows to one-third of a mile. It is at this point that the terminal (or retreatal) moraine near Durango is formed. North of this point a sheet of water-rounded matter containing many bowlderets and bowlders extends for many miles up Las Animas Valley. At the melting of the ice at this point the moraine and overwash plain formed a barrier or dam across the valley, and in the broad valley to the north there gathered a shallow lake. Into this temporary lake there came a broad sheet of sand and silt. It is now practically drained by the river cutting down through the dam at Durango.

The valley of Las Animas River for many miles in the mountains contains a body of water-rounded glacial gravel, now deeply eroded, so that in many places a little terrace here and there is all there is left of a deposit once 30 to 70 feet deep. In other places, as at Silverton, this gravel plain is still well developed.

It is thus proved that a glacier 1,500 or more feet deep originated in Las Animas Valley and flowed 70 or more miles southward. For many miles it was a mile or more in breadth. It left rather scanty moraines for a glacier of its size, but a very large amount of water-transported matter. Its distal extremity reaches 37° 15′ north latitude or less, an elevation somewhat below 6,500 feet.

Glaciers occupied the upper valleys of Los Pinos, San Juan, Navajo, Chama, and other rivers of the western slopes of the San Juan Mountains, but I have not explored them sufficiently for notice here.

UPPER RIO GRANDE VALLEY.

A very large glacier must have occupied the upper Rio Grande Valley. A large number of basins and valleys open down into it from the Continental Divide, all well glaciated. My explorations were near the head waters, and do not permit description of the lower end of this large glacier.

VALLEY OF THE SAN MIGUEL RIVER.

The main river flows in a box canyon deeply eroded in sedimentary rocks which are nearly horizontally bedded. Approaching the mountains, we find the branches occupying valleys eroded down through sheets of volcanic lavas and tuffs into sedimentary beds, while in the higher cirques

and valleys we find the volcanic rock alone. The mountains rise to heights varying from 11,000 to near 14,000 feet. They receive the first onset of the Pacific winds, and the precipitation is great. The valley of the North Fork was occupied by a glacier which left a terminal moraine near Keystone, about 5 miles west from Telluride. Many of the slopes are so steep that moraines would slide at once down to the bottoms of the valleys, but in many places there is a sprinkling of erratics on the sides of the valleys. Ophir and Trout Lake basins, on the South Fork of the San Miguel, each contained glaciers which left moraines in the bottoms of their valleys, but their gathering-grounds were small and they appear to have been less than 8 miles in length.

The bottoms of the valleys of the San Miguel River and its three principal tributaries were once covered with a deep body of well-rounded gravel and coarser matter up to bowlders. This original deposit has now been eroded to depths of 30 to 70 feet, leaving portions of the old plain as terraces on the steep sides of the canyons, the so-called high bars of the placer miners. These terraces, growing finer by degrees, extend 40 miles from the mountains—how much more I do not know. They in part consist of Tertiary drift. In these valleys the overwash apron of glacial gravel far exceeded in bulk the moraines. The glacial gravel is found all the way from the moraines up to the mountain basins.

VALLEY OF THE UNCOMPAHGRE RIVER.

This stream heads against Las Animas River and flows in the opposite direction northward, and, having cut deep canyons through the Mount Sneffles Range, emerges from the mountains a few miles below Ouray. South of Ouray the very ancient quartzites are intensely glaciated, but retain an uneven and hummocky surface. The gentler slopes of the mountains carry sheets of drift which in composition and character resemble those of the upper Las Animas Valley above described. Two V-shaped valleys join at Ouray, below which point the valley is U-shaped and soon broadens to a mile or more near Ridgway, where the Dallas branch joins the main stream. Here a broad series of ridges and heaps of erratics extends obliquely across the valleys of both branches just below their junction. Glaciers came down both valleys and left these moraines, which are more than a mile long and near half a mile wide, rising in places to 150 feet

in height. The moraines have been deeply cut by the river. I have not been able to find any moraines below Dallas, and probably these moraines between Ridgway and Dallas mark the extreme advance of the ice.

The bottom of the valley from Ouray northward 40 miles to beyond Montrose is covered with rounded and rolled gravel and coarser matter. In places this overwash sheet is more than a mile wide. The fact that the same sort of gravel plain extends for 12 miles above the outermost moraines proves that the subglacial streams during the retreat for a long time continued to pour out glacial gravel into the open valley in front of the ice. Where observed this gravel is rather horizontally stratified and shows none of the appearance of the reticulated kame ridges. The retreat of the ice appears to have been rather gradual, since there are only small retreatal moraines in the lower parts of the valley. The sides of the main valley show a sprinkling of erratics, except where precipitous.

The Uncompahgre glacier reached only 8 miles beyond the mountains, but transported a very large amount of morainal matter, and also glacial sediments. The base of the terminal moraine at Ridgway is at 7,000 feet elevation.

There were numerous glaciers in the valleys tributary to the Gunnison River, some of them of large size.

UPPER ARKANSAS VALLEY.

The glacial deposits of this valley were first described by the Hayden Survey, and later by Emmons in his Leadville monograph.[1] It is impossible to do justice to this interesting valley without going into detail more than is here practicable, and only a few points will be noted. The first thing that attracts attention is the enormous size of the moraines which the glaciers that originated in the Sawatch Range have left across the main valley. The Arkansas Valley from Leadville southward to Salida is from 2 to 4 miles wide between the bases of the steep mountains. The lateral glaciers flowing down from the mountains did not fill this broad valley—at least they did not for a long time during the last part of the ice period—and thus left moraines at the sides and in front of their valleys. Some of these moraines cover several square miles and are up to 1,000 feet in height.

[1] Geology and Mining Industry of Leadville, with atlas, Mon. U. S. Geol. Survey, vol. 12, pp. 40–42, 1886.

The lateral moraines form large ridges or terraces upon the mountain sides. The glaciers from the west side of the valley were much larger than those from the east. It is possible that at one time a broad glacier occupied the whole Arkansas Valley, but my own observations leave the matter in doubt as to the last glacial period. A good place for observing these phenomena is in the valley of Box Creek, and its tributaries, Willow Gulch and Harrington Gulch. They originate on the eastern slopes of Mount Elbert and flow southeastward and eastward into the Arkansas River near Hayden station, on the Denver and Rio Grande Railroad, about 12 miles below Leadville. Near here, on both sides of the Arkansas River, are well exhibited two types of valleys, the broad U-shaped valleys that were occupied by glaciers while their margins were being piled high with morainal and sedimentary drift, and the narrower valleys, generally V-shaped, due to recent erosion of a once continuous mass. The Arkansas River is here bordered by a rather level plain of glacial sediments about a mile wide. Extending west from this plain is the plain-like valley of Box Creek and its tributaries, from one-fourth mile to near a mile in width. Near the Arkansas they are bordered by mesas of glacial sediments ending in steep bluffs 150 to 250 feet high, while as we near the mountains they are bordered by bluff-like lateral moraines. These moraines prove conclusively that the upper portions of these valleys were filled by glaciers that originated in the large cirques of Mount Elbert. If the glaciers had stopped at the base of the mountain they ought to have deposited terminal moraines. Instead, a U-shaped valley of the same character as those bordered by lateral moraines extends continuously to the Arkansas Valley, which is also free from moraines at this place. The conclusion follows that three glaciers originated on Mount Elbert and united near its base to form a single tongue, and it in turn united with a glacier which filled the bottom of the Arkansas Valley for many miles below Leadville over a varying breadth of one-half mile to somewhat more than a mile. This main glacier received many tributaries from the adjoining mountains. Between the successive lateral valley glaciers and the main glacier that extended along the axis of the Arkansas Valley there were open spaces bare of ice into which the subglacial streams of the lateral glaciers poured and deposited overwash aprons of glacial sediments. Sometimes these alluvial mesas end next the river bluffs in sand or fine clay and rock flour, proving that here were glacial

lakes. In other places coarse gravel continues right up to the bluff marking the former margin of the Arkansas glacier, proving that the waters that were poured from above into these open spaces found ready exit into the subglacial waterways of the main glacier, and in such cases the alluvial mesa was formed subaerially, ending in a steep bluff because piled against the side of the Arkansas glacier. The symmetry of the U-shaped valleys bordered by bluffs of glacial sediments or moraines is better preserved in case of the shorter glaciers. The enormous amount of morainal matter brought down by the longer lateral glaciers formed dams that obstructed their flow and forced them to wander in search of an outlet. On the great moraines of the Lake Creek glacier, which are situated northeast of Twin Lakes, and which formed in part the lateral moraine of the Willow Gulch glacier of Mount Elbert, we find remarkably sudden transitions between morainal ridges and glacial sediments. The region has been prospected by placer miners, and thus were revealed the following facts: At the top of the great moraine a shaft was dug 98 feet in gritty clay. The digging is on a small level place. Two hundred feet west a steep ridge rises perhaps 50 feet above this flat and is composed of bowlders and other coarse moraine stuff. In several places are mounds or small mesas that rise 50 to 100 feet above the rest of the moraine, which are proved by tunnels and shafts to be composed of clay and fine sand. These local masses of fine sediments in the midst of moraines were probably deposited in small glacial lakes like those of the marginal region of the Malespina glacier, described by Russell. The retreat of the Mount Elbert glaciers here described seems to have been quite rapid until we reach the base of the mountain. Here the principal tributary, the Willow Gulch glacier, formed several frontal alluvial terraces at different elevations. Going up the mountain from this place we find only a few small deposits of glacial gravel, the streams of the shortening glacier becoming too feeble to transport much sediment. But the shrinking of the glacier is marked by a series of retreatal moraines that are found every half mile or so up to timber line. Near the base of the mountain the morainal matter is nearly all well glaciated, and often contains so much rock flour, clay, and fine débris as to resemble the till of New England. Going up the mountain we find the glaciation becoming less intense, till at the last we find rock piles in the characteristic form of moraines with few signs of attrition. This delineation is only intended to

describe the last part of the last glacial period. Earlier the lateral glaciers may have been confluent in an ice-sheet which covered all the Arkansas Valley from mountain to mountain.

We also here have the same alluvial aprons we find in the San Juan valleys. Not being confined in a narrow valley, they take the characteristic form of the alluvial cone radiating from the terminal moraines. The aprons are somewhat distinct as far south as Buena Vista; then they merge into a plain of coarse water-rounded matter that occupies the valley to a point beyond Pueblo, except where it has disappeared owing to erosion. Some of this water-rolled matter came from the Wet Mountains and the Sangre de Christo Range, but most of it came down the main Arkansas River.

The general law of frontal aprons of glacial gravel is that they become finer as we go away from the principal terminal moraines. From the mouth of Lake Creek to near Buena Vista there are multitudes of water-rounded bowlders in the plain of rolled matter that here covers the eastern part of the Arkansas Valley. Many of them are from 6 to 10 feet in diameter. Of course it is not meant to assert that they were not glaciated before being worn by the action of water. Below this point the material becomes finer.

Emmons has described the so-called "Lake beds" at Leadville. I have discovered there were local glacial lakes not far from Twin Lakes and at other points in the valley. They formed between the tongues of ice that then projected into the valleys and formed dams across it extending to the main valley glacier.

PIKES PEAK RANGE.

Glaciers formed in the valleys of some of the branches of West Beaver Creek that were 3 to 4 miles in length; also in the deep canyon-like valley that extends north from the peak, but I have not explored the latter systematically. A glacier formed on the south slopes of Pikes Peak in the valley of East Beaver Creek. Its terminal moraines form the dams that confine the Seven Lakes. The morainal matter is itself somewhat sandy and water-washed, but the valley below here contains no overwash apron of glacial gravel. Probably there was some rather fine sediment, but it has now disappeared by erosion on a steep slope. The length of this glacier was not far from 3 miles.

Lake Moraine is situated in a valley descending from the col between Pikes Peak and Bald Mountain. A glacier but little more than a mile in length occupied this basin. It left prominent lateral moraines near 200 feet above the bottom of the basin, and formed a massive terminal moraine near one-fourth of a mile long and 100 or more feet deep. There is a depression across the terminal moraine, in which a stream flows. No glacial gravel appears in the valley below, which is very steep, so that the overwash of the glacier would soon be eroded. In the bottom of the depression in the terminal moraine appears a mass of fine sediment, mixed with occasional bowlders, which, under the microscope, is seen to consist of glacial rock flour.

This little glacier was situated between 10,000 and 11,000 feet elevation. The snowfall of this range is much less than that of the Continental Divide. The temperature was low even in summer. The glacial waters flowed so sluggishly that even much of the rock flour did not get beyond the terminal moraine.

A little glacier formed on the east side of Pikes Peak and formed a diminutive moraine which now holds in a lakelet.

SOUTH PARK.

A number of glaciers originated in the Mosquito Range and flowed eastward into the South Park. Some of them were near 10 miles in length. They left moderate-sized moraines and plains of glacial gravel that extend 15 miles down into the open park. These plains are marked "scattered drift" on Hayden's maps. In most cases where I have had opportunity to examine a region thus marked they end in the mountains in a glaciated region and are frontal plains of glacial sediments. The proportion of glacial gravel to moraines is here probably greater than in the Arkansas Valley.

ROARING FORK.

The valley of the Middle Branch of the Roaring Fork contained a glacier 15 or more miles in length. The moraines of this glacier can be seen from the Colorado Midland Railway. Lake Ivanhoe, along this railway, is held in by a morainal dam. Below the terminal moraines the valley was left covered with a deep sheet of water-rolled sediments which has now been eroded to a depth of 30 or more feet.

The valleys tributary to the South Branch of the Roaring Fork were occupied by glaciers to a point not far below Aspen. They left moderate-sized moraines and a sheet of glacial gravel that extends for 30 or more miles down the valley. In the valley of Hunters Creek, east of Aspen, a line of perched bowlders marks the upper limit of the ice.

ROCK CREEK.

This stream flows for a few miles west, and then north, and drains the western slopes of the Elk Mountains. Glaciers extended 12 miles down the valley and have left numerous rather small moraines. The amount of glacial gravel in the valley is less than in most valleys of the western slope having so large a drainage surface.

When one follows the Roaring Fork down to its junction with the Eagle River to form the Grand River, and thence down to the Colorado, he will appreciate what a tremendous weapon the glaciers furnished the present rivers. The plains of rolled gravel and cobbles left by the glaciers have helped protect the higher slopes of the mountains from erosion, but the streams have rolled them down to the Gulf of California with fatal effect on the plains and plateaus. In time of high water the ceaseless rattle and roar of those stones as the Grand River surges them on is one of the most astonishing phenomena of the mountain slopes. If the ear be held near the water or against a boat, one hears a roar as of distant thunder mingled with the sharper click of near-by stones. After that the profound canyons of the plateau region are no mystery.

ESTES PARK.

Several glaciers 5 to 10 miles long flowed down into Estes Park. They left very large lateral moraines near where they enter the park, and smaller terminal moraines at about 6,100 feet elevation. The retreat of the ice is marked by a series of terminal moraines, which are found at intervals all the way up to the ultimate basins in which the glaciers originated. Nowhere have I seen such great masses of bowlders showing few or no signs of glaciation and without admixture of fine material, as some of these retreated moraines exhibit. They are locally known as bowlder fields, and are often almost impassable even to men on foot, owing to the large size of the bowlders. They are mostly of granite and are more

angular than ordinary bowlders of decomposition. The proportion of glacial gravel to morainal matter is smaller than in any other glaciers of the same size that I have found in Colorado.

In the higher cirques of this region there are numerous fields of perpetual snow. One of these in a valley lying on the northeast slopes of Hague's Peak is consolidated to ice and exhibits transverse crevasses. It is plainly sliding, if not flowing, down the mountain side. It appears so much like a true glacier that I have named it the Hallett glacier, after the discoverer.

VALLEY OF THE SALMON RIVER, IDAHO.

Many local glaciers originated in the Bitterroot Mountains and flowed down into the valleys of the Salmon River and its tributaries. The Lemhi Valley for many miles above Salmon City is several miles wide. It is a valley of erosion in sedimentary fresh-water lake beds. In the bottom of the valley is an extensive plain of rounded gravel and cobbles, while on the tops of mesas 200 to 300 feet higher is a thin sheet of similar material. This higher gravel may be due to a more ancient glaciation than the last, or it may have been formed on the margin of a great confluent glacier that filled the whole valley. It is probable that some or all of these are beach pebbles of the old lake.

West of Salmon City lies the Salmon River Range of mountains. They rise rather steeply from the valleys of Salmon River and its tributaries up to an altitude of 6,000 to 9,000 feet. The main range lies nearly north and south, and there are several spurs reaching out to the west and northwest. The rocks are very ancient quartzites, slates, and schists with intervening and bordering areas of coarser granites and a few extrusions of rather recent acidic volcanic rocks. The original masses of upheaval have been dissected into many valleys and basins, and show plainly the marks of geological old age. The mountains are well exposed to moist winds from the Pacific Ocean, and the precipitation is large.

Napius Creek drains a large area on the western slopes of these mountains and flows into Big Creek, itself a tributary of Salmon River. I have had opportunity to partially explore the upper 20 miles of this valley, extending 7 miles west from the old mining camp of Leesburg to the so-called Falls of Napius Creek. Here the stream cuts through a high ridge of granite, and thence descends by a series of rapids and cascades to

Big Creek. Numerous lateral valleys extend from the main creek from 5 to 10 miles into the mountains. The area of this part of the valley is about 300 square miles. The elevation of the Falls of Napius (or Bull of the Woods) is about 5,700 feet. Lying east of this point is an area of several square miles of volcanic rock, then a crescent of schists and quartzites, and around that a crooked belt of granites. This makes it easy to distinguish local from transported matter.

The lateral valleys and cirques were once filled by glaciers which united in the main valley to form a large glacier or ice-sheet that rose above the hills adjoining the main creek so as to extend back for a mile or more into the lateral valleys. This is proved by the following facts:

The quartzites resist chemical decay, but readily fracture. The volcanic rocks, granites, and schists yield to both fracture and chemical action. Hence the exposed rock has seldom preserved its glacial scratches. Fresh exposures reveal glaciated rock in various places in the valley.

MORAINES.

Moraines of four kinds were observed.

Lateral moraines.—The slopes of the hills next to the main valleys are strewn with a scattering of erratic material, but no distinct or prominent ridges or terraces were found.

Terminal moraines.—About 2 miles east of the Falls of Napius is a moraine on the north side of the creek beginning near the stream and extending at nearly a right angle to the creek northward up to an elevation of about 800 feet above the creek. It forms a series of low ridges with some outlying spurs. The mountainside on which it lies rises pretty steeply from the stream. The great depth of the ice at this point makes it certain that the glacier extended far beyond the region explored; hence this is a retreatal moraine. The moraine corresponding to this on the south side of the creek has disappeared near the stream on a very steep slope. There are several other small terminal or retreatal moraines above this at intervals in the valley.

Crag and tail.—The high granite ridge which extends northeastward from the Falls of Napius shows no erratics till we reach a point three-fourths of a mile north from the creek. Here on a broader part of the ridge is a moraine consisting of well-glaciated stones with a few bowlders. It forms a sheet

that caps the ridge and is only 200 or 300 feet wide and a short fourth of a mile long. It formed in lee of a small peak of volcanic rock that projects about 30 feet above the side of the little peak, and a few glaciated stones are also found on the other two sides of the crag, but none on its top. Perhaps a better name for this arrangement would be "crag and collar." This is about 500 feet above Napius Creek.

Crag and cap.—About 3 miles east of the last-named locality and 1 mile south of Napius Creek is an oblong-conical hill rising about 800 feet above the creek. The top of the hill is capped by a ridge of glaciated matter and erratics. The local rock is a dark schist entirely unlike the morainal matter. The ridge is hardly one-eighth of a mile long and 250 feet wide, with steep lateral slopes. It contains many granite bowlders from 10 up to 20 feet in diameter.

I noticed several other moraines capping hills at different elevations. These moraines are separated by large areas that show little or no foreign matter. We have not a sheet of till, like that which covers New England, but local masses here and there. The situations of these high moraines described as crag and collar and crag and cap appear to be similar to the moraines now forming at the nunatakker of the Greenland ice-sheet. They probably formed when the hills rose near or above the surface of the ice. It is doubtful whether this drift was transported subglacially or superglacially, or both. The large areas bare of transported matter favor the hypothesis of much of surface transportation; the intense glaciation of much of the morainal matter favors the subglacial hypothesis.

GLACIAL GRAVELS.

One of the most noticeable features of this valley is the large sheet of waterworn gravel, cobbles, and bowlderets, with some bowlders, which once filled the bottom of the main valley and thence extended up the lateral valleys for several miles. The stream has eroded the old plain to depths of 30 to 70 feet, the uneroded portions forming terraces, known to placer miners as bars. As we go back from the stream the gravel slopes upward 100 or more feet per mile. Excavations for placer mining show that under the gravel lies well-glaciated rock in place. The gravel plain is 2 miles wide a short distance west from Leesburg. Mixed with much waterworn matter are some stones bearing glacial scratches. The proportion of this sort of

stones increases as we go back from the main creek. Some of these enlargements of the gravel plain may have been deposited in glacial lakes caused by some of the lateral glaciers flowing across the main valley and damming it. I nowhere found, however, anything that resembles the reticulated kames, though there are here, as in numerous places in the Arkansas Valley, low swells or ridges obliquely transverse to the course of the glaciers showing one slope of the cross section shorter and steeper than the other. In all cases the distal slope is the steeper. A large amount of water-rounded matter is found in the valleys below the region visited.

SUMMARY.

An ice-sheet covered the bottom of the valley of Napius Creek and rose above the hills near the river. Higher in the mountains the hills separating the lateral valleys probably rose above the snow; they certainly rose far above the confluent glacier of the main valley. This ice-sheet formed "nunatak" moraines at various points, but no continuous sheet of till. The proportion of water-rolled as compared with morainal matter is very large. This seems to indicate that this gravel plain was formed in front of the ice during the final melting. The much-rolled matter was poured out by the subglacial streams in front of the ice, and the morainal matter that was on or in the ice fell into the water at the ice front, and thus received too little waterwear to efface the glacial scratches. The gravels poured out during the time of maximum depth of ice are beyond the field explored.

GENERAL SUMMARY OF THE ROCKY MOUNTAIN REGION.

The above-recorded observations cover nearly 10 degrees of latitude, though most of them were made in the State of Colorado.

Several characteristics of the glaciation of the mountain region deserve attention.

1. All writers are agreed that the mountain glaciers were confined to single drainage basins. We find the nearest approach to ice-sheets in the larger valleys, where the tributaries united to form glaciers that rose above the low hills and ridges nearest the main valleys.

2. In general the moraines formed at the ends or margins of the glaciers, not subglacially, with a residue of cases where the interpretation is doubtful.

3. All the larger glaciers formed extensive overwash aprons or sheets of water-rolled material, which are coarser in composition at the principal terminal moraines and become finer as we go down the valleys below them. This glacial gravel was deposited in diminishing quantities as we go upward from the outer terminal moraines. The retreatal terminal moraines extend higher up the valleys than the water-rolled matter, and often we find above the last gravel deposit a number of retreatal moraines scattered over a space of a mile or two. Almost every valley in the mountains attests that the small glaciers that marked the final disappearance of the ice formed but little glacial sediment, and what there is shows only a limited amount of waterwear.

4. The glacial gravel is deposited in rather level or even plains or terraces, sometimes rising one above another as we go back into the mountains. No ordinary kames or osars are found, though the low ridges transverse to the course of the glacier above noted are in some degree a correlative deposit to the retreatal moraines and "kames" observed by Wright near the Muir glacier. They are an eighth of a mile broad, and the interpretation is doubtful. They are well developed in a small valley 3 miles north of Twin Lakes in the Arkansas Valley. In several places, such, for instance, as the valley of the Arkansas 12 miles south of Leadville, on the east side of the river, there is a jumble of heaps and ridges of glacial gravel, but this is due to unequal erosion of a once continuous sheet.

The sheets of glacial gravel of the Rocky Mountain glaciers are rather horizontally stratified and in their surface features resemble the broad osars or osar terraces of Maine. They are the equivalents of the deposits I have termed "frontal deltas" in Maine. But whereas in the mountains the finer clay and sand was at once swept away by the rapid streams, except locally in glacial lakes, in Maine the slopes were so gentle that they form broad sheets of silts and clays widely covering the valleys all the way to the seashore of that time.

GLACIERS OF ALASKA.

The origin of frontal or overwash aprons of glacial gravel, also of kames such as are formed by valley glaciers, is illustrated by the Mount St. Elias glaciers described by Prof. Israel C. Russell.[1] The Malaspina

[1] Nat. Geog. Mag., vol. 3, pp. 53-204; also Am. Jour. Sci., 3d series, vol. 43, pp. 169-182, March, 1892.

glacier approaches the character of a local ice-sheet, and more nearly illustrates the conditions of the ice-sheet in Maine than of ordinary Alpine or valley glaciers. Over large areas it is nearly stagnant. During the decay of the ice-sheet in Maine there must have been many places where the ice was in nearly the same condition, the forward flow being arrested by high transverse hills in front, while often the supply from the névé was also obstructed by still higher hills 10 to 30 miles farther north.

Some of the formations illustrated by the observations of Professor Russell are the following:

OVERWASH APRONS.

Along the southern margin of the Malaspina glacier, between the Yahtse and Point Manby, there are hundreds of streams which pour out of the escarpment formed by the border of the glacier or rise like great fountains from the gravel and bowlders at its base. All of these streams are brown and heavy with sediment and overloaded with bowlders and stones. * * * The most interesting of these is Fountain Stream. This comes to the surface in one great spring fully 100 feet across. The water rises under such pressure that it is thrown 12 or 15 feet into the air, and sends up jets of spray 6 or 8 feet higher. It then rolls seaward, forming a broad, swift river which divides and spreads out in many channels both to the right and left and has inundated several hundred acres of forest land with gravel and sand.[1]

This admirably illustrates the formation of the large sheets of overwash gravels that extend outward from the terminal moraines of the upper Arkansas Valley and many other valleys in the mountain region. In Maine we have a nearly correlative deposit in the plain of coarse gravel that extends across the Carrabassett Valley near East New Portland and North New Portland, and in several other valleys, as elsewhere described, especially in the valley of the Androscoggin River in Bethel and Gilead, Maine, and extending into Shelburne and Gorham, New Hampshire.

OSAR STREAMS AND OSARS.

The principal streams on the eastern margin in 1891 were the Osar, Kame, and Kwik. Each of these issues from a tunnel and then flows for some distance between walls of ice. Of the three streams mentioned the most interesting is the Kame. This issues from the mouth of a tunnel in the ice about 3 miles back from the actual border of the glacier, and flows for half a mile in a narrow canyon with walls of dirty ice 50 feet or more high. The canyon then expands and forms a valley bordered by moraine-covered hills of ice, which gradually widens toward the east until it merges with a low marshy tract bordering the shore of the bay. Well-rounded

[1] Am. Jour. Sci., 3d series, vol. 43, p. 179, March, 1892.

sand and gravel is being deposited by this stream in large quantities. This covers the ice over which the stream flows, and during former stages was deposited in terraces along the lower portion of the channel. These terraces, in part, at least, rest on ice. The rounded and worn condition of the gravel and sand brought out of the tunnel is proof that it has had a long interglacial or subglacial journey.

On the north side of the open channel of Kame Stream there is a sharp ridge of well-rounded gravel which runs parallel with the present river, and in places can be seen to rest on an icy bed. This was evidently deposited by a stream similar to the present one, but which flowed fully 100 feet higher. This ridge of gravel seems to be of the same general character as the kames of New England and other glaciated regions. * * * The formation of osars seems fully explained by the subglacial drainage of the Malaspina ice-sheet.[1]

In two important conditions the Malaspina ice-sheet or Piedmont glacier varies from the ice-sheet of Maine. 1. In Maine the morainal matter was basal, i. e., contained in the lower part of the ice and taken into the ice from below, while the drift of the Malaspina glacier is on its surface (marginal) or scattered through it to a great height—the result of avalanches bringing down fragments of rock and depositing them in successive layers on the névés of the glaciers. 2. The Mount St. Elias glaciers are bordered by considerable land bare of ice, and a large amount of water warmed above 32° flows onto the glaciers and helps to form and enlarge the subglacial channels. The amount of heat thus transferred to points beneath the ice is very much greater than that carried by superficial waters of the ice surface pouring down crevasses. In Maine the hills are so low that in only a few of the most mountainous regions would the conditions at all approach those of Alaska. Over most of the State the glacier would be reduced to only 200 or 500 feet in thickness before any of the land would rise above the surface of the ice. In the upper Kennebec Valley there are a few high gravel terraces that may have been formed by streams flowing in the depression that forms at the margin of a glacier next a mountainside, but such gravels are rare. I have nowhere yet found in Maine the delta terraces of such marginal lakes as Professor Russell finds so abundantly in Alaska. The short hillside osars were formed by streams that flowed down steep southern slopes. They often expand into deltas at the bottoms of the hills, but there is no series of terraces marking successive levels of the water, except in the courses of the great osar rivers. These were fed by glacial waters, not by waters of the land bare of ice.

[1] Am. Jour. Sci., 3d series, vol. 43, p. 180.

It should also be noted that the extreme stagnation of the Malaspina glacier must favor the solidification of the lower ice and the other causes, whatever they are, for the subglacial streams rising onto the surface of the ice. In cases of rapid glaciers flowing into the sea the subglacial streams are discharged into the sea and do not rise to the surface of the ice some miles back from the seas, as is the case of this interesting glacier.

The ridge described above as found on the ice would probably lose its stratification during the melting of the subjacent ice and in structure resemble Indian Ridge at Andover, Massachusetts, rather than the ordinary stratified osar.

CHAPTER VI.

CLASSIFICATION OF THE GLACIAL SEDIMENTS OF MAINE.

PRELIMINARY REMARKS.

NAMES.

A complete classification of the glacial sediments will not be possible till the facts of all the glaciated countries are correlated. The masses of glacial gravel have everywhere received local names, the ones in most common use by geologists being the Scotch name *kame*, the Irish *esker*, and the Swedish *osar*. At first geologists employed these terms as promiscuously as they are employed in popular usage. Later an attempt has been made at a classification founded on genesis. In a recent letter Professor Chamberlin has set forth his views on this subject as follows:

> When these gravel accumulations arranged themselves in transverse irregular belts and represent marginal action, especially where associated with thrusting action on the part of the ice, they should be distinguished from the longitudinal gravel ridges which represent the internal drainage system of the ice and whose development is quite largely dependent on a stagnant or slow-moving condition of the ice in its last stages.

With the first class is associated the name "kame," with the second the name "osar."

As between the terms "osar" and "esker," the first, as I understand it, has right of priority. The finest known example of the longer gravel ridges is found in Sweden, the next is that of Maine. According to published descriptions the gravels of Maine are more like those of Sweden than of Ireland. Certainly the grandest gravel system of all ought to receive recognition in our nomenclature. I retain the term "osar" for the longitudinal gravel system, and shall for the present employ the word "esker" as a general term applicable to any mass or ridge of glacial gravel irrespective of genetic classification. Thus, if a series of separated deposits be known

as a discontinuous osar, we need some term to apply to the separate mounds and ridges, and for such purposes I employ the word "esker."

The gravel masses have various external features, such as continuity or discontinuity, narrowness of ridge with arched cross section or breadth with horizontal cross section, reticulations, etc., which have to be described by the use of various modifying terms.

It is often a doubtful question how far local usages of language ought to be followed by geologists. For instance, the word "plain" is in very common use in Maine to denote rather level or gently rolling tracts of glacial gravel and sands, generally with some definitive, such as "Norway plains" (meaning tracts of reticulated kames overgrown with yellow or "Norway pines"), "checkerberry plains," "blueberry plains," "Litchfield Plain." In all these cases popular usage has recognized that these "plains" are tracts of sand or gravel differing in composition from the soils of the surrounding regions; and since they are much more level than the hills, they come to be known as "plains," even though they as little deserve the title "plains" as do the Great Plains west of the Missouri River. It is doubtful if geologists can go to Maine and inquire their way to many of the localities and deposits described in this report without employing the word "plains" in their inquiries. While it may be conceded that in strict geological language it is desirable to use the word "plain" only where it has a natural geometrical application, yet there are disadvantages in cutting entirely loose from local usage.

On reflection, instead of the term "osar-plain" for the broad osar, the term "osar terrace" will often be used, partly because the term "moraine terrace" was used many years ago by Prof. C. H. Hitchcock[1] to distinguish reticulated masses of glacial gravel.

GLACIAL GRAVELS AS MODIFIED BY THE SEA.

I assume that all the outer coast of Maine below the contour of 225 feet, perhaps below that of 230 feet, was under the sea during the last part of the Glacial period. In the interior of the State the sea must have stood at a somewhat greater height in the principal river valleys, then deep bays.

In general the glacial gravels that were under the sea at any time are somewhat different in external form from those situated above the former

[1] Preliminary Report upon the Natural History and Geology of the State of Maine, p. 270, 1861.

sea level. The lenticular and broadly arched types prevail. The lateral slopes are usually quite gentle. In many cases the waves washed over the tops of the kames and osars, eroding a portion of the upper parts of the ridges and molding their external forms near to that of the sand bar of the coast. For some time I supposed that all the gravels that had been beneath the ocean had been thus acted upon. Later I have discovered mounds showing the same features in valleys that were occupied by long narrow straits and inlets, yet so protected from marine erosion that their change in form from this cause must have been small. Thus the north-and-south valley of Georges River was at one time a strait extending from the Belfast Bay of that period. For 10 or more miles it was only from one-fourth mile to near a mile wide. On the east were the high hills of Hope, Camden, and Lincolnville, and a high ridge lay on the west. The strait was well landlocked and protected from the outside waves. The gravel cones, domes, and short ridges of this valley are more or less covered by marine clay and have the same outline that is common elsewhere in the region that was under the sea, and there are no gravels washed down upon the adjacent clays. The same is true of the discontinuous system in the Medomac Valley above Waldoboro. While, then, it is certain that in exposed situations, as on the tops of the hills at Portland, the tops of the gravels were more or less eroded and molded by the sea, yet we must conclude that in addition to this effect there was a difference in the average forms of deposition of the gravels of the coast and those of the interior. The former are less steep and approach the flowing outlines of the drumlins.

Divided into classes according to their external features, the glacial sediments are as follows:

SHORT ISOLATED OSARS OR ESKERS.

These are perhaps the simplest form of the glacial gravels. The term "isolated" is applied to them because no other gravels are known to be near them in such relations that their formation can be attributed to the same glacial stream. They have the form of a cone, a dome, or often a short ridge, or sometimes several short ridges having a linear arrangement (lengthwise of the ridges), or occasionally a few somewhat parallel ridges inclosing basins. They vary in length from a few feet up to a mile or two. A distinguishing feature of the class is that they have no fan-shaped or enlarged

delta showing assortment of material from coarse on one side (next the ridge) to very fine on the other, the stratification also becoming more and more horizontal. Yet the material of the ridges often shows some horizontal gradation, the finer sediment being situated at the south. The assortment is not so complete when the deposit consists of ridges as where it expands into a broad, flat plain. Near the coast the isolated eskers mostly take the form of cones, domes, or short lenticular ridges. In the interior they are almost always short ridges, which the lumbermen report as "horsebacks." North of the region of the long osars they are the only form of glacial gravel reported by the State geologists of Maine or others, or discovered by me. Thus I have note of quite a number of short ridges in the valley of the Masardis or St. Croix River, which flows north into the Aroostook River. It is possible that these are part of a connected series, but I can not prove it. Lumbermen report great numbers of horsebacks in the region drained by the St. John River, but many of these are elongated drumlins—at least farther south I have found many of the horsebacks to be such.

What were the conditions under which the isolated osars or eskers were formed? A good type is found about a mile south of New Vineyard Post-Office. The esker is situated in the jaws of a north-and-south pass through the high hills. It is about 10 feet high and 150 feet long. In the pass is a divide where the drainage waters part, some flowing north toward New Portland, others south to Farmington. The ridge is situated on the northern slope about one-fourth of a mile north of the divide. There is a considerable amount of alluvium south of this divide all the way to Farmington, and it is probable that it is some form of glacial sediments or frontal matter, but this I have not proved. To the north of the esker broad open valleys extend all the way to Kingfield and Mount Bigelow. In late glacial time the ice would naturally linger in these valleys after the ice south of the divide was all melted, since a supply could readily come from the region of high hills near the Dead River. After the front of this tongue of ice had retreated north of the divide a small lake would be formed south of the ice, confined between the ice and the hill or divide lying south of it. The slopes are gentle, and this lake would not be more than 15 or perhaps 20 feet deep at the time when the extremity of the ice had receded as far north as the position of the ridge. The lake would nowhere be more than one-eighth of a mile wide. If a glacial stream poured into the supposed lake,

it would spread out its sediments to form a delta. There is some fine alluvium in the valley, but it is not in the form of an expansion of the esker. The place is so near the top of the divide that there has been but little erosion. The fact that we find a gravel ridge without a delta in a place so favorable to the formation of a delta indicates that the ridge was deposited within the ice walls before the ice had receded as far north as the esker, and before the formation of the lake, in which probably at a later period was deposited the fine alluvium of the valley near the kame.

At one of the small isolated eskers we have distinct evidence of a glacial stream for a short distance. Several questions naturally arise as to whence the waters came and whither they went, as to the work they had done before coming to the place of the esker, and what became of the finer mud and clay which they must have carried away with them. There are several alternative hypotheses.

1. A sediment-laden superficial stream here plunged down a crevasse. The coarser sediment was deposited in the enlargement, cave, or pool within the ice that naturally formed near the base of the waterfall. The water then escaped through a subglacial tunnel, carrying the finer matter with it.

2. The esker collected in an enlargement or pool in the bottom of the channel of a superficial stream. Such an enlargement may have been begun as a pothole or pool in the ice at the base of a rapid or waterfall over ice or where lateral tributaries poured into the main channel.

3. The esker may have been formed in the tunnel of a subglacial stream. In such a case we must account for the waters being checked for a part of the course of the stream, while above and below the water flowed so swiftly that it left little or no sediment in its tunnel, or else we must postulate some obstacle greater than elsewhere to the passage of the transported matter. Such an obstacle could be furnished by the stream crossing an up slope. We sometimes find isolated eskers in such positions, but also often on down slopes where change in angle of bed can not have checked the sediment. Such an obstacle might also be formed by a bowlder or mass of ice fallen from the roof of the tunnel.

The velocity of the water could be locally checked by an upward slope of the bottom of the channel, provided the tunnel was not full of water, but, as above noted, we often can not invoke change of slope to account for local deposition. Another way for checking the velocity would

be by enlarging the channel. Such enlargements must constantly be forming where superficial streams bring warmed waters and pour them down a crevasse into the glacial river.

Here are a number of physical causes capable of doing the required work, and perhaps no two of the kames were formed in exactly the same way.

I have many times examined the country adjacent to the isolated eskers for signs of glacial streams beyond the limit of the gravels themselves. Thus far I have found no ravine of erosion in the till or glacial potholes, either north or south of these eskers. They begin and end abruptly, and beyond them we pass into regions covered by ordinary till. But it may fairly be urged that the channels of subglacial streams, being underneath the ice, are now covered by the upper or englacial till, while in the region that was beneath the sea we have the search further embarrassed by the deep sheets of marine clays which cover almost all that part of the State. Indeed, it would be possible for a ridge to end in a fan-shaped delta and yet be so covered by the clay that only the top of the highest part of the ridge appeared.

The problem of the short isolated osars in the region that was under the sea is so nearly related to that of the discontinuous osars that it will be further discussed in connection with that class of gravels. Above the former level of the sea, and especially in the northern part of the State, the first and third of the above-mentioned hypotheses appear to me to be more probable than the second. Yet where the material is quite fine the second method may also have been employed. It is not necessary to premise that all the eskers were formed in the same manner.

These eskers are situated where no ordinary stream of land drainage could have deposited them. There is no way of accounting for them except that they were deposited between solid walls that have now disappeared, and ice is the only admissible solid with that property. The iceberg theory of the drift has no adequate explanation of them.

HILLSIDE OSARS OR ESKERS.

The only deposits of this class of which I have note are found in a broad belt extending northeastwardly across the State. Its southern border lies about 50 miles from the coast, and its breadth is perhaps 75 miles.

The region is hilly. I have noted about fifty of these eskers, and doubtless there are many more.

At their northern extremities a large proportion of the hillside systems begin at the southern brow of broad flattish-topped hills 100 to 400 feet high; others begin at various distances down the southern slopes of the hills. The hillsides fall southward or southeastward. I have discovered no ridges of this class on the northern slopes of hills, nor developed on the tops of the hills and plateaus. These eskers all end at the south in the valleys lying at the southern bases of the hills in which they are found. All expand somewhat at their southern extremities, some into a larger ridge, some into a small plexus of reticulated ridges inclosing basins, some into a fan-shaped or oval delta. Beyond the limits of this terminal enlargement I have not been able to trace glacial sediments, though in some cases the terminal deltas merge into the alluvium of the valleys in which they lie in such a way as to indicate that the alluvium is kame or overwash matter with respect to the ice and the glacial stream. These ridges meander somewhat, yet on the average diverge but little from the lines of steepest slope of the land surface. Owing to the outlook of the hills, this direction is nearly the same as that of ice flow, and also must be about the same as the direction of the slope of the ice surface in late glacial time. The hillside eskers vary in height from 5 feet or less to 20 feet, and in length from a short eighth of a mile to nearly 2 miles. The sediment composing them is usually gravel and sand, but in some cases there are cobbles, bowlderets, and even a few bowlders, all distinctly but not very much worn and rounded by water.

The position of the terminal enlargement and delta, their situations on the southern slopes of hills, and many other considerations prove conclusively that the flow of the streams that deposited the hillside systems was southward. If on the slopes of moderately steep hills the velocity of the waters that deposited the gravels was so gentle as to permit the deposition of sediment, such as sand and gravel, we may be certain that the conditions would be still more favorable to deposition on the northern slopes and the tops of the hills. On the contrary, no water sediments are found there, nothing but the usual till, and no ravines of erosion. If the streams which deposited these kames were subglacial in that part of their courses lying north of the kames, they there had a very gentle current, not capable of eroding the till or transporting sediments up the hills.

Again, if the hillside osars were due to local deposition in the channel of a long north-and-south glacial river, we ought to find similar gravels forming a system or connected series along the course of the hypothetical glacial river. But with a few exceptions the eskers of this class can not be brought into any kind of linear arrangement with other eskers or osars. In most cases hills higher than 200 feet lie to the south of these eskers, sometimes within a mile or two, sometimes 10 or 20 miles away. The great rivers that have left their gravels for a hundred miles could not flow over hills more than about 200 feet high. No reason can be assigned why streams that have left gravels for less than 2 miles should be able to flow over any higher hills, or, if so, why they have not left gravels to mark their channels.

All the facts point to the conclusion that the hillside eskers were deposited very late in the Ice period. They are found in regions abounding in rather high hills lying transverse to the direction of glacial movement. These hills stopped the motion as a whole after the depth of ice came to be less than about 500 feet, though local movements would continue along north-and-south valleys like that of the Kennebec. So, too, there would be a limited flow from north to south between the successive ranges of transverse hills, especially on the southern slopes of the hills. There would still be a surface gradient of the ice, since in general the melting was most rapid toward the south and the thickness of the ice had originally increased northward.

Some of the hillside ridges begin on the slopes of long hills and have 1 or 2 miles of hill north of them. In such cases it is possible that the osar streams were wholly supplied by melting ice and other drainage of the hill itself. But generally these ridges begin at or near the tops of the southern slopes of the hills, where the supply of local drainage would be very small. Yet the streams had considerable volume at the north, as, for instance, the esker near Wilton. Such streams plainly derived their waters in great part from the regions lying to the northward.

The best interpretation of the facts seems to be as follows: The ice front had retreated to near the point of the formation of the streams, but the ice north of the hills was still high enough to enable its drainage waters to flow southward over the hills. The absence of erosion channels or glacial sediments on the tops and northern slopes of the hills can be accounted for on the following suppositions:

1. That superficial streams flowed over the hills from the north.

2. That subglacial streams flowed up and over the hills. North of all hills there is always a portion of a subglacial stream tunnel where the water is in equilibrium to the top of the hill and flows only as it is urged by water from behind rising above the top of the hill. If the tunnel were rather large for the supply of water, the flow up the hill might be so slow that it would not erode channels in the ground moraine and the only glacial sediments would be deposited in the valley to the northward. I have found no such sediments as yet. Or the streams may have been too small to transport noticeable masses of gravels.

Superficial streams flowing from the north might at or near the tops and southern brows of the hills pour down the crevasses that would naturally form there and escape down the slopes as subglacial streams, or they might continue in superficial channels, in which, after they had cut down to the bottom of the ice, the gravels were deposited. But all observation proves that on these steep hill slopes the ice would almost certainly be deeply shattered by crevasses, and hence it is extremely unlikely that the channels were superficial on the hillsides. The esker or kame, elsewhere described in Jay, contains so large bowlderets and bowlders that it becomes probable that this kame was deposited in subglacial vaults. The plexus of reticulated ridges can be accounted for on either the theory of subglacial or superglacial streams. Where the terminal enlargement takes the form of a horizontally stratified delta, the stream evidently escaped into a pool within the ice, or where the delta spreads out in the valley and passes by degrees into the valley drift, the stream passed beyond the ice into the open valley. In this case it is doubtful if the delta furnished the evidence necessary to decide definitely the question of the nature of the streams.

The hillside eskers were perhaps not all deposited in the same manner. They are in situations so favorable to the production of crevasses that it would appear to be inevitable that a part, if not all, were formed by streams which, no matter what was their history toward the north, escaped down the hills as subglacial streams. On this hypothesis the shortness of the ridges would be accounted for partly by the fact that the water would cease to flow from the north as soon as the melting had progressed so that the hills emerged from the ice. Some of these kames seem to prove that the flow continued long enough to permit the formation of subglacial tunnels in places where there had been none until the ice became quite thin. These subglacial channels were not prolonged far.

The formation of reticulated ridges as a part of hillside eskers will be considered later.

These short kames or eskers are not so impressive as the long osars, but they are equally strong testimony to the existence of glacier ice, and they possess the essential parts of the longest osar—a ridge and often a terminal delta.

ISOLATED KAMES OR SHORT ESKERS ENDING IN MARINE DELTAS.

These are confined to the country lying below the former level of the sea. Litchfield Plain is a type of this sort of deposit. On the north and northwest are a series of broad ridges somewhat reticulated and inclosing a lakelet and some shallower kettleholes. The material of this part of the plain consists of gravel, cobbles, and bowlderets, all well rounded and polished by water. The slopes of the ridges are not very steep. Passing south and southeast, we find the ridges becoming confluent and merging into a rather level terrace or plain. The material at the same time becomes finer, and soon passes by horizontal gradations into sand, some of which may have been blown. The plain is situated in the midst of a rather level region at an elevation of about 150 feet. The Kennebec Bay of that time sent out an arm westward and covered the Cobbosseecontee Valley to Readfield. The salt water over Litchfield Plain would then be 75 or more feet deep. The country lying south and east of the plain is deeply covered by a silty marine clay. I was unable to determine whether the sand of the plain passes into this clay by horizontal transition. In places this appeared to be the case; in other places the junction was quite abrupt and there was reason to suspect blown sand. The plain is about a half mile in diameter.

At Litchfield Plain streams capable of transporting bowlderets 15 to 18 inches in diameter were so checked within the distance of half a mile that they could no longer carry even their fine sand. This gradual checking of a swift stream can be wrought only by its flowing into a body of comparatively still water. Two low passes lead from the plain, one northward the other northwestward, and two glacial rivers may have converged to this spot. If at a point so far north of the present coast these streams had flowed into a glacial lake, there would probably have been a series of similar deposits extending southward toward the sea. I have been able to

find no other gravel deposit for 10 miles south of it, and the nearest on the north is in the northern part of Litchfield, nearly 5 miles away. The great thickness of the marine clay in the vicinity and its somewhat sandy or silty character testify that one and perhaps two glacial streams here flowed into the sea at a time when the ice front had retreated to this point. To the northwest of the plain is a rather steep terrace in the till, which may be due to the erosion of the ground moraine. If so, this would be more probably performed by a subglacial than by a superficial stream. The rapid slowing of the water after entering the sea proves that the streams were not large. The great swiftness of a small stream required in order to transport so large bowlderets would be more probably attained by a subglacial stream under pressure in its tunnel by the water behind it.

Elsewhere are described two short eskers or kames in Amherst (see pp. 117–118) which at the south converge into a small plain of horizontally stratified matter showing clearly a horizontal transition of the gravel into They are at the foot of a hill sloping south, and were in places favorable for crevasses. They are, in fact, hillside kames situated below 230 feet.

The class of kames or eskers under discussion are here termed isolated because no other gravels can be proved to have been deposited by the same glacial streams to which these are due. The field evidence rather favors the hypothesis that they were deposited by subglacial streams. Besides, we have the general consideration that near the ice front crevasses could sand and finally into marine clay, all within about one-fourth of a mile freely form and conditions would be favorable to the formation of subglacial channels.

ISOLATED OSAR-MOUNDS OR MASSIVES NOT ENDING IN MARINE DELTAS PROPER.

These deposits, being very broad, are massives or mesas rather than ridges. They belong to the region below former sea level. One of these plains is found about 2 miles northwest of Freeport Village. It is solid and rather level on the top, somewhat uneven of surface, but with no reticulated ridges or kettleholes proper. The smoothness of surface may be in part due to the waves of the sea sweeping over it, since it occupies a position where it would be much exposed to the waves of the broad bay which then covered the valley of Royal River to the south of it. Judging from

the surface appearances at a few small excavations, the table-land consists of sand, gravel, and cobbles mixed in alternating layers, but the northern and southern parts of the plain do not vary much in degree of fineness. The transition between the somewhat lenticular mass of gravel and the marine clay is quite abrupt, proving that they were not formed simultaneously. Whereas in the delta deposited in the open sea the coarse sediments are stratigraphically continuous with the marine clays, one passing into the other by insensible degrees, in the case of the plain under consideration the glacial currents were, within the area of deposition, not checked sufficiently to cause them to drop their clay and silt. The gravel is overlain by the clay, but they are plainly of different origin and dates. Such a mass as this must have been deposited in a gradually enlarging pool or lake within the ice. The inflowing stream did not flow into a body of water as large as the whole plain. I conceive that it first flowed into a small pool, which it partially filled with sand, gravel, and cobbles. Subsequently, as the ice was melted and eroded, the water of the glacial stream continued to flow in the space between the enlarging central mass of gravel and the receding ice. Thus the flow was never checked, as it would have been if it flowed into a lake as large as this one finally became. This sort of structure is substantially the same as that of many of the massive plains that make the discontinuous systems of osars and the discontinuous portions of the osars. The more important features of the class are their solidity (freedom from kettleholes and reticulations) and their coarseness of material, which is in marked contrast with the horizontal passage into the finest sediment characteristic of the true delta. The top is somewhat convex, but not always conspicuously lenticular. They are found in a part of the State where subglacial streams abounded. They could be accounted for as being formed in the pool where a superficial stream fell down a crevasse, or where a subglacial stream entered a pool or lake within the ice. We know that a superficial stream can make such a pool. In case of a subglacial stream, it is more difficult to account for the pool. It is possible that a subglacial river of fresh water pouring into the sea, or having its channel obstructed for any other reason, would under some conditions be forced to rise up the crevasses, and when the ice became thin enough it could outflow upon the ice, or such a rise of water could be caused by a gorge in the tunnel. This water, now being exposed to the sun, would become warmed; and if so,

would in time form the pool. The problem is closely connected with the general subject of the discontinuous osars, and will be referred to again later.

GLACIAL MARINE DELTAS.

Before proceeding to the discussion of the discontinuous osars it will be of advantage to consider the general characteristics of the delta-plains deposited by glacial rivers in the sea. They are here named "glacial marine deltas." (See Pl. XXVII, *B*, opposite p. 336.) They were of two kinds.

I. Those deposited in front of the ice in the open sea. This class spread outward in rounded or irregular fan shape when deposited over broad and rather level plains where they were free to expand in all directions. In narrow valleys their shapes were necessarily determined in part by the adjacent hills. They conspicuously show the characteristic horizontal transition of sediments from coarse at the north to finer toward the south—that is, away from the mouth of the glacial river. The surface slopes gradually downward and outward radially to the outer edge of the delta, but in tidal waters this slope is much more gradual than on the land. The sand of the delta passes by insensible gradations into silt and silty clay, which in turn merges into fine fossiliferous clay. In the region of transition between the sand and clay the two deposits have the same surface level. Thus the proof is conclusive that they are contemporaneous and that the clay is a continuation of the coarser parts of the delta. But while logically and genetically the clay is part of the delta, yet since the sediments of the glacial streams are so much more largely composed of sand, gravel, and larger stones and bowlders, I here include under the term "deltas" only that portion composed of coarser matter. Moreover, the clayey parts of the deltas are so mixed with clay derived from wave erosion of the till, also with the clay brought down by the swollen rivers of land drainage at the close of the Glacial period, that it is difficult to distinguish the glacial from the other clays. So also the delta clays, being scattered up and down the coast, often blend with one another, and the separate deltas are indistinguishable. It is noticeable that the clays are thicker near the mouths of the glacial rivers, and doubtless the spirit level will sometimes reveal where the mouths of the rivers were in cases where to the unassisted eye the deltas are confluent. In mapping the marine deltas it has been a matter of difficulty to determine where sand ends and

clay begins. The only way to secure accuracy is by micrometric measurements of the size of the grains.

An interesting marine delta is in the valley of the west branch of the Union River, in Aurora. It is locally known as the Silsby Plains, and is elsewhere described. The valley of Union River was at one time occupied by an arm of the sea from 1 to 8 miles broad. Into this inlet the great Katahdin osar river for a time poured nearly at right angles. A delta of gravel and sand formed in front of its mouth. This delta extended across the whole breadth of the valley then under the sea, and for 4 miles southward and nearly a mile north of the mouth of the glacial river. The last-named fact indicates strong tidal currents on the coast of Maine at that time. If the Bay of Fundy was at this time a strait connecting the Gulf of Maine with the Gulf of St. Lawrence, the tides would probably not be so high in eastern Maine as now; yet here is evidence of considerable tidal action. Tidal currents sweeping along the coast would tend to mix the clay portions of the deltas of the glacial rivers.

II. Another class are here termed "ice-bordered" or "narrow marine" deltas. They are usually much longer from north to south than from east to west, having but little of the fan shape. At their southern ends they pass by degrees into clays having the same level, like the delta-plains above described. They are found in valleys or level regions much broader than they are, where there is no topographical reason why a delta, if deposited in the open sea, should not have spread outward in fan shape. Except at the southern extremity, the sand and gravel end abruptly. The east and west flanks commonly form a steep bank or bluff rising sometimes as much as 20 feet above the marine clay which here covers the base of the gravel plain. The transition from the coarse matter of the plain, such as sand, gravel, cobbles, etc., to the clay at the sides of the plain is very abrupt. Very evidently the clay was deposited later than the coarse matter at all points of the plain except on the south. Evidently the glacial rivers flowed in channels which were open toward the ocean, but at the sides were bordered by ice which covered the rest of the valleys and prevented the delta from spreading out into fan shape. At one time I described these deltas as being formed in bays within the ice, into which the tidal waters extended as they do into an estuary. They are all situated below the contour of 230 feet, and if they were deposited at the time the sea stood at its highest level

these broad channels in which the narrow deltas were deposited would indeed be estuaries. On further reflection I find they can also be accounted for as having been deposited in broad ice channels at a time when the sea stood not at its highest elevation but at the level of the delta itself, or perhaps at the place of transition from gravel to sand. The ice front then stood at or near the place of transition from sand to clay, where the clay of the local delta merges in the general sheet that covers all the coast. On this conception we have in the narrow deltas a type of the sediments poured into the sea or formed at or near sea level during a rise of the sea accompanied by melting of the ice as it advanced. If so, we could expect, on sloping shores, and where the flow of the glacial stream continued marine, a delta to extend backward from the outer one, up to the level of 230 feet. Such a recession would show finer sediments overlying the earlier and coarser ones, since at any given point the water would be growing deeper and the distance to the shore greater as the sea rose to its highest level. It is doubtful if the facts thus far observed make it possible to decide positively between the two hypotheses, and indeed narrow marine deltas may have been formed in both of these ways. On either hypothesis the delta as we go southward was bordered laterally by ice until we reach the place where the delta clay merges into the broader clay sheet of the coast. As the ice retreated and the delta channel broadened, clay was laid down over the valleys at the sides of the original ice-bordered delta. The currents would naturally be swifter in front of the main channel. For this or some other reason the later-deposited clay was thin or lacking on top of the sand-and-gravel portions of these as well as on the broad or fan-shaped deltas.

That the clay into which the marine delta-plains pass by insensible gradations is a true marine sediment is evidenced by the following facts:

1. The clay extends continuously from the delta-plains to the present seacoast, a distance of 10 to 30 miles, and in a few cases even a greater distance.

2. This clay thus is continuous with the clay that surrounds the beach gravels. We can not separate them.

3. In many places this clay contains marine fossils. Near the belt of transition between the glacial delta sands and the clays I have not been able to find fossils, but within 2 or 3 miles south from that point fossils

have been found in digging wells. The nearest I have found fossils to a large marine delta is about 4 miles.[1]

4. The deltas here described are all found below the elevation of about 230 feet, except those situated farthest northwest, which may have a higher elevation. Up to these levels the beaches are distinctly and incontestibly to be found.

5. This clay covers the whole of the State up to that elevation—that is, all the broader valleys and such places as would not form projecting headlands of the expanded sea.

6. The sand and gravel portions of adjacent marine deltas are often confluent or nearly so, proving that they were deposited in the same body of water. In York and Cumberland counties there is a succession of practically confluent delta-plains for about 40 miles.

Marine delta-plains form part of both the osars—the broad osars and the discontinuous osars—and they form the usual termination of the great plains of reticulated kames. The Katahdin system expands into two deltas deposited in the open sea: first, in the level region west and northwest of Deblois; second, in the valley of Union River in Aurora. It also expands into a delta in Greenfield, 30 miles farther north, but I am somewhat in doubt whether the last named is a glacial marine or a lacustrine delta. In like manner most of the longer gravel systems show from one to three marine deltas at different distances from the coast. These must mark either the retreat of the ice northward or an increase of elevation of the sea, or both causes combined.

One fact regarding the deltas here denominated "glacial marine" deserves special notice. By far the largest of the delta-plains are found between 170 and 250 feet above the present sea level. The high level deltas cover hundreds of square miles. They prove that the time of most active transportation of glacial sediments coincided with the time when the open sea covered all or nearly all the coast region of the State below the contour of 230 feet. They are so extensive and unmistakable in character, and all along the coast have so nearly the same relative development at that contour that they form an important part of the evidence as to the

[1] A leaf of sea-lettuce (*Ulva lactuca*) found in the upper clays at Lewiston. The lower layers of the clays are richly fossiliferous at Lewiston. The marine delta was situated not far north and east of Lake Auburn.

highest level of the sea in the coast region. Marine clays and these so-called marine deltas are found at all elevations up to about 230 feet near the coast, but the deltas have their maximum development as we approach that contour. Above that elevation the deltas are few and rather small, and are situated in the interior valleys. They are found at no prevailing elevation, and they are local, not confluent like the great deltas found at 230 feet or not far above and below. The locality before named in York and Cumberland counties is the best place for the study of the confluent marine deltas. To the careful observer in the southern parts of the State the contrasts between the surface deposits and characteristic scenery above the level of about 230 feet and those below that level is very great. In passing from one of these regions to the other we find a change such as in human affairs would be termed a revolution. The contrast is greater near the mouths of the great glacial rivers than away from them. It should be noted in this connection that the opinion is elsewhere expressed that the sea stood at higher levels 50 or more miles from the present coast than along the outer coast itself.

In the above discussion it is assumed that the broad rounded or fan-shaped deltas were deposited in the open sea. It is a possible hypothesis that they, as well as the narrow marine deltas, were formed subglacially, in places where the subglacial channels had enlarged themselves laterally as they entered the sea, so that broad portions of the ice were undermined and floated on the sea water. This would make the ice approach the condition of glaciers which flow into a warm sea, where they are melted from beneath.

1. The Waldoboro and other short peripheral moraines prove that the lower portions of the ice contained much morainal matter, though we do not know how great a height it attained. Unless the supposed broad subglacial river should melt all the part of the ice containing morainal matter, there would still remain till in the ice above the channel. As the undermelted ice fell off in icebergs, more or less of this débris would fall upon the underlying gravel and sand. The delta-plains are covered by no sheet of till, though, like the marine clays and all the rest of the country below 230 feet, they are strewn with occasional bowlders, which I attribute to ice floes.

2. The supposed caves beneath the ice must have been of mammoth size More than a score of the deltas contain a surface of more than 5 square miles each, and several of them contain two or three times that area.

3. The deltas of different streams are sometimes confluent. This fact still more enlarges the continuous areas of supposed floating ice.

4. Unless the till were, in New England, confined to the very bottom of the ice, the till contained in the ice above the limit of supposed melting would greatly increase the specific gravity of the floating ice. It is not proved that till-containing ice could be sustained by flotation in so shallow water. Out in the Gulf of Maine at a great depth the buoyancy of the purer upper ice would enable a thick sheet of till-bearing ice to float. But the largest of the glacial marine deltas are situated near the contour of 230 feet, where the water would be less than 100 feet deep. Only a thin sheet of pure ice could float under these circumstances.

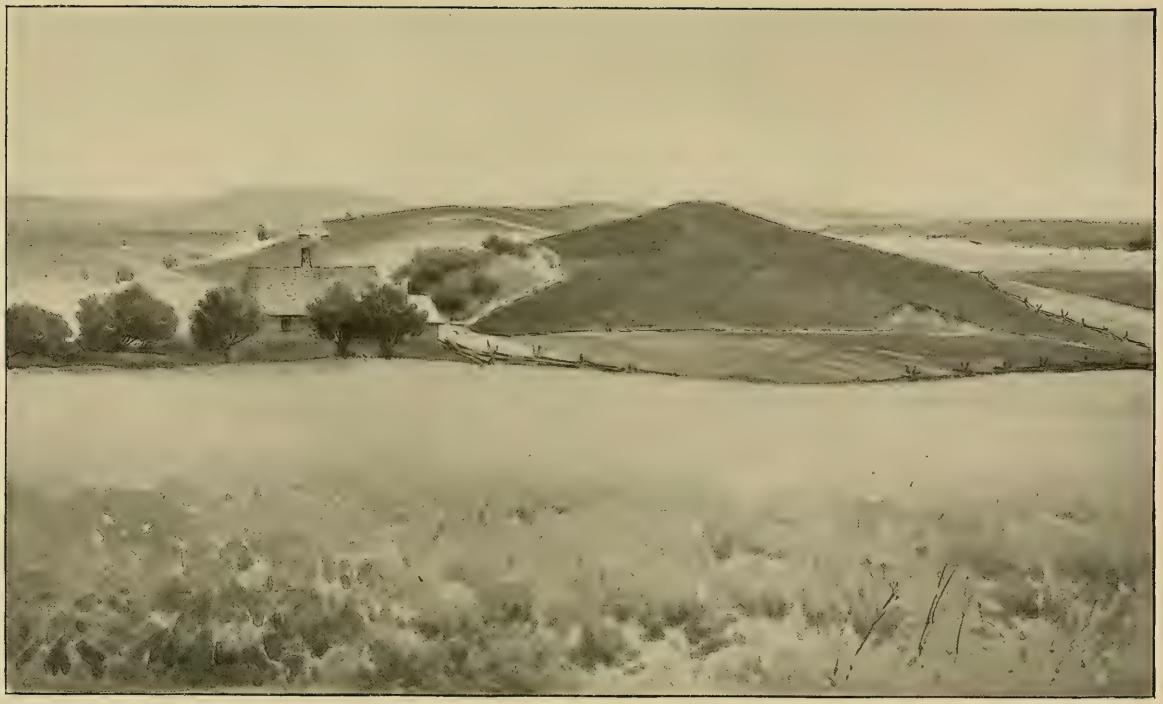
5. In the case of the Silsby Plains in Aurora, mentioned above, we have proof of tidal action, and most of the deltas spread outward so rapidly as to indicate the cooperation of the tides in the work of strewing the sediment of the glacial rivers up and down their valleys and along the coast and out to sea. Tidal currents in the open sea would do this work. It is uncertain what would be the action of the tides on the sediments beneath floating ice, since the free space beneath the ice would change with the state of the tide and the thickness of ice.

6. The rise and fall of the tides would cause a strain on the central parts of the supposed undermelted ice such that from time to time small bergs would break off and float away to sea. Thus, even if the bottom ice were melted over so large areas the upper ice would soon disappear and the supposed cave would become a part of the open sea.

The difficulties of the hypothesis of large areas of undermelted ice are so great that the hypothesis that the marine deltas were laid down over the bottom of the open sea I consider by far the best interpretation, though the margins of the ice channels would be undermelted, just as they were on the land.

SYSTEMS OF DISCONTINUOUS OSARS.

In this class a number of short ridges, often plain-like, have a linear arrangement and other relations such that they are regarded as having been deposited by the same glacial river. These systems have nearly the same general directions as the continuous osars, and their topographical relations are substantially the same. The osars as they approach the coast become discontinuous, like the systems now to be described. In the case of the



DISCONTINUOUS OSAR NEAR MONROE VILLAGE.

The three gravel hills in the center show the linear arrangement of the somewhat separated hillocks and ridges which together form a discontinuous osar system. Some of the domes and cones coalesce at their bases; others are nearly or entirely isolated.

osars there can be no doubt of the action of a single glacial river, even when the ridge becomes interrupted. The feature of noncontinuity can not, therefore, in itself be urged as proving the action of more than a single stream. Genetic connection is to be proved or disproved by general considerations, the nature of which has been referred to elsewhere.

The feature of systematic noncontinuity is almost wholly confined to the coast region. The longer osars and osar-plains frequently extend 10 to 30 miles south of the contour of 230 feet before they become discontinuous, but the discontinuous character rarely extends north of that contour, and then usually in a modified form approaching the osar type (e. g., at North Monmouth).

In the noncontinuous systems the gravel deposits are from a few feet up to 3 miles long, and they are separated by intervals varying within the same limits. The intervals between the successive deposits are a constant and distinguishing feature of the class. The intervals are due to the original manner of deposition. Ridges formed by the unequal erosion of a continuous plain are not entitled to the same name as ridges that were originally formed in substantially the same shapes they have at present. For this reason the terms "kame" or "osar" are not in this report applied to ridges consisting of portions of the valley drift or other alluvial plains which have been left as ridges simply because the surrounding matter has been eroded. The gravel masses under discussion have sometimes been eroded, but the erosion can readily be traced, and it can be asserted with greatest confidence that no continuous mass of gravel ever connected them. This is the more certain because they are mostly situated in the region that was under the sea and the gravels are wholly or partly covered by marine clay, which would protect them from erosion. Any agency which would erode the gravels must first erode the overlying clay. But in most places the clay still remains or has only partially been eroded. In some cases ridges which appear to be discontinuous may really be connected by a low ridge now covered from sight by the clay. But in many places streams flow across the space between the apparently separate deposits of the same system, and in their banks no gravels are seen, though they cut down to the till or even to the underlying rock.

Any satisfactory explanation of the discontinuous osars must account not only for the deposition of the gravels but also for the intervals between

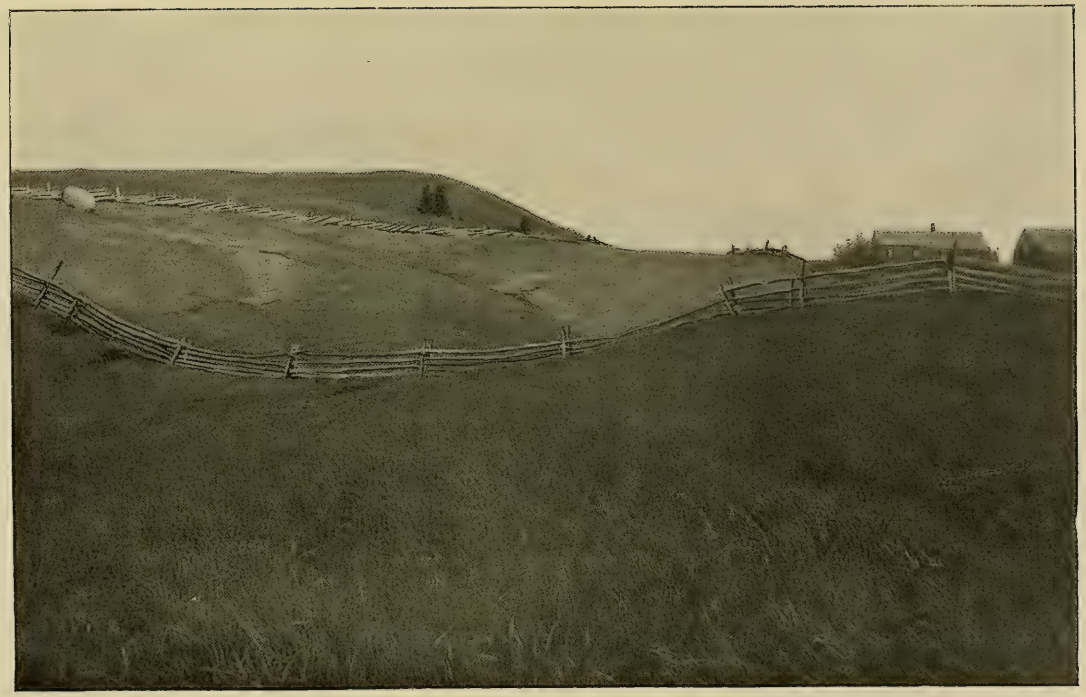
the gravels. Here arise special difficulties. The gravels afford much positive evidence regarding themselves, but in accounting for the gaps in these systems we have to rely largely on negative evidence. Probably no other problem connected with the glacial gravels is so difficult of solution. It will be seen that a discussion of the origin of the gaps in the discontinuous systems will apply almost equally to the discontinuous portions of the osars and broad osars. Indeed, if the streams which deposited the discontinuous kames had been longer, so as to extend farther north, nearer the névé, I believe that toward their northern extremities the separate ridges would be confluent and not distinguishable from the osars and broad osar terraces.

The deposits forming the noncontinuous osars are of several quite distinct types.

1. Marine deltas. The general characteristics of these plains have already been described. The longer of the systems under discussion almost always expand into one or two marine deltas; some of the shorter systems also contain deltas, but more of them have none. The deltas are found at intervals of several miles. Thus far I have not been able to find terminal moraines genetically connected with the marine deltas, though there is much reason to suspect this relation at the Waldoboro moraine; yet I have often suspected their existence beneath the marine clays. These clays are sometimes 80 to 100 feet deep, and large ridges might exist which are now hidden by the clays.

2. Broad solid ridges or gravel massives one-eighth of a mile or more in breadth, separated by the usual intervals. They sometimes have a somewhat uneven surface, at other times are rather smooth and with slightly convex surface. In external appearance they somewhat resemble the small deltas, but the horizontal assortment of sediments is much less perfect. They usually rise above the clay, and they do not pass into it by degrees. Even at their southern border the material is often quite coarse, and never finer than medium sand. The clays overlie these gravels at their bases and are plainly a later deposit; at least these are their relations on the surface. It is possible that in some cases a lower stratum of these plains passes into the clays by horizontal transition; but if so, the stratum showing that transition is buried out of sight. Often the exposures show conclusively that there is no such transition, and nowhere is there proof of it.

This sort of solid or massive hills closely resembles the plain before



TILL BOWLDER ON DOME OF GLACIAL GRAVEL; WEST BOWDOIN.

The gravel is flanked and partly covered by marine clay; the bowlder is attributed to ice floes.

described near Freeport (pp. 369–370). It will be convenient to refer to them as gravel massives. They are not so common a feature of the discontinuous osars as of the long osar and broad osar systems.

3. Reticulated eskers consisting of two or more reticulated ridges inclosing kettleholes, but not ending in delta-plains, such as the gravels near East Monmouth. These are a not uncommon form of the gravels. The material is nowhere very fine, showing that the waters were not much checked. The problem of the reticulations will be referred to hereafter.

4. Cones, domes, and lenticular short ridges, all with broadly arched cross section. As a class these deposits have rather gentle lateral slopes and their shapes resemble the drumlins or lenticular hills of till. The variety of individual forms is very great. All gradations can be found between domes and lenticular mounds on the one extreme and long ridges on the other. While they vary in size, height, and slope, yet the prevailing lateral slopes of the gravels that were below the sea are more gentle than those above that level.

GLACIAL GRAVELS OF THE COASTAL REGION.

RELATIONS OF GLACIAL GRAVELS TO THE FOSSILIFEROUS MARINE BEDS.

The glacial gravels are found in three relations to the marine clays. First. The gravels have the same level as the clays and pass by degrees directly into them. This is the characteristic relation of the glacial deltas and marks the coarser glacial sediments as being laid down simultaneously with the clays. Second. The clays overlie the glacial gravels, either wholly covering them or covering their base. The gravels were first deposited within ice walls, and subsequently, after the ice had melted, the clays were deposited. This arrangement is so common that for a long time I supposed it and the third named to be the only ones, the first being accounted for as due, not to original deposition, but to the subsequent action of the sea in remodeling the sediments. This was based on an exaggerated idea of the power of the sea to erode and transport. Third. The sand and gravel of the upper parts of the osar gravels overlie the fossiliferous clays which cover the bases of the same kames or osars. This happens in many cases,

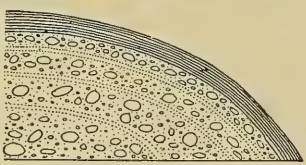


FIG. 27.—Sheet of marine clay overlying osar.

but, so far as I have noted, only in places where the ridges would be exposed to the surf. The fact could be accounted for in two ways:

1. The ridges were first deposited within ice walls. Subsequently the ice melted and sea water covered the ridges. Marine clay, or in some cases kame or osar border clay, was now laid down, covering the bases of all the ridges and the whole of the smaller ridges or osars, and a thin sheet of clay may have been spread over the tops of even the highest ridges that were under the sea. During the retreat of the sea to its present level the surf must have successively beat upon every part of the land as it emerged from the water. In exposed situations the waves would be able to erode the upper portions of such gravel masses as rose above the clays and to leave the matter in quaquaversal or anticlinal stratification along the lower slopes of the ridges and extending out a few feet or yards over the clay previously deposited upon the base of the gravel. In Carmel, Clinton, Detroit, and many other towns, wells dug in the flanks of the osars almost invariably are dug through a thin stratum of gravel, then through clay containing shells, and finally into a deep stratum of gravel in which water is found. The upper gravel extends only a short distance from the central ridge.

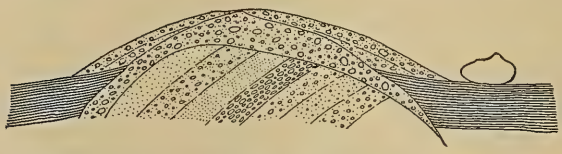


Fig. 28.—Marine clay overlying base of osar, and itself covered with a capping of gravel; Corinth.

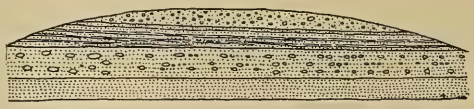


Fig. 29.—Marine clay and sand in the midst of osar gravel; Hermon Pond.

2. According to another theory, the sand and gravel which overlie the clay on the flanks of the osars may have been brought there by glacial streams. On this theory some of the coarser matter was swept out to sea for short distances beyond the retreating ice front and deposited over the marine clays that had already been laid down in the open sea. The theory would make the sand and gravel overlying the marine clay a sort of marine delta. The subject will be discussed more fully later. If the glacial gravel at Portland overlies the fossiliferous marine clays, it may do so in the manner here indicated, or if at the base it overlies the clays, this would form a fourth arrangement of the gravels

and clays. The difficulty of accounting for the deposition of gravel in the open sea without the formation of a delta is very great, if not insuperable.

A very important fact to be noted relates to the size of the gravel deposits at different elevations and distances from the coast. The osars and broad osars become discontinuous at or below the contour of 230 feet, but the longer gravel systems are continuous farther south than the shorter ones. But no matter how large the gravel systems are, they all become discontinuous before reaching the present shore of the sea. Invariably the size of the osars and osar terraces becomes smaller as we go south from the contour of 230 feet, and the intervals between the successive deposits increase. This remark applies to the solid ridges and domes. The marine deltas which here and there appear in the midst of the line of lenticular ridges interrupt the symmetry of the development, since they are much larger than the ridges and domes situated in the series both north and south of them. But measured among themselves, as a class, the marine deltas are largest near the contour of 230 feet and diminish in size southward. This rule can not always be proved—as, for instance, in case of the Katahdin system, where the deltas are situated in different drainage basins and it is difficult to compute the average depth of the delta. Apparently the delta west and northwest of Deblois is the largest of the system. It is that which is situated farthest south. But the case is complicated by the fact that the Seboois-Kingman system may have helped form this delta, and also by the fact that it rises nearer the 230-foot level than the Silsby Plains situated 20 miles northwest. The great development of the glacial sediments not far from the contour of 230 feet is still further aided by several of the larger gravel systems of the Androscoggin Valley which come down to near or a little below that elevation and then end—the Chesterville-Leeds, Canton-Auburn, Peru-Buckfield, and Sumner-Minot systems.

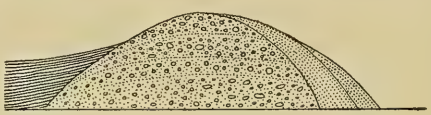


FIG. 30.—Marine clay overlying base of osar; Hampden.

In most cases the gravel systems of all types end before they reach the line of the present coast. The ridges grow shorter and smaller till they are only heaps 10 to 15 feet high, while the intervals between them grow on the average larger. In Western phrase, the gravels "peter out." The only places where they plainly end in bluffs on the shore are at the north

ends of bays or fiords considerably north of the general coast line. Thus two systems end in Belfast Bay and one in the north end of Penobscot Bay. The Clinton system ends very near the fiord known as Sheepscot River, and another comes almost to Cobscook Bay, in Pembroke, and another near the sea at Waldoboro. Since the deposits become smaller toward the south, it is possible that some of the systems really extend farther than they seem, the small deposits of gravel which form their southern ends being covered by the marine clays. But in many cases this can not be admitted. Thus three systems seem to end near the Head of the Tide, Belfast. One of them, if extended, would be found beneath Belfast Bay, but the two more westerly systems would cross the city of Belfast, where excavations for wells, foundations, etc., are so numerous that the gravels would certainly have been discovered. In these cases and in most of the gravel systems the evidence that they really end before reaching the sea is satisfactory. Another exception is found on the coast from Scarboro for many miles southward. The shore is formed of marine-delta sand. It is difficult to estimate how far the delta originally extended out into the region at present covered by the ocean. In Jonesport a plain of glacial sand reaches nearly to tide water. With the exceptions named the gravel systems all end north of the present shore, and in most cases only 10 to 50 feet above sea level.

LENTICULAR SHAPE OF THE COASTAL GRAVEL MASSES.

At Winslows Mills a round-topped hummock of glacial gravel lies directly beneath the more northern ridge of the Waldoboro moraine. It was exposed by excavations made during the building of the dam and mills. At the time of my visit the gravel had fallen into the excavation so as to make it impossible to determine what was the original nature of the stratification. Enough could be seen of the general shape of the mass of gravel and cobbles to show that it does not materially differ in external form from the other hillocks of the system of glacial gravel of which this forms a part. This is a discontinuous system which extends from near the sea at Waldoboro northward along the valley of the Medomac to a point somewhat more than a mile north of the moraine at Winslows. The moraine lies directly on the gravel dome, without transition beds. I could discover no sign that the glacial stream which deposited the gravel was flowing at the time the

TILL BOWLDERS ON MARINE DELTA GRAVEL; WATERBORO.

The bowlders overlying the gravel are attributed to floes of shore ice.

moraine was itself deposited. The moraine near the esker showed no more sign of water wash than at a distance. The lenticular eskers or short osars extend about 3 miles south of the moraine and along a curved valley. We can not admit that these small hummocks separated by intervals of one-fourth mile or less could be formed in the open sea by a glacial stream issuing from the ice front while the moraine was forming. Their materials as well as their shapes testify that they were formed within ice walls by currents that at no time were checked as they would have been if poured into the open sea. The hummock underneath the moraine has the proper shape, size, position, and composition of one of the parts of this system. If at this point

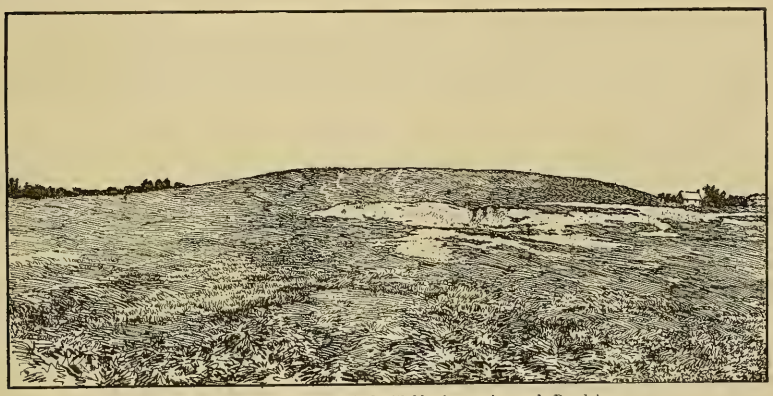


FIG. 31.—Lenticular esker flanked with blowing marine sand; Bowdoin.

a subglacial river continued to flow during the time the moraine was being formed, it ought to have more or less washed away the moraine and left, not a line of discontinuous hummocks separated by intervals, but continuous ridges or delta-plains of frontal gravel extending south from the moraine. The same would be true of a superficial stream. This makes it probable that there is no genetic connection between the hummock that underlies the moraine and the moraine itself. More probably the gravel system had all been deposited prior to the moraine, and at the time of the moraine the glacial stream had ceased to flow in this part of its former channel, or was too feeble to form such deposits.

It is possible that the Waldoboro moraine was due to an advance of

the ice after it had once retreated northward of this point. Any great readvance would imply general or climatic increase of intensity of glacial conditions. If so, we ought to find similar moraines all along the coast. The few short moraines certainly demand pauses in the retreat of the ice, and they may indicate a readvance. In either case the moraine must have been formed while the ice was in motion. The conclusion follows that if the ice was not stagnant at the time of the moraine it could not have been at any time previous. Its motion at the time of the deposition of the moraine was a continuation of the motion it had had previously and continuously. The situation of the place was here favorable to the continuance of the flow up to the last.

Three inferences are indicated. 1. The Waldoboro system of discontinuous gravels was formed while the ice was in motion. 2. The osar beneath the moraine proves that the thin ice of that time (less than 200 feet in thickness) could flow over gravel ridges or domes without pushing them forward. 3. This gravel was probably deposited in a subglacial channel.

In the valley of Georges River, and also near Belfast, we find several discontinuous systems of gravels. In these localities the direction of the ice flow during the last part of the Glacial period was many degrees different from the earlier flow, as is conclusively proved by two or more series of glacial scratches. The systems of lenticular eskers follow the direction of the scratches last made. They date, then, from a late period, when the ice could no longer flow over the higher hills, but was forced to flow around them.

The fact that the series of lenticular eskers are so nearly parallel with the direction of ice flow favors the hypothesis that they were formed beneath the ice by subglacial streams. In several places, as near Union, the surface layers of the northern sides of the lenticular gravel hills are crumpled and distorted, while beneath these layers the stratification is, in the cases observed, perfect. Such surface distortion might result from the direct pressure of ice flowing over the gravel hillock, or it may be due to the settling of gravel deposited over ice. Thus it is possible that pieces of ice containing morainal matter may break away from the roofs of tunnels and be rolled along for a time like stones. If such were deposited as a part of a mass of glacial gravel, the melting of the ice subsequently would

distort the stratification. So also where flowing ice abutted against a subglacial mass of gravel it might often do so unevenly, so that cavities of unequal thickness would lie between the ice and gravel. Into these, if new gravels were deposited, the subsequent advance or melting of the ice would change or obliterate the stratification. If such distortions were prevailingly on the stoss side of the gravel hillocks, as they were in the places examined, motion of the ice during the formation of the gravel deposit would be indicated, and also subglacial origin. That subglacial streams abounded near the coast is directly proved by the glacial potholes, also by the presence of the hummocks of glacial gravel directly beneath the Waldoboro moraine, and by other facts.

The general inference follows that the lenticular kames were formed beneath the ice at a time when it was so thin that it was forced to flow over them without pushing them forward and incorporating them with the till of the terminal moraine, as appears to have been the case at the great outermost terminal moraines. And if these lenticular masses were formed beneath flowing ice, their shapes must be due in part to the same forces that produced the lenticular hills of till. Like the latter, the surfaces of the gravels were molded into the forms of stability by the ice as it flowed over them. But in the case of the drumlin the ice pressure was a comparatively constant quantity, while in the esker the action of the water in melting and eroding the ice was a controlling agency to change the pressure and in part to mold the form. The ice, as it advanced, found the head of its columns literally melting away, so that if the supply of water continued, the enlargement of the channel might often proceed even more rapidly than the advance of the ice. During the summer time if these lenticular gravel hills were formed at the base of "glacier mills," it is doubtful if the ice could advance so fast as to impinge against the kame. But during the winter, when the supply of water was small and almost all of it ice cold, the amount of melting and erosion would be greatly reduced. Now and then the ice would abut against the gravel and be forced to flow over it, at the same time helping to carve it into the lenticular form. Indirectly the flow of the water in the space between the gravel and the ice of the glacier—a space caused by the gradual melting and erosion of the advancing ice—would tend to the broadly arched form of gravels. Yet since the water would erode and melt the ice somewhat

irregularly, we can not expect the gravels to be so symmetrical in shape as the drumlins.

The lenticular eskers or osars, then, have the natural form that a short mass of gravel takes when formed beneath flowing ice. This hypothesis assumes that the present deposits were stationary and the ice flowed over them. It is barely possible that a glacial waterfall where a surface stream falls down a crevasse may form a series of enlargements at intervals, and that these enlargements may be pushed bodily forward with their continued gravels. This would imply thick ice and small masses of gravel. At the time the present lenses were formed the ice could not push forward the gravels, but, as at Winslows Mills, flowed over them, only now and then distorting the stratification on the stoss sides. The question whether the continuous ridges began as a series of separated lenses which at last became confluent will be referred to later.

DECREASE OF GLACIAL GRAVELS TOWARD THE COAST.

As has already been repeatedly stated, the maximum development of the coarser glacial sediments occurs near the highest sea level, which in the coast region is not far from the contour of 230 feet.

Among the causes of great precipitation at this elevation may be mentioned the following:

1. The length of time the sea stood near that elevation. That the changes of level of the sea with respect to the land were geologically rapid is proved by the fact that the till was only partially eroded over the submerged area. I have found no cliffs of erosion in the rock, and thus have no proof of long pauses in either the advance or the retreat, and therefore assume that the rise and fall of the sea were somewhat uniform in rate. If so, it follows that it stood near its highest level for a longer time than at any other—that is, during the last part of the period of advance, the time of stationary level, and the earlier part of the retreat. During this period the modern rivers began to flow and form deltas off the shore of that time. Thus a vast quantity of sediment was stopped near the highest shore-line. It could not reach farther south because checked in its motion soon after entering the sea.

2. The effect of steeper land slopes north of the contour of 230 feet. By a coincidence the slopes of the land are steeper to the north of the

230-foot contour over large parts of the State. The steeper slopes were areas of greater than average denudation by glacial rivers, and the more level plains were areas of accumulation. The marine deltas of York and Cumberland counties pass upward into great tracts of reticulated ridges that rise to 450 or 500 feet in a few of the valleys, but the deltas in that part of the State are at 230 to 250 feet. Obviously the proximity of the change in slopes with the old shore line is a mere coincidence.

3. Possibly a more rapid rate of melting. The lower marine clays are blue to black in color and are very fine grained and often richly fossiliferous. The later marine clays pass upward as the basal clays of the valleys, they are lighter in color, they seldom contain fossils, and in general they are a little coarser grained. Evidently quiet conditions prevailed for a time after the ocean advanced and animal life flourished. Later the conditions were unfavorable. If due in part to the great inflow of fresh water, this proves more abundant fresh waters. If due to the muddiness of the water, the streams must have been rapid, which could be accounted for by increase in the size of the streams or by steeper land slopes. Apparently the reelevation of the land took place after the upper marine clays were deposited. The advance of the sea over considerable portions of the land ought to have helped to ameliorate the climate at the time it stood at its highest level irrespective of other conditions. On the whole, we conclude that while it is not positively proved that there was any marked increase in the flow of fresh waters into the sea at the time it stood at its highest level, yet this is probable.

The above-cited causes help to account for a large development of the glacial sediments at or near the highest shore-line. In comparing the gravels at this elevation with those found near the present shore, we are confronted by an important question: Did the ice retreat from the coast region before the advance of the sea?

If this had happened, we ought in that region to find overwash gravels and terminal kames, such as naturally mark the recession of ice on the land A good place to look for such gravels is at the Waldoboro terminal moraine. It is 6 miles long and crosses two valleys favorable to the formation of overwash aprons. At the road from Waldoboro to North Waldoboro are a few bars of subangular gravel that probably are an overwash deposit made while the moraine was being formed. If there is any other overwash

matter it is thin and covered by the marine clays. I found none exposed in the banks of the Medomac River, though the discontinuous osar gravels are easily traced.

Frontal gravels ought especially to be abundant in the valleys of the larger streams, such as the Penobscot and Kennebec, if the ice melted over them before the rise of the sea, and we do not find them. On the contrary, they do not either of them show even a marine delta near the rivers, though there are a few situated a few miles back from the rivers.

The conclusion follows that the ice had not melted over the coast region previous to the rise of the sea over this area. The retreat of the ice front was accompanied by the advance of the sea, if not in part caused by it.

A related question refers to the earliest glacial sediments of the ice-sheets. As before noted, the ice front during the time of thickest ice must have been far out in the present Gulf of Maine. While a part of the wastage then took the form of berg discharge, yet there must have been subglacial rivers which deposited more or less glacial sediment near the ice front. We do not know what development these gravels took, or how far they were incorporated with moraines and berg droppings, nor do we know the extreme depth beneath the sea to which a subglacial stream can penetrate and retain sufficient velocity to transport sediment. Omitting details, we can at least affirm that the earliest glacial gravels are now under the ocean.

What is the date of the earliest gravels now exposed on the land? As elsewhere stated more fully, in the coast region there are several places where the glacial gravel systems follow the scratches last made when the ice was deflected by hills and therefore much reduced in thickness from the maximum. These reach as far southward as any of the systems except the great ones that come to Portland, Jonesport, and Columbia, and appear to be as old as any, with perhaps these exceptions. This gives field support to what we should expect from general considerations—that the osars were not deposited till the later days of the ice-sheet.

In comparing the quantity of the coast gravels with those of the interior, we have to consider the effect of the position of the névé line at various periods of the ice-sheet's history. I conceive that only under extraordinary conditions is the névé line stationary during periods of the advance and the retreat of the ice front. It is perhaps possible that there can be such a balance of circumstances—such as length of the glacier, surface gradients,

rates of precipitation, changes in seasonal temperature, and other climatic conditions—that a glacier can grow thinner and finally disappear without change in the horizontal position of the névé border. But in the case of a great ice-sheet, subject to other than local conditions, it seems to be highly probable that there was a retrogression of the névé border comparable with the retreat of the ice front itself. If so, there must have been a time when the area of the zone of wastage from melting attained a maximum over Maine. Previous to that time part of the zone of wastage had extended southward, where the ocean now is, and took the form of iceberg discharge. As the névé border retreated north the area of wastage by melting that was over the land broadened till the time when the outer margin had retreated back to the present coast. Whether the névé border of the ice front would retreat the faster after that is uncertain, since we do not know what effect the rising sea had in melting the ice before it. Leaving open the question as to when the area of the zone of wastage from melting over Maine was greatest, we can at least conclude that so rapid a decrease in the quantity of gravels as takes place within 30 miles of the coast could not have been caused, unless in small measure, by changes in the position of the névé line. This may have had some effect, but it seems improbable that its effect could all be concentrated within so narrow a belt and be so conspicuous here while hardly traceable elsewhere.

The causes above stated account for the great development of the gravels near the highest level of the sea, but throw only partial light on the causes of the rapid decrease in the gravels toward the coast. The subject is so closely related to the fact that as the gravels become scanty they also become increasingly discontinuous, that the further treatment of the subject is postponed and will be considered in connection with the latter topic.

SUMMARY.

The most important characteristics of the glacial sediments of the coast region are the following:

1. Most of the systems contain one or more marine deltas situated at different distances from the coast. These deltas are interpolated in the midst of the linear series of glacial gravels that were deposited within ice walls.

2. The continuous osars and osar terraces of the interior as they approach the coast break up into ridges separated by intervals. Toward

the south the intervals become on the average longer and the ridges shorter, till the latter are reduced to cones, domes, and short ridges or plains. The deposits continue to become smaller, and the systems end north of the average line of the coast, and most of them only a few feet above it.

3. The maximum development of the glacial sediments is found near the contour of 230 feet.

4. The gravel deposits of the coast region usually have rather gentle lateral slopes and convex summits, and as a class they may be referred to the lenticular type of eskers.

5. The other characteristics of the coast gravels, their topographical relations, etc., do not differ materially from those of the interior, except that in certain places the gravels of the discontinuous systems or the discontinuous portions of the osars and osar-plains have the marked characteristic of appearing on the tops of low hills (less than 120 feet high), while in the intervening valleys gravels are seldom found.

The above-named facts present special difficulties of interpretation. It is certain that some of the gravels were deposited in the open sea, others in ice channels, but we have to determine, if possible, whether the latter were deposited beneath sea level. Observations made on the land can give us little help in studying offshore deposits; and we are haunted in our investigation by the uncertainties attending the determination of the border line of the névé. We are able to point out certain agencies that must have been engaged in the work, but a satisfactory explanation demands a quantitative estimate of their relative efficiency. This field of investigation is untrodden as the névé of the ice-sheet itself, and my views have not infrequently changed while studying the subject. It seems impossible to take up these questions at any point without anticipating later discussions.

RETREATAL PHENOMENA.

A topic germane to a comparison of the discontinuous coastal gravels with those of the interior of the State pertains to the manner of retreat of the ice over a country so diversified by hills and valleys as Maine at a time when a considerable part of the State lay beneath sea-level. Thus, if the terminal melting was either more or less rapid where the ice was in contact with the salt water than where it was above the sea, the retreatal phenomena would be very complex. The ice of the drainage basins of many of the

glacial rivers would not only be attacked from the front lengthwise of their courses, but often might be cut off by the sea penetrating transverse valleys and thus arresting their flow at some point many miles to the north of their previous mouths. Thus, from the north end of the Georges River discontinuous osar system in Searsmont it is a less distance eastward to Belfast Bay than southward to the coast at Thomaston or St. George.

In marking the lines of synchronous retreat of the ice front the deposits we have to depend on are, first, terminal moraines; second, marine glacial deltas; third, frontal or overwash aprons of glacial sediments. There are many such deposits in Maine, but unfortunately they are several or many miles apart and no contemporaneous deposits connecting them have as yet been recognized. In the table on page 393 these deposits are divided into classes. The order of deposition was first determined for each glacial river separately. Of two neighboring deltas the one that was north of a line passing through the other parallel to the general coast line was assumed to be the later deposit. This assumption is unsafe, but is the best practicable test at present. Obviously the rate of retreat of the ice front is determined by the ratio between the rate of terminal melting and ice flow. Naturally the symmetry of the retreat is much marred in a hilly country, and may be still more in a country where the deeper valleys for 100 miles or more from the coast were beneath sea level. If the ice melted more rapidly before the advancing sea than on the land above sea level, then long bays on the fiords of the sea would deeply penetrate the border of the ice; if slower, there would be formed lobes of the ice reaching as capes into the sea. Thus the long Penobscot and Kennebec valleys were at that time below sea level for more than 100 miles. Their general trend is nearly parallel with that of the ice flow, and both open northward into numerous tributary valleys. They were thus favorably situated for a rapid rate of ice flow.

Two glacial rivers flowed from the Penobscot Valley eastward through low passes into the valley of Union River, where they deposited large marine deltas that demand considerable time for their deposition. One of these overflows was from Clifton to Otis, the other from Greenfield to Aurora. Manifestly in both cases the ice lingered in the Penobscot Valley all the time they were forming, while the open sea prevailed over the valley of Union River. Both glacial rivers departed from places in the Penobscot Valley that were considerably below the highest sea level. The distance

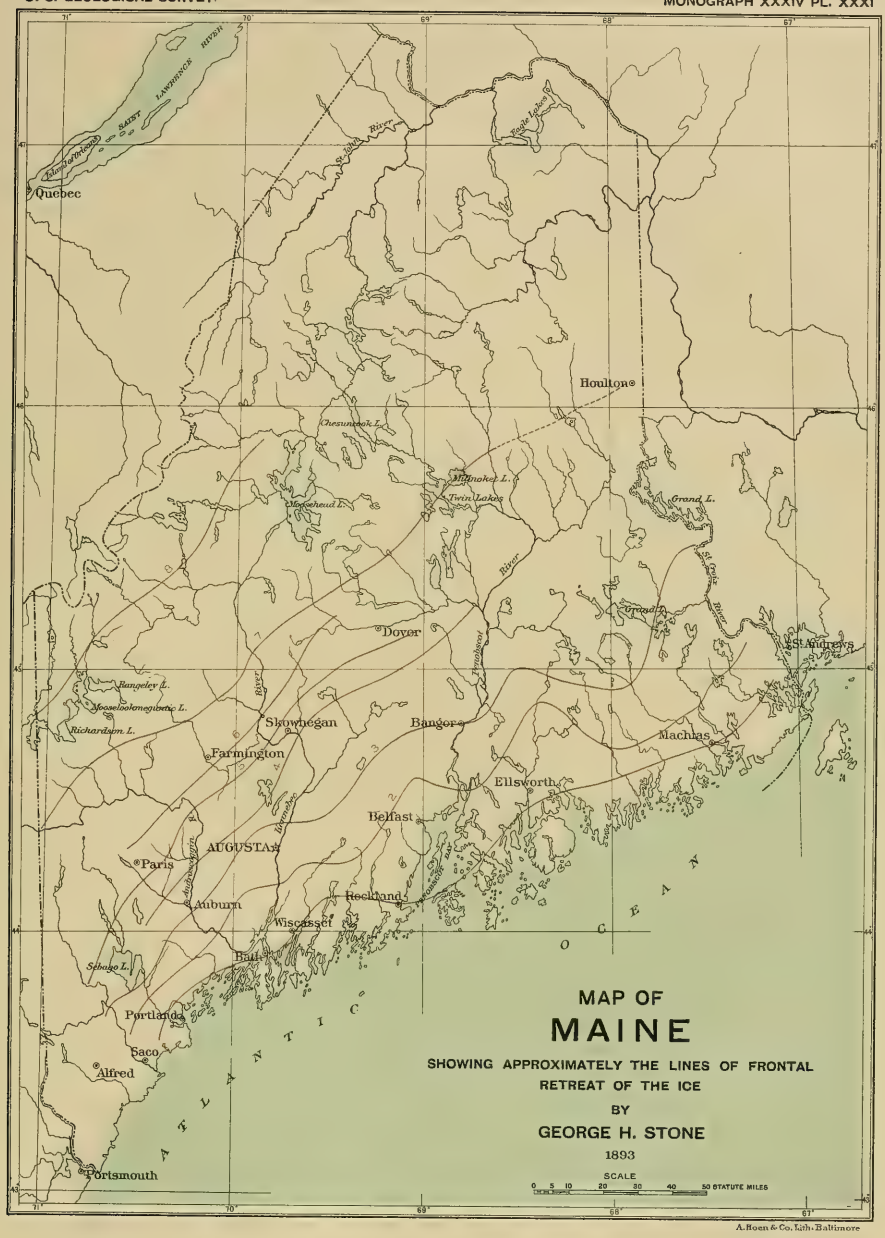
from Clifton to Penobscot Bay is about the same as from Otis to the mouth of the Union River. If the sea that rose on the land was so warm that the ice melted before it as fast or almost as fast as the sea rose, then the ice would have retreated in the Penobscot Valley to Clifton as soon or nearly as soon as it retreated to Otis in the other valley. This would arrest the flow eastward of the glacial river. If any delta formed in Otis it would have been very small instead of large, as it really is. The same reasoning applies to the overflow to Aurora.

Several inferences follow. Although the sea was deeper in the Penobscot Valley, yet the retreat of the ice was relatively slower in this valley than in that of Union River. Part of this difference may be due to the southeastward motion of the ice, but in any case we know that the ice could flow into regions below sea level and maintain itself for a considerable time. The sea was cold, and ice in it melted slowly. Comparing two valleys, both beneath the sea level of that time, the one most favorably situated for a rapid flow of the ice showed a slower rate of retreat than the other, where the flow of the ice from the north was embarrassed by transverse hills.

Elsewhere are described the glacial lakes that were formed near Lead Mountain, Beddington. These were formed in level grounds south of hills that would early arrest the flow of ice from the north. For many miles the glacial river that deposited gravels in these lakes flowed a half mile or more west of the Narraguagus River and on ground 50 to 100 or more feet above it. During all the time the glacial river was flowing into the lakes the deeper river valley was filled with solid ice to a point south of the lakes at least. In other words, the ice in lee of hills melted sooner than the ice in the adjacent north-and-south valley favorable to a rapid flow from the north. This happened above the highest sea level.

Thus both above and beneath the sea we have proof of a lobate front during the retreat of the ice, but thus far no definite means of comparing the relative rates of retreat in the two cases.

The lines of synchronal retreat were drawn on the map (Pl. XXXI) to connect deposits independently determined to belong to approximately the same stages of retreat, as set forth in detail in the table. When the given points are so few it is manifestly impossible to exhibit the narrower sinuses and lobes that probably marked the actual lines of retreat.



A. Boen & Co. Lith. Baltimore

The following list gives the data on which the lines were drawn on the map. It must be considered as tentative, not final.

List of approximately synchronous glacial deposits.

Localities.	Kind of deposit.
FIRST SERIES.	
Machias, near Little Kennebec Bay	Terminal moraine.
Jonesboro and Jonesport	Gravel massives, apparently passing into the sea.
Lamoine	Delta.
Waldoboro	Terminal moraine.
North part of Alna	Delta.
Stevens Plain, Deering	Do.
SECOND SERIES.	
Meddybemps-Dennysville	Delta.
Old Stream Plains, in part	Do.
Mont Eagle Plains	Do.
Deblois and vicinity	Do.
Otis and Aurora	Deltas.
Monroe	Delta.
Waldo and Brooks	Do.
North Searsmont, Liberty, and Appleton	Deltas.
Washington	Delta.
Windsor	Do.
Litchfield Plain	Do.
West Bowdoin (Pine Nursery)	Do.
West Cumberland	Do.
Gorham and North Scarboro	Deltas and gravel massives.
THIRD SERIES.	
Codyville	Marine glacial delta.
Old Stream Plains	Delta.
Race Ground near Machias River	Do.
Greenbush, Greenfield, and Milford	Do.
Dixmont, Unity, and Thorndike	Deltas.
Belgrade, Sidney, and Augusta	Delta.
Sabatisville	Terminal moraine.
New Gloucester and Gray	Delta.
Standish-Limington	Do.
FOURTH SERIES.	
Orneville-La Grange	Delta?
Harmony, valley of Half Moon Stream	Valley drift and marine beds.
Readfield	Terminal moraine.

List of approximately synchronous glacial deposits—Continued.

Localities.	Kind of deposit.
Curtis Corner, Leeds	Delta.
Turner-North Auburn	Do.
Poland Corner	Do.
FIFTH SERIES.	
Baldwin and Saco Valley	Glacial gravels mixed with frontal overwash.
South Paris	Valley drift passing into marine fluviatile delta.
Sumner and Buckfield	Glacial marine deltas.
Livermore and Jay	Valley drift passing into fluviatile marine deltas.
Cornville	Valley drift and fluviatile marine delta.
Canaan	Overwash plain and delta?
Dexter and Corinna	Valley drift passing into marine beds.
SIXTH SERIES.	
Woodstock, Paris, Hartford, Jay, Mount Vernon, Mayfield, Kingsbury, etc.	Belt of short hillside eskers.
SEVENTH SERIES.	
Conway?	Terminal moraine and overwash gravels.
State line, Androscoggin River	Do.
Sunday, Bear, Ellis, Swift, and Wild rivers	Overwash.
Upper Sandy River Valley	Do.
New Portland	Moraines and overwash.
Upper Kennebec Valley	Overwash.
Blanchard, Piscataquis Valley	Do.
Katahdin Iron Works	Moraines and overwash.
Seboois River	Osars and overwash.
EIGHTH SERIES.	
Umbagog outlet	Ridge of till, probably terminal moraine.
Kennebago Valley	Kames and overwash.
Kibby Stream	Osar and overwash.
Parlin Pond?	Osar.
Leadbetter Falls?	Do.

CAUSES OF NONCONTINUOUS SEDIMENTATION WITHIN ICE CHANNELS.

The nature of the phenomena here referred to can best be understood by consulting the descriptions of the discontinuous and continuous osars, also of the osar terraces. They are briefly set forth as follows: If we start from a point 30 or 40 miles from the coast and go southward, we find the gravels becoming more and more discontinuous (and correspondingly smaller in size), and almost all the systems end a short distance from the shore and at only a few feet above tide water. That gravel systems of varying lengths and having very different topographical relations should terminate over the whole coast at almost the same level is a remarkable fact and apparently associated with the feature of noncontinuity.

Omitting from present consideration the deltas which were deposited in the sea or in lakes sufficiently large, relative to the inflowing glacial river, to permit a horizontal classification of sediments from coarse at the proximal to the finest clay and rock flour at the distal end, we confine the inquiry to sediments deposited in ice-bordered channels or basins, under such conditions that the finest of the glacial débris was carried away by the glacial rivers and only the coarser left. We premise that each of the discontinuous osar systems, as well as the discontinuous portions of the osars, was deposited by a single glacial river. The question then resolves itself into this: How can a glacial river systematically deposit sediments at intervals in its channel and the intervals increase as the size of the gravel deposits decreases?

Noncontinuous sedimentation by a single glacial river might be accomplished in three ways: First, the river might be depositing sediments in two or more separate parts of its channel simultaneously, the intermediate portions of the channel being at the same time areas of erosion and transportation; second, sedimentation might proceed by stages, the separated deposits being made one after the other, each one being finished before the next of the series was begun; third, both these methods might be in operation simultaneously in different parts of the same glacial river.

Again, part of the physical agencies that lead to noncontinuous sedimentation may be operative only when the tunnels of the subglacial streams open beneath the sea or other body of water, and others may depend wholly on conditions originating within the glacier itself or on other

conditions independent of the presence of a body of water rising above the bottom of the ice at its distal extremity.

Moving waters drop a portion of their load of sediments when their velocity is for any reason diminished, or they have a greater component of the force of gravity to overcome, provided they were just able to carry the load.

One cause of a reduced velocity of current is the enlargement of the channel. Local enlargements of the tunnel of a subglacial stream, resulting in a localized slowing of the waters, are formed at the bases of crevasses down which warmed superficial waters pour. They may also form in rapids where the waters rebound upward in passing over rocks, or where they fall to the ground again and spread laterally, or where the subglacial waters rise into crevasses or onto the surface because of insufficient or clogged outlets. Perhaps the most important method of enlarging narrow tunnels into lake basins is that whereby a large superficial stream forms a pool or lake where it pours down its shaft into a subglacial or englacial tunnel. Gradually the warmed surface waters melt a large shaft and ultimately form a pool. If from time to time the outlet became clogged or proved insufficient, so that the pool and shaft became filled with water exposed at the surface to the sunlight, the melting would be accelerated and ultimately a lake would be formed. When once the water of the lake became exposed to the sun for a large part of the time, the enlargement would be still more rapid. A lake might also form where, on account of stoppage of the subglacial stream, the waters rose through crevasses onto the ice and absorbed heat from the sun The extension of a subglacial stream northward incidental to the thinning of the ice might cause a series of new crevasses to open across the course of a superficial stream and a corresponding series of enlargements at their bases. In these and other ways we can account for local enlargements of subglacial tunnels into hollow cones, domes, and caves of various shapes, also into basins open above to the air, the impetuous waters acting on the ice both by mechanical erosion and by melting.

When a subglacial stream tunnel passes up and over a hill or opens at the ice front beneath a body of water, some special phenomena demand notice. The water in the tunnel below the top of the hill or surface of the body of water (making allowance for the difference in the specific gravity

of the glacial and the frontal water) is in equilibrium. This part of the tunnel and all its connecting crevasses are permanantly filled with water that can flow only when there is an effective head of water rising above or behind it. At the proximal end of this permanent body of water the streams in summer flow with such velocity as to keep their channels clear of sediment, but during the fall and winter the small streams are checked as they flow into the body of permanent water and deposit their sediments, probably to wash it away during the next flood. A rising or falling sea or frontal lake might under some conditions cause the deposition of a series of such sediments formed at the successive levels of the subglacial portions of the sea or lake.

Among the conditions of retreat in presence of a cold sea (the depression of the Chiegnecto Peninsula would assist in maintaining a rather cold sea on the coast of Maine) is the marginal zone of submarine ice. When a glacier ends in a warm body of water, the ice margin overhangs; but when it ends in a cold body of water, and especially in salt water that can be cooled below 32°, the waves erode the upper ice just as they do other rocks, and leave cliffs overhanging the surf, while there is left a shelf of ice passing out beneath the sea and from time to time breaking off in blocks and rising to the surface.[1] The breadth of this zone of submarine ice would be increased if the basal ice contained a considerable quantity of glacial débris and thus weighted it down, so as to prevent it from rising as bergs. The breadth of this ice would increase during the winter, partly because of the colder sea and partly on account of the violence of the winter storms in eroding away the upper part of the ice. In summer the ice would begin to melt this projecting shelf, and under favorable circumstances might before autumn melt it all away and even cause an overhang of the upper ice.

If crevasses opened from the subglacial tunnels upward to the surface of this submarine ice, the subglacial streams would rise in the crevasses and escape on the surface of the sea, partly because their specific gravity is less than sea water and partly because they would thus meet less friction. If so, the stream would drop much of its sediment at the base of the crevasse.

Another cause of the diminished velocity of the subglacial streams is a

[1] Russell, Nat. Geog. Mag., vol. 3, p. 101, 1892.

differential subsidence of the land whereby the proximal extremity of the ice-sheet is more depressed than the distal. This effect would be intensified if it was accompanied by a corresponding rise of the sea to diminish the surface gradient of the waters of the glacial streams.

In addition to the varying velocities of current that favor sedimentation, we also must reckon with friction and the force of gravity. Thus manifestly the slopes of the bed of a subglacial stream favor sedimentation when the stream leaves a steeper down slope for one less steep or for an up slope, since a greater component of the force of gravity is to be overcome.

Thus far in our discussion we have assumed the ice to be stationary. But one of the important works of glacial ice is to push forward the sediments that gather in subglacial tunnels. Thus, in the Kettle moraine of Wisconsin there are many stones that have been very much rounded by water action and subsequently thrust forward and incorporated with the other morainal matter. The same phenomenon is seen at the larger terminal moraines of the Rocky Mountains. When the rate of ice flow is rapid and the larger part of the débris is superficial, all or nearly all the glacial gravel is brought forward to the front of the ice, partly by the streams and partly by ice pushing. A considerable part of the waterworn matter is left as a part of the moraine in most cases. Indeed, it is difficult to account for gravels being deposited in transverse tunnels, or in the transverse portions of tunnels, without being pushed forward, while the ice remains deep and the flow rapid. It is equally difficult to account for gravels being pushed forward by the ice that were deposited in longitudinal tunnels of uniform size. Occasional mounds occupying caves in the base of the ice might be pushed forward. Such pushing would probably obliterate the stratification, but the floods of the succeeding summer would restratify it, and at the last, when the ice became sufficiently thin, it would no longer be able to thrust it onward, but would be forced to flow over it, or at the most could only disorganize a portion of the mass on the stoss side. In like manner we can account in part for the failure of the ice to push forward transverse gravels at a time of stagnant thin ice and rather rapid rate of enlargement of the subglacial channels.

When we come to apply these general principles to the problem of the coastal gravels of Maine, we note, first, that domes and cones of gravel up to one-eighth or even one-fourth of a mile wide were left on the tops of low

hills, some of them wholly or largely composed of till. Here great enlargements of the glacial channels were formed in places favorable to the production of crevasses. Both to the north and south of these local deposits the glacial rivers left no gravels, often for a considerable distance. On the whole, we must admit that the local situations of such of the coastal gravels as cap hills are favorable to local enlargements of the channels of the glacial streams, and therefore to sedimentation. The slopes of the hills up which much of this sediment must have been transported would also aid sedimentation. In other cases there are no relief forms of the land that we can connect with the positions of the discontinuous gravel masses. Only in part, then, have we field evidence that gravels were deposited at places favorable to local enlargements of the stream channels.

What effect had the marginal zone of submarine ice on the distribution of the gravels?

As elsewhere noted, one of the mounds of the discontinuous Medomac Valley system of gravels lies beneath the moraine at Winslows Mills. The material of this mound is much waterworn. If any of the deposits of much worn gravel can be connected with the marginal submarine ice, it ought to be this, for it bears a definite relation to the ice front at a certain period. The opinion is justified elsewhere that the gravels were deposited and the glacial stream that left them had ceased to flow before the ice had retreated to the position of the moraine. The bars of subangular gravel that lie in front of the moraine at the road from Waldoboro to North Waldoboro may be frontal gravels, or possibly they were deposited in the marginal zone of submarine ice a few rods in front of the moraine. These gravels are only a very little worn and are unique in character. If there were any gravels deposited in the submarine ice, they would probably be more like these than like the more rounded gravels. The rather steep two-sided ridges that form the terminal moraines in the coast region point rather to overhanging ice than to a projecting wedge of submarine ice as bordering the margin at the times the moraines were deposited. At other times it may have been different.

If a subglacial river dropped its coarser sediment as it went up through crevasses in the submarine ice, it ought to have deposited its finer sand and clay near by as a delta or overwash apron. Such deposits would be formed near the ice margin, for we can not admit any great breadth of submarine

ice. They would be retreatal, capping older sediments, and but rarely would they form an isolated mass by themselves, as I conceive.

While admitting that some marginal submarine ice probably exists, and that it might act in the manner indicated, I have found no certain field evidence of this form of ice action.

Were the discontinuous coastal gravels begun as a series of subglacial tide-level deposits during a gradual rising of the sea?

The answer to this question is short and positive. The discontinuous systems cross valleys and hills and gently rolling ground. North of the hills the water in the stream channels, no matter whether they were superglacial or subglacial streams, would be dammed by the hills in front. The rising of the sea could produce no effect beneath the surface of this glacial dam. On a continuous southern slope we might admit as a possibility a series of tide-level deposits as inaugurating sedimentation at intervals, but by no means on the north sides of hills in confined channels in the ice. But in another way we may have proof of the action of the subglacial sea, if we may so term the body of glacial water that filled the cavities of the ice-sheet up to sea level. The East Machias osar shows a series of broad reticulated ridges at the highest sea level, but no delta proper. In Lagrange and Orneville, in the Penobscot Valley, and in Canaan and Cornville, in the Kennebec Valley, we find near the highest sea level that the long osars that follow these valleys for 50 miles expand into plains with some of the characters of narrow marine deltas and also of the broad osar terraces. Here it is probable that these plains or partial deltas were formed at sea level, but at some distance back from the ice front, so that no delta proper could be formed. If so, this would prove that enlargements of glacial channels and sedimentation took place at the point where the stream flowed into the permanent subglacial and submarine body of water. Such deposits are, however, very different in structure from the discontinuous gravels of the coast region.

In three instances in Maine osars are conspicuously discontinuous on level ground at long distances from the coast. The first instance is that of the Katahdin osar near South Lincoln; the second, that of the Moosehead Lake osar in Abbott, Guilford, Sangerville, and Dover; the third, the Anson-Madison osar in the northwestern part of Anson. In all these cases the discontinuous deposits are below the highest sea level, or in a glacial lake. A similar coincidence occurs in central New York, where Mr. G. K.

Gilbert and others have described a frontal glacial lake. At one time it lay between the ice on the north and the hills on the south and overflowed the Rome divide into the Mohawk Valley. A delta deposited by glacial streams in this lake is found in Schroeppel, Oswego County, and extending southward into Clay, Onondaga County, and other towns. Over most of the Ontario slope in that region there are numerous short ridges and mounds of glacial gravel, and some of them are arranged in north-and-south lines, suggestive of deposition by a single glacial river. Is this association of discontinuous deposits in the course of a single glacial stream, not only on the coast of Maine but elsewhere, with the presence of a body of water in front of the ice, causal or only accidental?

Regarding the cases of discontinuous gravels in Maine at long distances from the coast, the problem is complicated by the fact that in two or three cases there were other causes that may have been more significant than the presence of the frontal body of water. Thus, in Anson we are only 2 or 3 miles from a large terminal moraine, and the gravels may have formed near the ice front as local kames rather than as parts of the original osar, dating from a time when the ice of the Carrabassett Valley practically formed a local glacier. The conditions in Abbott and Guilford may be very similar.

The first question that arises in this discussion pertains to the effect of the presence of the frontal body of water on the development of the subglacial tunnels. We have seen that when the glacier lies partly below the level of the frontal water, the tunnels and the connecting crevasses are permanently filled with glacial waters up to the level of the sea or frontal lake. The water in the crevasses would soon attain a temperature of 32° and then float above the somewhat warmer water contained in the tunnels below them. All the water of surface melting in this part of the glacier would fall into the crevasses and become mixed with the water already occupying the lower parts of the crevasses. The convection currents would be feeble, and but little of the heat brought down by the surface waters would get down into the subglacial tunnels and be available for enlarging them. Only where the larger surface streams poured into crevasses would the surface waters carry a surplus of heat into the subglacial tunnels. The smaller brooks and seeps would be so mixed with the cold waters of the crevasses that their heat would be expended in melting the ice walls of the

crevasses perhaps some hundred feet above the tunnels. Thus over all those parts of the ice-sheet where the basal ice was submerged in the sea but little of the water of local melting was available for enlarging the main tunnels, but the melting was diffused, so to speak, over many times as great an ice surface as where the water could pour down a crevasse and escape at once along the tunnel, as happens in case of glaciers not flooded by basal waters. The net result would be that in the parts of the ice-sheet where the basal ice was submerged the subglacial tunnels were far less enlarged than they would have been if the gently warmed surface waters could have sunk at once into them. It is uncertain how far the outward pressure of deep bodies of water can overcome the inward flow of the walls of the tunnels, but on the coast of Maine the depth of the permanent water in the crevasses was at the most only about 200 feet, and it is improbable that such a pressure would perform any important work. But irrespective of any possible partial collapse of tunnels formed on the land as they were pushed beneath the cold sea, we can at least infer that the tunnels were not enlarged commensurate with the supply of waters. For there was as much water of surface melting here as elsewhere on the glacier, but it could not help to enlarge the tunnels so much as that above sea level. The tunnels naturally were inadequate to carry off the water of summer melting as fast as it fell down from above into the crevasses. Each crevasse became filled with water above sea level and formed a standpipe to the main tunnels. A great hydraulic "head" of water was the result, but could never be greater than that which was due to the gradient of the ice surface, since if the crevasses filled to the top the water would then overflow on the ice. The result was a high velocity of the streams in their narrow channels with consequent little sedimentation, and that only of the coarsest matter and under the most favorable circumstances. The local effect of basal waters would be felt by stream channels lying wholly in the submerged area as well as by those originating above the sea and pushed beneath it.

In other words, the normal transfer of heat by surface waters to the base of the ice, where it is the chief cause of the enlargement of the subglacial tunnels, is in a large part arrested where the base of the glacier is submerged to any considerable depth, and the heat is expended in melting ice in the crevasses far above the tunnels.

In a minor and more indirect way the noncontinuous gravels appear to owe their peculiar development to the presence of the sea in front of the ice. Under any admissible surface gradient of the ice the presence of 200 or more feet of frontal water rising above the base of the ice would arrest the flow of such of the subglacial streams as did not have their sources more than 3 to 5 miles back from the front, so as to have sufficient head to drive them after the rise of the sea. Several of the shorter discontinuous systems do not exceed this length. In such cases the rising of the sea would cause the development of the gravels to cease, and we would now find them in that stage in which they happened to be when their streams were arrested. If we grant that the sea had no direct, only a modifying, effect in causing noncontinuous sedimentation, still it would be a not unimportant rôle to fossilize, so to speak, the work of the shorter glacial rivers at a particular period of their history and preserve it for our inspection.

Having thus set forth what appear to be the more important agencies in producing noncontinuous sedimentation, it remains to examine them in their mutual relations and thus obtain a more general view of the subject.

RÉSUMÉ: HISTORY OF THE COASTAL GRAVELS.

As already repeatedly noted, the three distinguishing features of the discontinuous coastal gravels are their rapid decrease in size toward the coast, their occurrence at longer and longer intervals, and their termination a short distance north of the shore and at only a few feet above tide water. The three phenomena are so widely associated that they would appear to have had, in respect to their principal causes, a common origin.

The history and causation of the coastal glacial sediments, so far as now appears, were probably about as follows, assuming that in the coastal region of Maine most of the glacial sediments were deposited by subglacial streams:

If these changes were observed in case of only a few of the gravel systems that reach nearest the coast, one here and there, the facts would seem to indicate local causes. But when gravel systems are found every few miles along 200 miles of coast, all of them exhibiting the first two of the above-named characteristics, and all but five the third, we are forced to

look for agencies operating along the whole coast. Horizontally these changes take place within a zone generally not exceeding about 30 miles in breadth, but sometimes, especially in the larger north-and-south valleys, exceeding that limit. Some of the systems end some distance back from the coast in marine deltas, and such are not here included among the coastal gravels proper. The southern ends of such of the systems as reach nearest the coast lie approximately at or near the northern ends of the bays or fiords of the coast. Vertically the northern ends of the discontinuous systems are found at elevations from 50 up to 350 feet; their southern ends have elevations rather less than 50 feet.

The existence of numbers of glacial potholes near the shore proves the presence of subglacial streams in the coastal region south of the ends of the gravel systems. The scantiness or absence of gravels at the shore by no means leads to an inquiry as to the local absence or feebleness of subglacial streams near the sea. The problem is an entirely different one: How did it happen that at nearly the same elevation all but five of the glacial rivers along 200 miles of coast found themselves with so large a supply of water, as compared with the sizes of their tunnels, that they were able south of that line to sweep their tunnels clear of sediments, or nearly so, while above that level and to the northward they left, in channels within the ice, sediments that rapidly increase in quantity and continuity for 30 miles or more? These changes are so great and so rapid that it is practically a revolution we have to account for.

Looking at the rapid transitions as we go north and south, we are reminded that the zone of transition is approximately parallel with the position of the ice front during the retreat, and we naturally seek for the causes of these phenomena in some phase of the ice-sheet's structure or behavior consequent on its final melting and disappearance. On the other hand, when we look at the great differences between the osar rivers as to size and length; when we see how parallel some of them were to the ice flow while others were for long distances transverse; how some flowed in a single drainage valley of the land while others spanned several such valleys; how some were in broad north-and-south valleys, where the ice flow was faster, while others were south of transverse hills, where the flow was slower; and yet all but five end before reaching the shore, and there is no proof that these five extend far beneath the sea; when we think of the small ver-

tical differences between the southern terminations of the gravels left by so many glacial rivers, having so many topographical relations and scattered over so wide an area, we are driven to seek for agencies capable of acting horizontally over the whole coast simultaneously. In view of the great differences between the glacial rivers, also of the lobal ice front during the retreat, it seems improbable that there was any agency capable of thus widely acting so nearly parallel to the surface of the sea except the sea itself.

What conditions of the ice-sheet independent of the sea would tend to produce such a development as is shown by the coastal glacial gravels?

Little or no permanent accumulation of sediments can be made within small subglacial or englacial tunnels—small, that is, compared to the flow of waters—because of the great velocity of the streams during the summer floods. And such they remain while the ice is deep and the rate of flow rapid. Before the streams have time greatly to enlarge their channels new ice advances from the area of accumulation and the ice containing the tunnels already somewhat enlarged has reached the front, where it is melted or discharged as bergs. Under these conditions the rapid subglacial streams transport almost all their sediments to near the front of the ice and deposit them as marginal kames or beyond the ice as overwash aprons. In this they are often assisted by the pushing of the ice. On rather steep down slopes, especially where the waters are collected in the lower parts of valleys, these conditions prevail throughout the whole time of the retreat, until the glacier becomes too small to support large streams. Thus all the larger glaciated valleys of the Rocky Mountains contain retreatal plains of frontal gravels up to about 5 miles from their sources. The gravels of the Androscoggin River from Bethel to Gorham, New Hampshire, and also those of the upper Carrabassett Valley are probably in part of this character.

But when an ice-sheet covers a variety of surface, such as plains and gentle down slopes, and especially adverse slopes, or when there is a subsidence greater toward the source than at the distal extremity, the glacial streams become able greatly to enlarge their channels as the ice grows thinner and by degrees stagnant, and are no longer able to keep them free from sediment. The process of sedimentation begins at favorable places in the channels, such as local enlargements, or where obstructions rise on the

beds of the streams, such as rocks or low hills. At first these places are few and at long intervals, but as the channels still more enlarge, sedimentation occurs at shorter intervals, until at last it is practically continuous. A deposit once formed that the ice can not push forward becomes a nucleus around which more gravel gathers. The resulting narrowing of the channel aids in its further enlargement, and thus in process of time very great masses are collected. The causes of enlargements of the channels have already been noted.

One class of the coastal gravel deposits demands special attention. These are numerous massive mounds, also plains up to 5 or 10 miles in length and half as broad. They often contain kettleholes, but their glacial character is that of massiveness, and they are by no means so conspicuously ridged as the plexus of reticulated kames. Often the kettlehole is simply a depression in what would otherwise be a mesa or plain with a rather level or gently undulating surface.[1]

These deposits are sometimes bordered in part by hills, against which they lie like terraces, but they usually end in bluffs, rising above the adjacent land. They were evidently formed within ice walls either wholly or in part. One of the most remarkable of these bluffs is that along the top of which the base line of the Coast and Geodetic Survey was measured in Deblois and Columbia. Now, if even the largest of the glacial rivers flowed into lakes as large as the largest of these plains, they would have deposited deltas showing a horizontal assortment of sediments from coarse at the proximal to fine clay and rock flour at the distal end. Instead, these plains are composed of rather coarse matter—sand, gravel, cobbles, etc.—with but little horizontal classification. Some of them are 150 feet in height and must contain 10 to 15 square miles of surface.

The absence of such reticulated ridges as are found at the proximal ends of the moraine deltas proves that the subglacial rivers did not flow into very large open bodies of water. It is a better interpretation that a small channel or lakelet open to the air was first formed. These gradually enlarged by the lateral melting of their walls, partly by the heat of the inflowing waters, but most rapidly from heat directly absorbed from the sun. The subglacial and perhaps to some extent the superficial streams

[1] See the descriptions of the Portland, Readfield-Brunswick, and Standish-Buxton systems, also of the gravels of Gorham, Charlotte, Freeport, Auburn, Jonesboro, Columbia, and Deblois.

brought in sediments and dropped them in the lake. If sedimentation proceeded at about the same rate as the enlargement of the lake, there would never be a space between the central bar of gravel and the ice walls wide enough to permit the formation of a delta, but the finer débris would be carried away. The outlets of the lakes were too narrow to permit the deposition of sediment within the tunnel until another enlargement or the sea was reached. It does not seem probable that the surface waters could take down beneath the ice heat enough to produce the larger glacial lakes. In such cases we must postulate lakes open to the air and absorbing heat from the sun.

It is not meant to imply that in all cases the gravels were deposited in the central parts of the lakes. The essential part of the process is that the size and velocity of the streams bear such a ratio to the size of the lake that the streams are not sufficiently checked to permit their depositing the finer débris. Elsewhere are described the gravels of northeastern Monmouth, where the glacial river flowed swiftly across the middle of small glacial lakes, depositing a terrace of coarse gravel on each side of its course and leaving a central ravine to mark its channel.

Among the possible causes of a small enlargement of the subglacial tunnels south of the north ends of the bays or fiords of the coast (fiord line) may be mentioned an increased rate of ice flow at that line. The fiords continue for some miles beneath the ocean, as is shown by the Coast and Geodetic Survey charts, but they are shallow, and on the whole the sea floor is less uneven than the land, and the slope southward is somewhat steeper than the average land slopes north of the fiord line. We seem, then, to have a right to assume that, near the shore, after the ice had passed the higher obstructing hills, it would have its rate of motion somewhat accelerated. Crevasses due to tension owing to the more rapid flow toward the ice front would be here more abundant than northward, while those due to inequalities of the land would be rather less abundant. On the whole, the conditions probably favored the restriction of the subglacial channels, but it would be difficult to place a quantitative estimate on this agency.

We must also consider the possibility that the retreat of the ice may have been at very unequal rates, and that the gravels formed near or not far back from the ice front would be determined in part at least by these varying conditions of retreat. If so, we might find corresponding types of

development of the glacial gravels in belts marking certain stages of the retreat such as I have not attempted to mark on the map. Thus far I have found only two such stages—one at the coast above described, and the other the overwash aprons deposited in valleys above sea level. While it is probable that the osars were deposited somewhat recessively, yet the absence of well-marked stages traceable in the different systems, except such as bear a relation to the old sea level, indicates that the retreat of the ice alone was insufficient to account for the termination of so many gravel systems at nearly the same elevation. Besides, where the zones of accumulation and waste were so wide as they must have been in so great an ice-sheet, it seems hardly probable that retreatal phenomena would take the form of a great transition within so narrow a belt The ice must have extended 30 miles beyond Mount Desert Island at the time it flowed over that island if it had a surface gradient of 50 feet per mile, which is twice the average gradient of the ice surface between there and Mount Katahdin.[1] Without allowing for berg discharge, the ice would reach 60 miles south of the coast, and perhaps actually reached half or two-thirds that distance. The coastal gravels may have been deposited 20 or more miles from the ice front. Under these conditions it will require direct and positive evidence to connect the peculiar development of the coastal gravels with any marginal phase of retreatal action. Various modifications of the hypothesis suggest themselves, such as a coincidence of the subsidence of the St. Lawrence Valley with the close of the period of deposition of the coastal gravels, whereby the flow of ice from Canada over the St. John divide was impeded and the development of the osars of the interior of the State became more perfect than that of the coastal gravels, which was arrested while in the earlier stages, etc.

What conditions favorable to such a development as is exhibited by the coastal gravels depended on the sea?

The subsidence of the land beneath sea level, especially a greater subsidence toward the north, would destroy part of the effective "head" of the subglacial streams. Most of the discontinuous osar systems lie in regions that were beneath the sea throughout their whole length. The absence of marine deltas favors the conclusion that numbers of the shorter osar rivers

[1] Distance, 120 miles; elevation of surface at Mount Katahdin, 4,500 feet; at Green Mountain, Mount Desert, 1,500 feet.

ceased to flow because of the rise of the sea before the retreat of the ice as far back as the southern terminations of the gravel systems—that is, their work ceased while they were yet in the early or discontinuous stage of ice-channel sedimentation. It is uncertain how far this remark applies to the longer rivers that formed no marine deltas.

As previously pointed out, the subsidence of the ice-covered land beneath sea level would cause the tunnels and lower part of the crevasses to become permanently filled with water at 32°. The manner in which these basal waters tend to restrict the enlargement of the subglacial tunnels has been already described at some length. Of all the agencies known to me for the production of the coastal gravels and their limitations, this appears to have been the most efficient.

LATE GLACIAL HISTORY OF THE COASTAL REGION.

The history of the coastal region appears to have been about as follows:

Without assuming any definite positions for the southern border of the area of accumulation at particular periods of the life of the ice-sheet, we may confidently affirm that during the time of maximum glaciation a large part of the zone of waste was south of the present shore and that the earlier kames and overwash gravels are now beneath the ocean. At the time when the coastal gravels were being deposited the higher hills of that region were able to deflect the ice from its earlier direction of movement. The height of these hills limits the thickness of the ice of this period to not much if any more than 1,000 feet, and it may have been considerably less. On the other hand, the flow of the osar rivers that deposited the Medomac Valley system of discontinuous gravels had ceased at the time the Waldoboro moraine was being formed—that is, before the ice had become less than 100 to 200 feet in depth. The coastal gravels date, then, from the time just preceding the retreat of the ice to the present shore, or perhaps to the north ends of the fiords. The absence of frontal gravels from the coastal region except in the form of marine deltas proves that the sea beat against the front of the ice, or at least against its base, during all the time of the retreat up to the highest beach. Some of the marine deltas were formed not more than 100 feet above the present sea level and only 2 to 5 miles north from the southern ends of the gravels of the same systems. We infer that the sea had reached at least one-half of its final elevation by the

time the ice had retreated back to these deltas—how much more we do not know. We thus reach the conclusion that the sea was somewhat above its present level at the time the coastal gravels were deposited, but how much is not yet determined by the gravels themselves in their development as deltas.

During the thinning of the ice the subglacial streams were extended farther north into regions before drained by superficial streams which were situated far up on the glacier and extended into the slush zone of snow. None of the basal débris could get up so high above the ground as this, and only Mount Katahdin has been supposed to have been above the ice surface. This class of superglacial streams could not have deposited the coastal or, unless rarely, any other glacial gravels. The class of superficial streams that form near the ice front may have assisted in the formation of the coastal gravels, as at the marine deltas, the glacial lakes, and by collecting sediment which they poured into subglacial tunnels. No matter where the névé line had been at the time of deepest ice, it certainly was far north of the shore at the time the coastal gravels were deposited, for this was well on in the period of retreat. As the névé line retreated northward and the subglacial drainage was correspondingly extended, the time came when that portion of the ice-sheet drained by subglacial rivers was at a maximum over the State. Obviously the longer a glacial river is, the greater will be the enlargement of its channel, other things being equal. The amount of water passing southward at the shore would increase so long as the length of the subglacial streams north of the shore was increasing, up to the time of the retreat of the ice to that line, if the sea did not interfere with the development. The time of maximum subglacial drainage surface probably was near the time when the coastal gravels were deposited, or somewhat later. This would cause a large flow of water, but not a large sedimentation, except where there was a corresponding enlargement of the subglacial channels. For a time the base of the ice in the coastal regions was flooded with cold waters because of the subsidence beneath the sea, and the flow of the ice was probably more rapid south of the fiord line. These and other physical causes so far prevented enlargement of the subglacial tunnels in the coast region that sedimentation became more scanty and at longer intervals southward and finally ceased near the fiord line. South of this line, in all except a few instances, the glacial rivers were so

large, as compared with the capacity of the tunnels, that they were able to sweep their tunnels clear of sediments, or nearly so. In many places near the coast there were formed at this period glacial lakes too large to be ascribed to melting by subglacial waters and which were probably open above to the sun. The ice could have been only a few hundred feet deep at the time of their formation. They appear to have been formed by gradual enlargement around a growing plain of gravel. Numerous marine deltas are found in this region, sometimes alternating in the course of the same gravel system with the massives or plains deposited in the glacial lakes, which massives show little or none of the horizontal assortment of sediments belonging to the delta deposited in still water. The deltas and terminal moraines mark lines of retreat, but it is difficult to synchronize them.

SUMMARY.

The waters of surface melting utilize the crevasses of the glacier for penetrating to the bottom of the ice or into it, where they force a passage along the crevasses or beneath the ice, assisted more or less by the basal waters and furrows in the base of the ice.

The narrow channels due to fracture or the crannies which the waters open by their pressure are enlarged by melting and mechanical erosion into tunnels which sometimes expand into chambers, caves, and channels of various shapes and sizes, and may open above to the sunlight.

Other things being equal, when glaciers lie on the land and disappear by melting without berg discharge, the amount of enlargement of the tunnels varies directly as the time they are being enlarged, i. e., inversely as the rate of ice motion.

The enlargement of the tunnels is antagonized by a slow inward flow of the ice walls. The laws that govern the rate of inward flow, how far the rate is determined by the depth of ice or by variations of pressure caused by the ice movement over obstacles or by heat transmitted through the ice, etc., are unknown.

The transfer of energy beneath the glacier by gently warmed surface waters, the heat of which is generally available for the enlargement of the subglacial or englacial tunnels by melting their walls, is greatly hindered when the glacier flows into a body of water, since, as the warmed waters pour into the cold waters that bathe the basal ice, they become more or less

mixed with them, and thus a large portion of the heat is expended in melting ice within the crevasses and not within the tunnels.

Other things being equal, surface melting is independent of the basal condition of the ice, i. e., whether the ice is submerged or not. In other words, the flowing of a glacier down into a body of water prevents the enlargement of the subglacial tunnels to the full sizes they would have had but for the presence of the water, while the supply of surface waters under like conditions is not diminished.

An increased supply of water with a corresponding enlargement of the outlets implies an increase in the velocity of flow, hence increased transportation and diminished sedimentation.

A sudden and marked decrease in sedimentation at or near a certain contour along 200 miles of coast implies some agency acting horizontally over a wide area to produce an increase in power of transportation (with decrease of sedimentation) below that level.

In Maine we have such a transition at the southern ends of such of the gravel systems as reach nearest the coast, and thence extending for a few miles northward. In general there are topographical conditions favorable to a somewhat more rapid rate of ice flow south of this line, but on a somewhat hilly and uneven coast this cause ought to result in differences in the elevations of the southern ends of the gravel systems. Hence, while it is probable that the rate of ice flow was accelerated south of the northern ends of the fiords (fiord line), it could have been only a contributory rather than a controlling cause of the relatively small enlargement of the subglacial tunnels south of the fiord line.

The ending of the gravels at nearly the same elevation can best be accounted for by supposing the basal ice to have been submerged in the sea to an unknown depth not exceeding, along the outer coast line, about 200 feet below the highest level attained by the sea.

The highest beaches along the outer coast have nearly the same elevation above the present sea level. This is independent evidence that the surface of the sea, measured northeast and southwest, at the time of its greatest elevation was approximately parallel to its present shore, with perhaps a little local warping in the Penobscot Valley and in a few other places. If the petering out of the gravels near the fiord line was largely the result of basal submergence of the ice-sheet in the sea, the termination

of the gravels at their southern ends so near the same horizontal line could have been predicted and is just what it ought to be according to that hypothesis.

There is independent evidence that the sea beat against the ice front, or at least against its base, all the time of the retreat back to the highest beaches. This proves a somewhat higher level of the sea during the time when the coastal gravels were being deposited, and is presumptive evidence of the presence of the sea over the present land at such a level as would then submerge the basal ice at the fiord line and account for the revolution or transition in the development of the glacial sediments that took place near that line.

Thus, from whatever point of view we approach the subject, we find the development of the coastal gravels, according to the hypotheses indicated, presenting a connected and self-consistent series of phenomena. If so, a corresponding development ought to be found wherever glaciers flowed into the sea from regions where the conditions were such that continuous osars formed on the land. Probably the presence of marginal glacial lakes of fresh water also helped to arrest the enlargement of the subglacial tunnels, but perhaps not so much so as sea water.

So complex is the problem that it can not be claimed that all the elements have been set forth above.

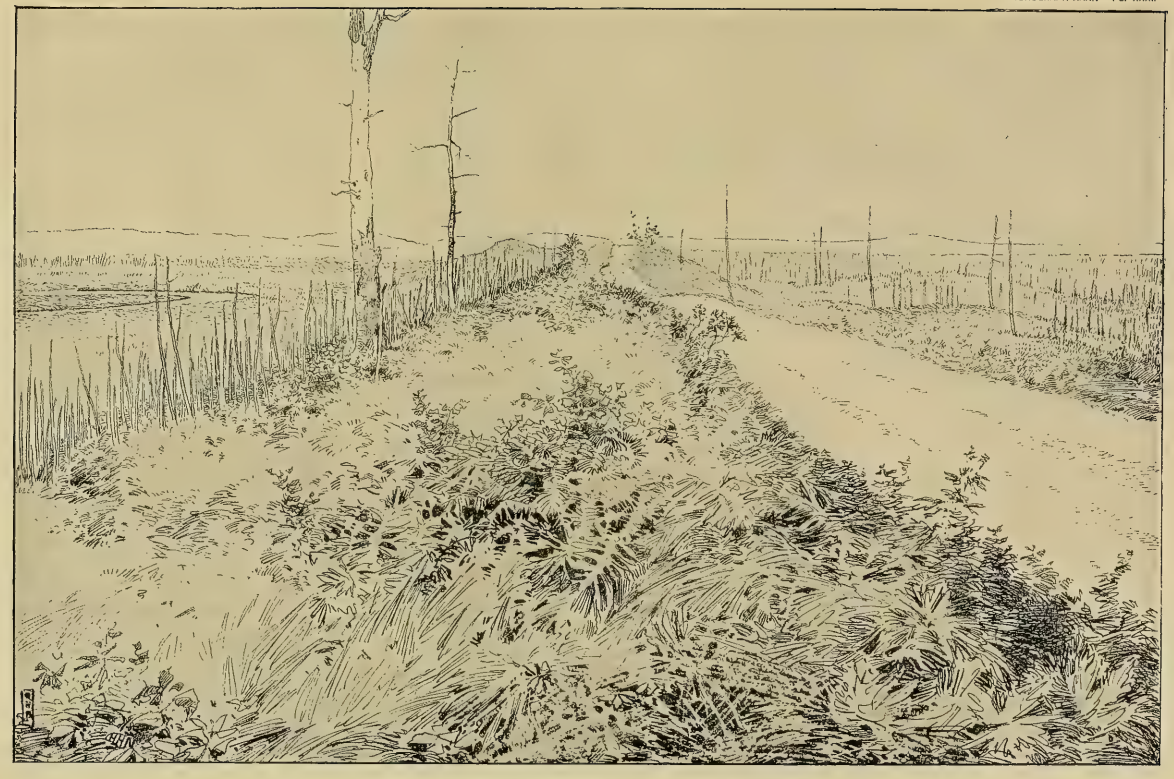
OSARS.

The long continuous ridges, or osars, are a feature of the interior of the State. They are usually continuous for only a few miles and then are interrupted in various ways. Where they go up and over hills the gravel is usually abundant on the northern slopes, while little and sometimes no gravel is found on the tops of the hills, especially when penetrating narrow passes. On steep southward slopes the gravel is often scanty or absent for long distances, and then at the foot of the slope large ridges or often plains are found. Here and there on these steep southern slopes (20 to 80 feet per mile) may be found small masses of bowlderets and bowlders that are well rounded by water. These as truly are the local representatives of the osar as if they formed a large ridge. It is not a definite amount of gravel that is necessary to form an osar or to prove where the glacial river ran. The above-named gaps in the osars appear to have a direct relation of effect

and cause to the slopes of the land. But gaps are not seldom found in the midst of a level plain, which we can not attribute to conditions of the land surface. There is no change in the slopes, nor hills to produce crevasses, nor narrowing of valleys. Such gaps must have been produced wholly by local conditions of the ice and glacial streams. Many of the osars have been washed away by streams, but such breaks in the ridges are not considered as true interruptions of the system. Erosion gaps were made subsequently to the formation of the ridge, an accident having nothing more to do with the original form of deposition than if the gravel had been drawn away to build a road. The osar in this report is considered "interrupted" only when for some reason the gravel was not originally deposited continuously. These gaps are so short, as compared with the long reaches of gravel, that on the State maps they often can not be represented without exaggeration. When mapped, the ridges are seen to have a linear arrangement which the longest of the gaps do not obscure. If represented on a detailed topographical map, the close connection of the ridges would be still more clearly indicated.

The ridges formed by a single glacial river, including its tributary and delta branches, are marked as a single system. Osars marked as tributary can be traced to a definite junction with each other or to points very near each other, where they are separated by intervals no greater than are ordinarily found in the main ridges in the same region and on the same sort of land surface. When osars approach each other as if they were tributaries, but instead one (or both of them) expands into a delta and seems to end before reaching the other, they are regarded as distinct systems (e. g., Pleasant River and Lilly Bay systems).

The osar systems are of various lengths up to 130 or 140 miles. Briefly summarized, the more important facts are as follows: Their materials are more or less rounded, polished, and assorted by flowing water. The water flowed along the ridge. In most if not all cases it flowed southward, as is proved by the direction of transportation, by the dip of the strata, by the positions of the deltas, and by the fact that at the north ends of the systems the stones are usually much less waterworn than at the south ends. The gravel usually rises above the land on each side. These phenomena, as well as the meanderings of the systems, could be produced only by rivers flowing between solid barriers that have now disappeared. Ice is the



KATAHDIN OSAR, WHALESBACK; AURORA. LOOKING SOUTHEAST.

The low pass by which the osar penetrates the hills is shown in the distance near the center. The ridge rises 100 feet above Union River, shown on the left.

only solid that can have served this purpose. The osar rivers had tributary and delta branches like those of ordinary rivers. While often following drainage slopes like surface rivers, yet more often they traversed rolling plains or passed over hills from one drainage basin to another, thus freely disregarding the minor inequalities of the land. In only a few cases did they cross hills rising more than 200 feet above the valleys on the north. They penetrate the hilly regions along low passes, and often take the form of terraces far up on the hillsides.

Several features of the osars require further discussion. The osars proper are best developed in central and eastern Maine. The northern parts of the longer ridges are rather small and narrow and have rather steep lateral slopes. Standing on the narrow top, the meandering ridge often presents an uneven, heaped appearance, much like a moraine. Going southward, on the average the ridges become larger and have a more even surface. When within about 75 miles of the coast, every few miles enlargements of the ridges are found which have various forms. Sometimes they are little tables only 200 to 300 feet wide and two or three times as long. These may be solid or may contain one or more shallow kettleholes. Here and there a hummock appears on top of the osar, rising 20 to 40 feet above the rest of the ridge, and at these "pinnacles" the ridge is generally broader than elsewhere. At one or two places within the belt of country lying between 50 and 75 miles from the coast, we find the osar usually divides into two or more ridges which after a time come together again and form a single ridge. They thus inclose long, narrow basins, or, when connected by cross ridges, rather deep kettleholes. These areas of reticulated ridges are not large, a mile or two in length and hardly an eighth of a mile wide. In this part of their courses several of the osars expand into broad, solid plains or massives a mile or two long and nearly half as wide. Thus, in Greenbush the Katahdin system twice expands into massives of this kind rising about 100 feet above the rest of the osar and the level plain in which they are situated. Their surfaces are rolling and afford some shallow basins, but they can not be regarded as a plexus of reticulated ridges in their present form. They are what such a plexus would become if the inclosed basins were nearly filled up with gravel so as to leave only shallow hollows. One of these massives thus represents a single broad ridge of uneven surface.

Most of the osar systems also expand at various distances from the coast into marine or glacial lacustrine deltas.

When we come within 20 to 40 miles of the coast, we find in many cases large plains of reticulated kames. These are much longer than the areas of reticulated ridges found farther north. They extend from 230 feet up to 400 or 500 feet. At about the same distance from the coast all of the osars begin to become systematically discontinuous. Southward the ridges become on the average shorter and smaller and the intervals between them longer, and in all but a few cases they apparently terminate near the north ends of the bays of the coast and only a few feet above sea level, as has been stated of the discontinuous osars.

COMPARISON OF CONTINUOUS WITH DISCONTINUOUS OSARS.

The osars are thus seen to be somewhat discontinuous, but not systematically so until they approach the coast. In almost all cases in the interior their interruptions have a direct connection with the slopes of the land or places where there would naturally be swift currents, as where the rivers crossed hills or penetrated narrow passes. But the discontinuity of the coast is very different. There the sediments are gathered more often on the hills, while the lowlands show no gravels. Only in comparison with the coastal gravels, then, are the osars continuous.

A plausible theory of osar formation postulates that it began as a discontinuous series of separated deposits left here and there in enlargements of the channel or other places favorable to sedimentation. As the channel was gradually enlarged, sediments could be deposited more and more frequently, until at last continuous ridges were formed. On this hypothesis both the continuous and discontinuous systems began in the same way, but the osars went on to a more perfect development.

Elsewhere we stated numerous facts proving a gradual retreat of the ice and forward advance of the sea and bare land. The limited amount of wave erosion proves that the Champlain elevation of the sea was geologically brief, yet it afforded time for the completion of a large amount of geological work. This fact rather favors the hypothesis that a continuous ridge begins as a series of discontinuous deposits, which gradually become confluent if the flow of the river is continued long enough, or at least is not inconsistent with it. Yet some weak points remain in the argument.

First. A ridge formed by filling in the gaps between shorter ridges ought to show the fact by its stratification. Thus far I have not observed stratification of this kind. To this it may fairly be answered that the number of accessible excavations in the osars is too small to be considered crucial in the case.

Second. The assumption that the glacial streams continued to flow longer in the interior of the State than near the coast does not necessarily imply that they were employed in osar making for a longer time. Superficial streams could not begin to build osars till the melting reached the débris in the ice. We do not know that subglacial streams of sufficient size to form osars extended over all the northern osar territory during all the time that elapsed between the forming of the osars near the coast and the final melting of the ice in the interior. This region may have been in the zone of superficial streams during the earlier part of this time, until the subglacial streams were extended northward.

Third. When we reach northern Maine, only short ridges have thus far been found. It is certain that the ice lingered longer here than it did farther south, and it is at least supposable that an osar could be prolonged northward as the ice receded. Instead, the appearances are as if the regions of osar deposition were shifted from one place to another at the successive stages of retreat—that is, not by a recession of the same osar to the extreme northern part of the State, but by a transfer of osar forming to some other glacial river. The hills of northern Maine would in general not be so hard for osar rivers to surmount as many hills they crossed farther south. But it is impossible now to determine the reasons the osars were not prolonged to the St. Lawrence-St. John watershed or beyond it, since we do not yet know all the phenomena of the retreat of the ice-sheet. It is a generally accepted doctrine that very deep ice invaded the Adirondacks, also the Green and White mountains, from the north. This could not have happened unless the valley of the St. Lawrence River were at one time filled by ice as far east as the White Mountains. In a paper read before the Portland Society of Natural History in 1881, I called attention to the apparent diminishing of the severity of glaciation northward in Maine. This was inferred from the increasing number of areas where the glaciation has not obliterated the preglacial surface of weathering, also from the smaller amount of attrition exhibited by the stones of the till. The latter

argument would not be valid if what I then assumed to be subglacial till is really englacial. The scarcity of drift bowlders in some parts of eastern Aroostook County also points in the same direction and toward less intense glaciation eastward as well as northward. Recently Mr. R. Chalmers, of the Geological Survey of Canada, has published the opinion that in eastern Quebec the ice flowed northward into the Gulf of St. Lawrence. Obviously it makes a great difference in our views of the ice-sheet that covered Maine whether we regard it as fed from the Hudson Bay region or by a névé in the upper St. John Valley that sent out glaciers north, east, and south. The breadth of the zones of accumulation and wastage would be very differently estimated in the two cases. Such a radiate flow from the upper St. John Valley would naturally occur during the last of the glacial epoch, no matter what may have been the history of the time of maximum glaciation. Until the St. John-St. Lawrence watershed is thoroughly explored from the White Mountains northeastward, I do not feel justified in insisting on a local névé in northeastern Maine, at least as anything more than an incident of the decay of the ice-sheet, although my observations in Maine accord well with that hypothesis.

Concerning the theory that a continuous osar is in all respects the same as one of the systematically discontinuous series in a more advanced stage, it must be admitted that it is somewhat probable, and yet there are reasons for seriously doubting its tenability. It seems to be difficult to correlate the two classes of deposits when there were so great differences in the conditions under which they were deposited.

1. The discontinuous gravels of the coast were formed in a region that was at one time under the sea. At the marine deltas we have direct proof of subglacial rivers flowing into the sea, and the tunnels appear to have been below sea level. Without assuming that the subglacial tunnels were beneath sea level at the time either the discontinuous or the continuous osars were deposited, the fact that the progressive changes of sea level may have caused the pressure of the sea to extend farther and farther back within the tunnels must be allowed its full weight in casting doubt on the question, What would have happened in the coast region of Maine if the sea had not risen on the land? Before we can admit that the continuous ridges are only an advanced stage of the discontinuous series, and that the

difference is due to causes arising wholly within the ice irrespective of the sea, we must learn what the development of osars is beyond the reach of submergence, say in Nova Scotia, and show that they conform to this hypothesis.

2. If, as seems probable, the deposition of sediments in the glacial channels was somewhat recessive, the matter of local slopes of the land may have been an important factor in determining the development of the gravels. Near the coast we are beyond the ranges of transverse hills with little obstruction to the flow of the ice, while northward the thinning ice would be more obstructed by the transverse hills, except in a few of the deepest valleys. It may therefore have happened that the continuous ridges of the north were deposited when the ice at the place of deposition was more nearly stagnant than when the more southern gravels were deposited.

3. It is evident that the ice continued to flow after the transverse hills rose above the ice surface, for at the low cols of the hills there are in numerous places small rounded swells of till, a form of an incipient moraine, marking where small glaciers for a time crept over the low places in the hill ranges. In general these morainal ridges are small, very much smaller than the Waldoboro moraine. At the time the terminal overwash aprons of glacial sediments elsewhere described were formed the ice had retreated far north of two transverse ranges of hills (counting from the coast region backward) and the ice front was near the foot of south slopes. Here the motion of the ice would naturally be more rapid. The morainal ridges found near Katahdin Iron Works and East New Portland date from this period, and they are rather larger than the Waldoboro moraine. For some years I was not sure that these ridges and mounds were not a freak of the subglacial till, but my observations in the Rocky Mountains have now (1893) convinced me that they are moraines of englacial matter.

We have hints here and there, then, that the rate of ice advance varied from time to time during the decay of the ice-sheet, according as the glacier terminated on an up or a down slope. Presumably the surface gradient of the ice varied also. What effect these changes would have on the recessive development of the glacial gravels remains to be determined. This uncertainty embarrasses our comparison of the continuous ridges of the interior of the State with the discontinuous gravels of the coast region.

WERE OSARS DEPOSITED BY SUBGLACIAL OR BY SUPERFICIAL STREAMS?

Neglecting basal melting, we divide the ice-sheet into a zone or area of diffused superficial waters, a zone of superficial streams, and a zone of subglacial streams. But these superficial streams are formed only where there is considerable thickness of snow and ice, near the margin of the névé, and seldom if ever would englacial matter get up to such a height in the ice. These streams may have helped determine the courses of subglacial streams, but they could not have deposited glacial gravels until the ice was so far melted that the bottoms of their canyons approached so near to the ground that they found englacial matter to roll and transport. The height to which basal morainal matter can rise in the ice, especially in a hilly country, is quite uncertain, but most of the englacial matter must have been low in the ice. Without assuming any definite height of the englacial matter, we can safely affirm that if any osars were deposited by streams that flowed in channels open above to the air, it was when the ice at the place of deposition was rather thin. Such streams would not be the correlatives of the surface streams found far up toward the névé, but rather of those described by Russell near the extremity of the Malespina glacier, or by Wright near the retreatal moraines of the Muir glacier. It has been often assumed that those who maintain that the osars were deposited by superficial streams mean that they were deposited far back from the extremity of the glacier toward the névé, whereas, since most of the osars are stratified, this hypothesis postulates channels cut down through the ice to the ground or nearly to the ground, a condition that can occur only near the distal end of the glacier, where the ice is not very deep. Such supposed channels, open on the top to the air, might have very different antecedents. They might be formed by surface waters eroding and melting a channel downward in the ice, they might have become open to the air by the melting of the roofs of subglacial tunnels, or a subglacial tunnel might have become stopped, either by sediment or by ice, whereby the stream was forced to rise and overflow on the ice or form an englacial channel. In case of a subglacial tunnel proving insufficient to conduct all the water, a portion might often run off on the surface, as happens at the time of the discharge of the Märjelen See, and thus a single river might have both a subglacial and a superglacial outlet. Such accidents might often be facili-

tated by a body of water rising above the mouth of the stream tunnel, such as the sea, or a glacial lake, or even the dam found on the proximal side of hills over which subglacial streams flow. Thus it might often happen that the same osar river was in different portions of its course subglacial, englacial, and superglacial. The important matter, from the geological standpoint, is to be able to recognize the deposits of these different kinds of streams in the field. We therefore make a preliminary inquiry as to the tests by which to distinguish them.

LENGTH OF RIDGE.

I have been able to devise no crucial test between the two kinds of streams depending on the length of the ridge, yet there is much to prove that the deposits in a subglacial tunnel are more likely to be longer and those in superficial channels shorter. We omit from this discussion the case of subglacial streams becoming superficial by the disappearance of their roofs, since that is a late phenomenon which happened at some time to all subglacial tunnels, and is of significance only when the deposit of gravel continued after the collapse of the roofs.

Obviously the normal place for the subglacial river is beneath the ice, and the cases where it rises for a time into englacial or superglacial channels are exceptions. Such portions of its course must be shorter than the subglacial. We may therefore eliminate from this comparison all except two cases: The rising of a subglacial river onto the surface near the ice front, like the kame river of the Malaspina glacier, and the case of the channel supposed to be wholly due to superglacial waters.

Regarding such terminal or marginal superglacial channels as those of the Malaspina glacier, we must admit that the conditions under which they occur are unusually favorable as compared with other glaciers or known ice-sheets. This glacier is situated near sea level; it is so nearly stagnant that large areas have become covered with forest; it is in slow retreat, though almost fossil, and has rather steep terminal slopes. For some reason the glacial streams have either formed no subglacial tunnels under a marginal zone of uncertain breadth, or the original tunnels have become blocked by ice or sediment or moraines so that the streams have been forced to form englacial tunnels, which become superglacial by the melting away of the overlying ice, and the streams continue such as they flow

down the terminal ice slope. If the glacier continues to retreat, it seems probable that a ridge or series of ridges such as are now forming and abandoned channels of these rivers will be prolonged northward as far as the englacial channels reach. This furnishes an observational basis for the conclusion that during the retreat of the ice-sheet, wherever the ice was very stagnant and the subglacial streams found their tunnels choked near their outlets, they freely rose into englacial or superglacial channels. Since in doing so they would naturally wander more or less from the course of the original tunnel, a plexus of ridges would more often be formed than a single ridge.

Now some of the shorter osars of Maine belong to regions lying north of transverse hills, where, after the hills in front were bare, the ice must have been somewhat stagnant and the conditions would be favorable to the formation of marginal ice canyons of this class. But the longer osars go up and over hills, and some of them occupy the longer north-and-south valleys, where the ice flow would be rapid and subglacial streams would be easily formed anywhere near the ice front.

One other class of superficial channels in which it is supposable that osars were deposited is due to waters of superficial melting cutting canyons in the ice down to the ground. At one time I considered it a probable hypothesis that in a country like the interior of Maine, where the ice overflowed so many transverse hills, the subglacial streams would not readily develop, and that here were the proper conditions for surface streams to continue to flow until near the final disappearance of the ice. The Malaspina glacier makes it difficult to maintain that contention. It is not admissible that there were in Maine any more favorable conditions for surface streams than that glacier affords, except that the summer melting may have been more rapid in the more southern latitude and that there was less water warmed on bare land to go down beneath the ice to enlarge the subglacial tunnels. If on so stagnant a glacier with so narrow crevasses the surface waters are able to find their way into the subglacial tunnels, it must be admitted to be improbable that large surface streams could exist anywhere near enough to the margin of the glacier to have reached the englacial matter of the ice-sheet, unless under extraordinary conditions that could have prevailed only for a limited time and over limited areas. The conclusion follows that the great length of the osars of Maine favors the hypothesis that they were mainly formed in subglacial tunnels.

ANGLE OF LATERAL SLOPE OF THE RIDGES.

The lateral slopes of the ridges are in general rather less steep in the region below than in that above 230 feet. Not only the lenticular kames but also the continuous ridges have as a rule rounded summits and gentle side slopes below 230 feet. This is partly, but not wholly, due to the waves of the sea washing over the tops of the ridges. Assuming that the lenticular eskers were formed beneath the ice and that their gentle side slopes are in part due to the action of the ice in flowing over them, we can not set up that fact as a crucial test for subglacial streams. The overhanging walls of a superficial stream may impinge on the contained gravels, and when these channels were greatly enlarged at the base, the contained gravels might have as gentle slopes as the subglacial. In the interior of the State some of the ridges have very steep lateral slopes, and are of uneven size, and show hummocky heaps like a terminal moraine. I do not see how we can admit that the ice flowed over these ridges since their completion. If they are stratified at their bases, they must have been deposited in superficial channels, the gravel rising above the basal enlargements or in subglacial tunnels after the ice had ceased to flow, or nearly so. The test here is not infallible, but the probabilities slightly favor the superficial streams.

INTERNAL STRUCTURE.

Sediments deposited beneath the ice must be stratified unless the stratification is obliterated by the pushing forward of the sediments by the ice. Facts are elsewhere recorded indicating that the ice had a limited power to disorganize small portions of eskers on their stoss sides. In various places the osars appear to have lost their stratification. At one time I thought the Corinna-Dixmont osar had been disorganized where it crossed valleys, while it remained stratified on the hills. Later excavations make this doubtful. It is very difficult to find excavations in Maine that do not show more or less surface sliding, unless they have been made very recently. Seldom can a sand-and-gravel bed be implicitly trusted after even a single winter. I therefore leave out of account many cases of apparently pellmell structure observed in the earlier years of my exploration, since my notes do not definitely show that the excavations had been made during the summer they were examined. A residue remains where osars have apparently no

stratification, yet plainly are composed of water-washed material. My conclusion is that where the whole of a ridge of till, from which the finer detritus has plainly been washed by water, has lost all signs of stratification and has a pellmell structure, the best interpretation is that it was deposited upon the ice in a superficial or englacial channel, and that when the ice underneath the sediment melted, the gravel slid down irregularly and the original stratification was lost.

A well-marked instance of an osar with pellmell structure is Indian Ridge, at Andover, Massachusetts, described many years ago by Dr. Edward Hitchcock, and more recently and fully by Prof. G. F. Wright. Professor Dana has referred to this ridge as a moraine. But the material is slightly polished by water and the finest parts of the till have been washed out of it. It is not the ordinary till of the region, but the residue after a portion has been removed by water. There has also been some water transportation, but not much, or the stones would be more polished. Moreover, it stands in substantially the same relation to the plain of stratified sand and gravel near Ballardvale as the osars of Maine stand to the deltas deposited in glacial lakes. In a sense all glacial gravels are morainal. It is not proved that Indian Ridge was bodily transported horizontally by the ice after its deposition, yet this may have happened. If so, it will be a disputed question whether to term it a moraine or an osar. The criterion of distinction between the till and the glacial sediments proposed in this report is that the one was brought to its present position by the ice and the other by water. In case of ice transportation of Indian Ridge as a whole, we would have a mingling of the two processes. But where a transported ridge maintained its individuality as a mass of water-washed matter distinct from the adjacent till, I should not hesitate to apply the term "osar" to it. It is certain that few, if any, of the osars of Maine were thus bodily transported by the ice, at least in the last stages of their development. Where an osar is stratified in some parts of its course and is pellmell in others, there can have been no bodily transportation on any theory yet suggested.

In general we remark: A stratified internal structure is consistent with either subglacial or superglacial streams. Pellmell structure of a large mass of glacial gravel strongly favors the hypothesis that it was deposited on the ice, not beneath it. Quaquaversal stratification of a cone (not due to surface wash by the sea waves) is in favor of the theory that the gravel

was deposited by a superficial stream as it plunged into a pool beneath the ice, or by a stream that was wholly subglacial.

MEANDERINGS OF A RIDGE.

For convenience, the meanderings may be divided into two classes.

Meanderings of the first class are deflections for several or many miles, such as all the longer osars and osar-plains of Maine make in order to follow valleys or to find a low pass through the range of hills. Many of the longer deflections along valleys are where the ice was also deflected and the osars are parallel to the glacial flow. Such places would be favorable to the formation of subglacial tunnels. Other long meanderings are found in level regions where the direction of ice flow would be substantially the same over all the plain. If subglacial tunnels were here formed, it must have been for a part of the distance transverse to the direction of glacial flow. The Seboois-Kingman-Columbia osar leaves the valley of Seboois River, a tributary of the Penobscot River, and takes a course for 20 miles southeastward over two divides to Patten. It here abandoned a north-and south valley, down which the ice could freely flow, for a course transverse to the motion of the ice. Here the course of the glacial river must almost certainly have been transverse to the direction of the ice flow, but often we are in doubt as to the direction of ice flow during the very last of the Glacial period. Doubtless many of the deflections then prevalent were never recorded, since the movements took place over land already covered by the ground moraine, and scratches made on rocks then bare of till have usually weathered away. Hence it may often be that these apparent deflections from the direction of ice flow are not such at all, as we should see could we find the record of the latest glaciation.

I can assign no physical cause for the formation of subglacial tunnels for long distances in a direction transverse to the flow of the ice, except in regions much broken by crevasses, such, for instance, as those near the outer terminal moraines. This seemed likely to afford a crucial test between the subglacial and the superglacial streams, but uncertainties as to the direction of flow of the ice during the very last of the Ice period, and as to the power of a superficial stream to cause an extension of a subglacial tunnel to follow nearly its own course, have intervened. Just as we get in sight of a crucial test it eludes us.

Of the longer meanderings, all that can be said is that they are transverse to any known direction of flow of the ice.

Meanderings of the second class are short—from a few rods to a large fraction of a mile. They are such as might be produced by either kind of stream. They are plainly such as would characterize the channel of a superficial stream. On the other hand, a subglacial stream would often follow a transverse crevasse for a short distance, and thus could flow transversely to the glacier. It is not certain how far it could thus find its way transversely. So, also, in the northward extension of a subglacial tunnel its course might often consist of short zigzags caused by its attempt to follow a superficial stream in a direction transverse to the glacier.

In general it may fairly be urged that many of the meanderings must have been formed simultaneously, and that some of them must have been transverse to the glacier. Now, though ice is protean in its resources, it can not be all things at the same time. The osars of Maine skirt too many hillsides and cross too many valleys of natural drainage to permit the admission that the subglacial waters could everywhere penetrate the ice transversely to the direction of ice flow. The probabilities are overwhelmingly against the hypothesis. For subglacial waters to flow transversely to the motion of the ice must have been the exception rather than the rule in Maine, except near the ice front, where the ice was much crevassed. Near the great outer terminal moraines and in the tracts of reticulated ridges or kames the ice was so crevassed that probably the subglacial waters could make their way so as to practically follow the slopes of the land.

The longer meanderings transverse to the direction of ice flow certainly add some difficulties to the hypothesis of subglacial streams.

PINNACLES OR ELONGATED CONES.

On the theory of subglacial streams the "pinnacles" or elongated cones which here and there rise above the rest of an osar can be accounted for as having been deposited in an enlargement of the subglacial channel, such, for instance, as forms at the base of the cascade where a superficial stream plunges down a crevasse into a subglacial tunnel. On the theory of superficial streams they could be explained as having been deposited in the broad pool that formed where a lateral tributary joined the main stream, or in one of the numerous pools that would form at the base of waterfalls

or rapids. Another way of accounting for them would be by the action of ice dams such as would naturally form when the spring floods began to break up the ice and snow that had gathered in the open channel during the preceding winter. As the waters poured over the dam, the unusual velocity would erode sediments that had previously been deposited in the channel, and they would be piled up a short distance below. On this theory there ought to be a gap in the ridge just north of the cone of gravel. Such gaps are found north of the "Pinnacle" at Pittsfield, also north of several similar enlargements of the Exeter Mills-Hermon osar. I have no sections showing the nature of the stratification at these places. If the stratification of the cones is quaquaversal, it will favor other theories rather than the ice-gorge theory.

On the whole, we must conclude that the pinnacles do not afford a satisfactory test as to whether the osars were deposited in subglacial or superglacial channels.

BROAD AND MASSIVE ENLARGEMENTS.

Such are the so-called "mountains" of Greenbush. On the one theory subglacial streams poured into a gradually enlarging lake. On the other a very broad and deep enlargement was gradually made in the superficial channel. It is only the case of the pinnacle on a large scale. But in this as in many other cases the rival theories may have to compromise. A surface stream may have poured into a pool, like many of the streams of the Greenland ice, and have escaped as a subglacial stream.

I can discover here no satisfactory test for the two theories.

RETICULATED RIDGES.

Reference is here made to the plexus of ridges into which an osar often expands.

Superficial channels can become filled and new ones formed, as every river delta proves, and as we see exemplified on every hillside during the melting of the snow and ice in spring. A subglacial channel can also become clogged by sediment, and it is easy to conceive circumstances such that a new channel could be more readily formed than the old one could be enlarged. The conditions under which the reticulated ridges were formed will be more fully discussed hereafter. For the present I only

remark that the plains of reticulated ridges are often found in very level regions not favorable to the production of crevasses, except perhaps those of tension near the ice margin. So far the probabilities favor the theory of superficial streams. On the whole, the reticulated ridges can not be admitted as affording a crucial test.

PROBABLE VELOCITIES OF THE TWO KINDS OF STREAM.

In many places in the osars we find rounded bowlderets and bowlders in the midst of much finer material. To account for these bowlders we may postulate moderate currents for most of the time, with now and then a sudden flood; or, more often, such bowlders probably fell from the ice onto the gravel in the bed of a glacial stream and were rounded, not so much by being themselves rolled forward as by the attrition of smaller stones pushed past them. Such bowlders are very common in the reticulated ridges of western Maine. In these cases we need not postulate more rapid currents than would be necessary to move the finer matter. If we make proper allowance for such adventitious bowlders, obviously the size of the transported rocks and stones will measure the velocities of the currents.

If most or all of the morainal débris was contained in the lowest part of the ice, as is generally believed, then the superficial streams that are found near the névé line, or anywhere high upon the ice, would be glacial torrents, but not osar-forming débris. Obviously, only those portions of superglacial channels that are in ice containing débris can be of significance in osar formation. The theory that such streams could form osars where the ice was deep must stand or fall with the theory that the débris reached high elevations within the ice.

We need not, then, in estimating the velocities of the superficial streams, consider the general surface gradient of the ice, but only that of the marginal portion rising to the height of the englacial matter, perhaps a few hundred feet above the ground. Here for a few miles, say 2 to 5 miles, we can grant to the superficial streams waterfalls, rapids, pools, and all other accidents of open surface channels, and velocities both greater and less than those due to the surface gradient of the ice.

On the other hand, the velocities of subglacial streams are only in part determined by the slopes of the land. When the capacity of the

tunnel suffices to carry off the water without its rising in the crevasses, the velocity is chiefly determined by the land slopes, but any surplus causes some of the water to rise in the crevasses as into the standpipes of an aqueduct system. The only limit to the effective "head" in the crevasses is determined by the height of the tops of the crevasses over which the water can overflow on the surface. During the summer floods, when the supply of water is large as compared with the capacity of the tunnels, the water may often be driven by the pressure of hundreds of feet of water in the tunnel and crevasses. In other words, the effective "head" of subglacial streams can not exceed the vertical differences in height between the mouth of the tunnel and the top of the nearest crevasse connecting with the tunnel, and therefore subject to overflow. When we come to compare the two kinds of stream with respect to velocity, we find a mechanism in both cases for producing high velocities with corresponding coarseness of sediments. It is doubtful whether we are able to distinguish between the two kinds of stream by the size of separate fragments of the sediments.

EROSION OF THE GROUND MORAINE.

Both kinds of stream would erode the subglacial till while in contact with it. A subglacial stream being necessarily in contact with the lower till the whole time of its flow, ought to erode it more than a superficial stream, which could reach it only after it had cut its way to the bottom of the ice.

Erosion beneath the osars.—This is a difficult subject of investigation, owing to the character of the exposures. Artificial excavations do not go deep enough, and at the rivers which have eroded the osars there is almost always surface sliding of the gravel from above. At Pittsfield Village the Sebasticook River has eroded one side of the Hartland-Montville osar and the gravel distinctly lies upon the bare rock. At numerous places the gravel near the edge of the osar overlies the till, but this may be due in part to surface sliding since deposition. At Clinton and various other places excavations show that the gravel near the axis of the ridge extends nearly to the rock, and then the base of the gravel was not reached. The facts observed are too few for generalization, but point to considerable erosion of the ground moraine beneath the osars.

Erosion of the ground moraine in places not now covered by gravel.—Along the courses of the osar rivers are many gaps in the ridges where we can now see the

former beds of these rivers. In a few places, as northwest of North Monmouth and northeast of Hogback Mountain in Montville, a ravine of erosion has been excavated in the till. Generally where the larger glacial rivers crossed the hills, or on steep down slopes, we do not find a definite ravine of erosion, but the till is scanty or almost wholly absent over an area several times as broad as the ordinary breadth of the osar. In these places there is less till than in the surrounding country, and we must admit a large removal of till, both the englacial and the subglacial. On the other hand, there has been but little erosion of till in several passes and on several divides where the circumstances would appear to be favorable to erosion. Among these may be named the pass south of Grand Lake on the Houlton system, the divide near Forest station on the Hersey-Danforth branch, the Katahdin system in a low pass situated just northwest of the Whalesback in Aurora, The Notch in Garland, and the valley of the east branch of Georges River in Montville.

We have, then, several cases of very great erosion of the till on the line of the osar rivers, many cases where there has been a moderate erosion, and perhaps an equal number of cases where there are now no gravels yet there has been but little erosion of the till by large osar rivers. No positive inferences can as yet be drawn from the observed facts bearing on the question of subglacial versus superglacial streams, though the probabilities rather favor the superficial streams. On the theory of subglacial streams it is difficult to account for such facts as are elsewhere recorded as being observed at The Notch in Garland. While there are a large number of cases where the subglacial hypothesis is equally in accord with the facts, and in some cases better in accord with them than the hypothesis of superficial streams, there are other places where superficial streams are as strongly indicated by the facts. All this points to the conclusion that the osar rivers were in some places subglacial and in other places superficial or englacial. This may be bad for the symmetry of theories, but seems to be true to nature.

GAPS IN THE OSARS.

Both subglacial and superglacial streams could sweep their channels free from sediment at places where the channel was narrower or shallower, or where the slopes of the land gave unusual velocity to the current. The velocity of subglacial streams is certainly often much greater than that due

to the slopes of the land. It is doubtful if continuity or noncontinuity furnishes a crucial test between the two kinds of streams, but the phenomena near the coast make it probable that noncontinuity is a distinguishing feature of an early stage of subglacial sedimentation.

SIZE OF THE OSARS.

If, as I assume, the only superficial streams (if there were any) that were concerned directly in osar formation were situated near the ice front, then the probability of such a stream forming a large ridge is not so great as that a long subglacial stream would form one. The only way such a stream could make a very large ridge is retreatally, and even then it is difficult to account for one, especially for the stratified osars. For sedimentation in the present stratified condition could not have begun till the ice in the bottom of the superficial channel was melted, and since that would happen only late, it seems improbable that a very large ridge could collect after that time before the ice was all melted. The great size of such ridges as the Whalesback, Aurora, favors the subglacial hypothesis.

LOCAL VERSUS FAR-TRAVELED MATERIAL.

Professor Chamberlin has shown that in the West the osars are composed of local matter clearly differentiated from the englacial till, which was derived from the distant crystalline hills. His argument is that subglacial streams would reach the local matter, whereas superficial streams would rarely do this, but their sediments would consist of englacial matter from a distance.

Several disputed questions are involved in the application of this argument to Maine, such as the manner in which basal débris got up into the ice, the angle of its supposed ascent, the height it attained, etc. In many places in Maine I have not been able to draw so fine distinctions as those of Professor Chamberlin between subglacial till of local and englacial till of distant origin. There are multitudes of places, especially in eastern Maine, where local matter appears in the upper part of the till within a few feet or rods from the northern edge of an outcrop of rock. This is especially noticeable in the case of granite bowlders. Whether this is subglacial or englacial till is a question for determination. I have not always been able

to distinguish them. The application of this test is not so simple as it is in the West. Only in eastern Maine are the outcrops such that the test can be applied without considerable study of the local rocks. In Enfield and Prospect, granite bowlderets and some bowlders appear in osars within much less than a mile from the north edge of a granite area—in fact, it may be only a few rods. On the other hand, in Aurora and eastward toward Deblois the water transportation has been so great that almost all the gravel has traveled several to many miles. This was in the course of the Katahdin osar river, one of the largest glacial rivers of the State. The law seems to be that the local matter appears in osars of moderate or small size.

But these ridges at Enfield and Prospect are stratified; hence, on the superglacial hypothesis, the bottom of the superficial canyon had probably reached the ground at the time of deposition; and if so, would contain basal and local matter. The most noticeable thing about these granite bowlderets and bowlders is that they appear on the tops of ridges 30 to 50 feet in height. I do not see how superficial streams can elevate bowlderets and bowlders, whereas the subglacial streams of the Malespina glacier do raise such coarse matter. If the osars were deposited by superficial streams, the bowlderets and bowlders in question must have been raised by ice movements, and when released from the grasp of the ice by the melting, they tumbled into the canyon. If so, they must have risen in the ice 30 to 50 feet within a fraction of a mile, and that, too, on level ground or on a gentle northern slope, as in Enfield, not from the brows of crags or hills. This is only one of numerous instances where the superglacial hypothesis demands that the englacial débris should arise very rapidly in the ice and to considerable height.

After making allowance for local difficulties, it appears to me that on the whole the sudden appearance of local matter in the smaller osars and to such a height in the ridges distinctly favors the hypothesis that the osars were formed by subglacial streams. At one time it seemed to me incredible that the subglacial streams could raise bowlderets, and especially bowlders, against the force of gravity. Anyone who has doubts on this subject can have them all removed by inspection of the device for placer mining termed the hydraulic elevator.

PHENOMENA OF GLACIAL RIVERS IN CROSSING HILLS AND VALLEYS.

As before noted, the hills of Maine are in large part transverse to the direction of glaciation. Hence the courses of the longer glacial rivers very often led them up and over hills. On the steeper down slopes the behavior of subglacial and superglacial streams would, perhaps, not be very unlike, but in the valleys and on the northern slopes of hills their action might be quite different. The osars are in the main stratified, and the only superglacial streams here referred to are those the bottoms of whose canyons had reached the ground at the time of deposition of the gravel, or so nearly that the stratification was only obliterated locally, if at all, during the unequal melting of the subjacent ice. This I conceive could take place only in the marginal region near the ice front. Some distance back from the front a superglacial channel might contain sediment, if the englacial débris reached so high as the ice, but it would overlie such deep ice that if left in this condition the unequal melting of the subjacent ice would usually confuse the stratification. It is not assumed, except for the sake of argument, that such streams helped to deposit the osars.

We first suppose a subglacial tunnel to cross a transverse valley and hill, as in the accompanying diagram, fig. 32. The water in the tunnel below the horizontal line *AB* touching the top of the hill will form a dam or lakelet and be in equilibrium, like the water of a sewer trap. Water will rise to the same level in all crevasses opening into the tunnel. As fast as water flows from the north into the trap an equal amount will flow southward over the hill at *B*. The general law of velocities in the tunnels is that if the tunnels increase in capacity from north to south at an equal ratio with the increasing supply of drainage waters, other things being equal, the velocities will be uniform throughout the whole courses of the tunnels. But there are at least two causes for the tunnel being smaller in the valley than elsewhere—that is, relatively to the supply of glacial waters.

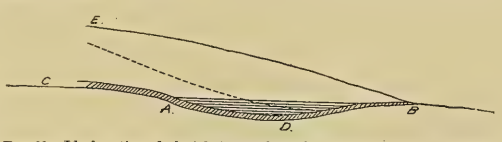


FIG. 32.—Ideal section of glacial stream channels crossing transverse valleys. *EBC*, glacier; *ABD*, subglacial stream; *B*, *C*, transverse hills.

First. The depth of ice, and presumably the rate of inward flow of the tunnel walls, is greater in the valley at *D*.

But then the inward flow of the walls is antagonized by the outward pressure of the contained water. Also in Maine no glacial rivers are known to have flowed over hills higher than 200 to 250 feet, except in one extreme case of 400 feet, measured above the valleys lying to the north of them. This represents only one-fifteenth to one-twentieth of the maximum depth of ice. If we assume so great plasticity of the ice that so small a difference in thickness could make much difference in the sizes of the subglacial tunnels in the two situations, it seems difficult to account for very deep crevasses or subglacial channels. On the whole, it seems improbable that so small differences in thickness of ice would much restrict the enlargement of the subglacial tunnels in the valleys; yet it might to some extent.

Second. It will be seen that the basal ice north of the hill is permanently bathed in cold waters, and that the crevasses also are filled to the same height as the top of the hill. All the waters of local melting that pour into the crevasses in this part of the tunnel must more or less become mixed with the cold waters of the crevasses, and their heat will largely be expended in melting the walls of the crevasses, not in expanding the tunnels, just as has been pointed out in the case of a glacier flowing down into the sea. Now some of these dams or permanent bodies of subglacial water must have been several, perhaps many, miles in length. Thus the subglacial dam north of Springfield, in the course of the Seboois-Kingman-Columbia osar river, was at least 15 miles long, and that of the Portland system north of North Woodstock extended as far as Andover, a distance of 20 miles. Because of the greater subsidence toward the north, the length would at that time be somewhat greater than now. The ice would be many years in passing over such distances, and the cumulative effects of such dissipation of the energy that otherwise would help to enlarge the tunnels must have been considerable wherever the courses of the glacial rivers were so nearly parallel to the ice flow that the same body of basal ice in its progress was thus continuously modified for a term of years.

We are therefore justified in assuming that in the longer valleys situated north of hills crossed by the glacial rivers the subglacial tunnels would be small relatively to the supply of water, and the velocities would be rather high during all the earlier stages of ice-channel sedimentation. Ridges deposited at this time would be rather narrow and composed of coarse material. Indeed, the sedimentation might often be of the discontinuous

type, the streams in places having velocity sufficient to clear their channels of sediments.

Later, when the ice became thin and could no longer flow up the hill, this stagnant condition would favor the enlargement of the tunnels in spite of the interference of the basal waters. When the ice surface sank to the top of the transverse hill, or near to it, the stream could no longer escape southward over the hill. It would then escape transversely to the east or west along the top of the ice or between the ice front and the hill, or by transverse subglacial channels. But in most cases the rivers crossed the hills by passes leading up to low cols, and the hills at the sides of these valleys would hold in the stream till the ice had melted back to the north ends of the passes. The retreat of the ice from the tops of the divides back to the northern ends of the passes might occupy several or even many years, and during all this time there would be a marginal body of water between the ice and the top of the col, absorbing heat direct from the sunlight. This water would most rapidly extend itself northward along the line of the subglacial river, partly through mechanical erosion and the heat of the stream waters and partly because the ice near the tunnel would already have become somewhat honeycombed by melting within the crevasses above the tunnel. Thus the frontal lake would be narrowly V-shaped, extending deeply into the ice, as an enlargement of the original tunnel, expanding toward the south till it passed beyond the ice front and extended across the whole valley or pass. Into this deltoid body of water the glacial river poured its sediments. The coarser matter was left near the mouth of the subglacial tunnel, and thence the sediments would grow finer obliquely outward. If the lake became very broad as compared with the size of the river, we might even have a delta deposited in it like that in Unity and Thorndike, or in Dover, northwest of The Notch, Garland. If so narrow that the velocity of the current was less checked, an osar terrace or broad osar would be deposited in the marginal lake, like the terraces that border the Whalesback in Woodstock, Milton, and Rumford. In the lake or within narrower ice channels near its northern end, a plexus of reticulated ridges might be deposited. The development of these broad-channel or lacustrine sediments would go on retreatally northward till the ice front receded to the north ends of the passes, when the waters might or might not be diverted into new courses back of the ice front, but in any case the surface of the marginal lake began

to sink to lower level. The suddenness with which the development of the gravels was often arrested and the absence of transition beds laid down in transverse channels or of terraces between the end of the ice and the hills that rose in front of it, may perhaps be best interpreted as proving that the ice sometimes became so greatly shattered near the front that the waters spread outward and often transversely in a multitude of small delta branches, none of which were large enough to deposit gravels in the short time that elapsed before the ice was all melted in that region. The nature of the development of the glacial sediments during the retreat of the ice down the northern slope and thence back to *C* (fig. 32, p. 433) would depend on many conditions, and we might expect many different manifestations. One of the critical points, so to speak, is at the northern end of the permanent water trap at *C*. At the time of diminished flow in the fall and winter the stream would no longer fill its tunnel and more or less sediment would drop where it entered the permanent water trap *ABD*. Now and then this might result in the channel being clogged during the floods of the succeeding summer, forcing the waters to rise, and causing the formation of an englacial or superficial channel and the opening of a lake at the place where the stream rose on the surface or flowed down again after passing the obstruction in the tunnel. In such a lake broad ridges or an osar-plain might form, or reticulated ridges, but not a delta, unless it was very large compared to the river. Or the broad channel or lake might be extended continuously across the valley, perhaps by the confluence of a number of lakes that originally formed in the course of the channel. When the waters forced a transverse passage north of the hill early enough to permit considerable enlargement and deposition of gravels, we have the phenomenon of delta or diverging and transverse branches like the intricate reticulations of the gravel systems of southwestern Maine. Here the rocks are mostly granitic and the till is very abundant. This must have favored the clogging of the subglacial tunnels and the digression of the streams to new channels that often diverged widely from the original channels.

We next consider what is conceived to be the probable behavior of a superglacial stream in the same situation, i. e., during the retreat of the ice over a valley situated north of a hill crossed by an osar system, premising that it must be able to deposit stratified osars, and hence that the bottom of its canyon must reach the ground or nearly to it. At first the bed of the

stream lies approximately parallel to the ice surface *EB*. As the ice melts, the bed will come to occupy the position of the dotted line and dip beneath the horizontal line *AB*. A marginal lake will form in front of the ice, just as in the supposed case of a subglacial stream. The melting will be most rapid along the bed of the stream and near the mouth where it enters the lake, and thus the form of the lake will probably not differ much from that when a subglacial stream flows into it. In this broad channel or lake we might have reticulated ridges or an osar-plain deposited. As the ice retreated toward the bottom of the valley it would seem that the glacial gravel ought to be more abundant in that region than anywhere on the northern slope. It certainly would be so, and of frontal or overwash character, unless the superficial stream forms a glacial lake at some point toward the north, which arrested the transportation of sediments from the north. We can admit transverse escape over the ice to the east or west or around the front of the ice next the hills, but not subglacial or englacial escape, since this would be inconsistent with the supposed conditions, i. e.,

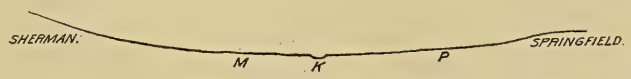


FIG. 33.—Section of valley between Sherman and Springfield. *M*, at Macwahoc; *K*, at Kingman; *P*, at Prentiss.

ice so stagnant that the crevasses were not sufficient to enable a subglacial tunnel to be formed. This is a large demand to make so near the ice front, but my purpose is to give the theory every possible chance to account for the field phenomena.

These general principles have been discussed with a view to their application to certain localities.

The great Seboois-Kingman-Columbia osar system descends the valley of Molunkus Stream from Sherman to Kingman, where it crosses the Mattawamkeag River nearly at right angles, and then ascends the other side of the Mattawamkeag basin, through Webster, Prentiss, and Springfield, where it crosses a divide near 200 feet higher than the river at Kingman. This great osar river has left gravels for 40 miles or more north of Kingman, where it crossed the deep transverse valley of the Mattawamkeag. Fig. 33 represents the system in this part of its course. The slope of the Molunkus Stream is moderately steep from Sherman to Macwahoc; then the valley

is nearly horizontal to Kingman, and thence the slope rises moderately steeply again to Springfield. From Sherman to Macwahoc, and again from Prentiss southward, the gravel takes the form of a broad osar, or osar terrace, of sand and rather fine gravel. At Macwahoc and Prentiss it expands into complexes of reticulated ridges inclosing kettleholes and composed of coarse gravel, cobbles, and bowlderets. For 3 or 4 miles near Kingman the system takes the form of a narrow osar of rather fine sand, and is somewhat interrupted. It is the narrowness and fineness of this ridge near the bottom of the transverse valley that specially demands explanation. The noncontinuity is in part, and possibly may be wholly, due to postglacial erosion. On both theories there were broad osar channels north of Macwahoc and south of Prentiss. Both postulate a lake-like expansion at Macwahoc, and another at Prentiss, in which or near its margin was left a plexus of reticulated ridges. On the subglacial theory the tunnel would be relatively small where it crossed the transverse valley, and sedimentation scanty or in narrow ridges. This corresponds well with the osar at Kingman, but for a long time I had difficulty in accounting for the fineness of the sediment. Now Macwahoc and Prentiss are not far from the same elevation, and only 3 miles or so from opposite ends of the subglacial dam. During the retreat a broad channel was formed north of the divide in Springfield, which extended itself as far north as the complex in Prentiss. North of there the sediments were scanty or absent until the lake or broad channel was opened at Macwahoc. If the opening of this lake was due to a clogged channel, the water may have overflowed laterally, so that the old channel was never thereafter used, except for local drainage, and thus only sand would be deposited. But as the channel was not permanently clogged, the coarse sediment from the north would mostly stop in the lake at Macwahoc and only the finer pass on across the valley to gradually fill the old tunnel or parts of it just preceding the time that the ice retreated so far north that the tunnel was disused. On the superglacial theory the order of events must have been substantially the same. The opening of the lake at Macwahoc and deposition of the plexus of reticulated ridges is essential to both theories. But the distance between the complexes of Macwahoc and Prentiss is about 10 miles, and we must suppose deposition in one began immediately after the other was ended, or there would be an osar-plain or other body of retreatal gravels left over the

lower parts of the Mattawamkeag Valley near Kingman. This enlarges our claims for superglacial osar rivers from small streams near the ice front to the long osar rivers themselves.

Thus we here discover no crucial test between the two rival theories, though the difficulties of the superglacial hypothesis are increased with every complication, such as that involved in the claim of their ability to form glacial lakes in which stratified gravels were deposited, and hence must have reached to the bottom of the ice, or nearly, and that, too, at a distance of 10 miles back from the ice front. It is a matter of observation that pools which presumably would expand into lakes in a time of stagnation of the ice movement are formed in Greenland where large surface streams flow beneath the surface and escape subglacially, but no instances are recorded where they form very deep lakes and escape superficially.

In all cases known to me where the osars went up and over rather high hills with long valleys to the north, such as the Portland system north of North Woodstock, the Smyrna series north of Danforth, the Bridgton series north of Baldwin, the north end of the Peru-Buckfield system, and others, the field phenomena prove that the gravels of earliest deposition north of the higher hills were deposited in rather narrow tunnels and that the streams had considerable velocity. There are several cases of reticulated ridges on the northern (up) slopes, which may, perhaps, be accounted for on either theory. Where broad osars or lake deltas are found in such situations they are plainly a rather late if not a retreatal phenomenon.

A sufficient cause, as it appears to me, has been pointed out for the restriction of the subglacial tunnels north of these hills, but I know of none on the superglacial hypothesis. At Kingman we may perhaps account for the absence of broad-channel phenomena by the convenience of the broad channel or lake at Macwahoc, but in other places there is no such way of accounting for the lack of broad-channel deposits in the valleys north of hills.

On the whole, I conclude that the subglacial hypothesis is strengthened and the superglacial weakened by the behavior of the glacial rivers where they crossed transverse valleys and hills.

It is not here meant to assert that all the broad osar channels date from so late a period of the ice-sheet as that assumed in this discussion.

It must be admitted that the various tests for distinguishing in the

field between osars deposited respectively by subglacial and superficial streams are not so definite as is desirable. Probably all the field phenomena can be accounted for on either hypothesis, though sometimes only by cumbrous complications that in the end must break down any hypothesis that has to resort to them. Often in the last fifteen years I have discovered what was hoped to be an unmistakable and crucial test, only to find my quest unsuccessful.

Some of the elements of the problem of the osars have been set forth above. It remains to correlate them with others in order to get a more general view of the osars, their history and causation. This is reserved for a subsequent chapter.

BROAD OSARS OR OSAR TERRACES.

Several of the osars, after preserving the form of a two-sided ridge with arched cross section for a distance of 5 to 30 miles from their north ends, expand into a level-topped plain varying in breadth from one-sixteenth to three-fourths of a mile. These plains or terraces contain no kettleholes proper, though the surface is sometimes gently undulating. More often it is very level. The material of the plain is usually rather fine gravel and sand. In some cases they are found as terraces on hillsides far above any ordinary stream, and can without difficulty be at once pronounced as of glacial origin. But they often extend across the whole of the valleys in which they are situated, and so closely resemble valley drift that they can with difficulty be distinguished from that form of alluvium. The principal tests for distinguishing the two kinds of sediments are the following:

1. Topographically, the broad osars occupy the same position with respect to the osars lying north of them as they would if they were deposited by the same glacial rivers. The existence of the osar north of them indicates that a glacial river flowed from the north to the point where the osar expands into the broader plain. This river must be accounted for. It could not disappear except in a lake or the sea, or by flowing out of the ice into a valley where the ice had already melted. But the osar terrace is not a delta proper, showing a complete transition from the gravel to sand and finally clay. It was not deposited in a lake proper or in the sea; at least the velocity of the water was only partially checked. The glacial river must

therefore have continued in a channel confined wholly or in part by ice, or it flowed into a valley over which the ice had melted all the way to the sea. In the last-named case the sedimentary plain is a frontal delta, and ought to extend continuously down the valley to the level of the sea as it existed at the time of deposition. If at any point the sedimentary plain in question leaves the valley in which it was deposited and takes a course on the hillsides or passes over hills into another drainage basin, we have proof of the continuity of the glacial river sediments over even the lower parts of the valley where for a time they were found in form so much resembling valley drift. The sediments here termed "osar terraces" cross hills and valleys just the same as the osars, and these topographical relations are inconsistent with the hypothesis that they are valley drift, though in the valleys their situation is such that they must since deposition have been subject to the action of streams and often have been eroded by them, and often were overlain with valley drift. If an osar-plain were confined wholly to a single valley we should have no topographical test to distinguish it from valley drift. This does not apply to the osar-plains of Maine.

2. The material of the beds of ordinary streams in every part of the State I have visited has been carefully examined with a view to determining the amount of attrition to which the existing stream gravel has been subjected. Everywhere the testimony of the gravel of the osar-plains, when compared with that of the adjacent streams having the same slopes and size of drainage basin, is substantially the same. The average shape of the gravel of the osar-plains shows immensely more waterwear than the gravel of the existing streams. The proofs of this are abundant and overwhelming. Only in the mountain regions where the slopes are 100 or more feet per mile do the stones in the beds of streams show rounded forms at all comparable to those of the glacial gravels.

3. The quantity of the broad osar sand and gravel is usually much greater than the valley drift of the adjoining regions.

4. Many of the osar terraces do not extend across the whole of the valleys in which they are situated, and show no tendency to expand into a delta at a broad part of their valleys, but sometimes end at one or both sides in a well-defined bluff rising quite abruptly above the level of the adjacent land. At such places we must grant they were bordered by ice walls, or the alluvium would have spread obliquely outward across the valley.

While the sediments of broad osars are prevailingly finer than that of narrow osars, yet these plains show decided variations in coarseness of material in different parts of their courses, just as the osars do. Thus the great Portland system on a north slope in Rumford and Milton consists of fine gravel and a large amount of sand. Approaching the top of the divide at North Woodstock, we find gravel and cobbles, while on the south slope from North Woodstock past Bryants Pond to North Paris it consists of pebbles, cobbles, bowlderets, and many bowlders 2 to 4 feet in diameter, all very much waterworn.

FIG. 34.—Diagrammatic section across osar-plain; Woodstock and Milton.

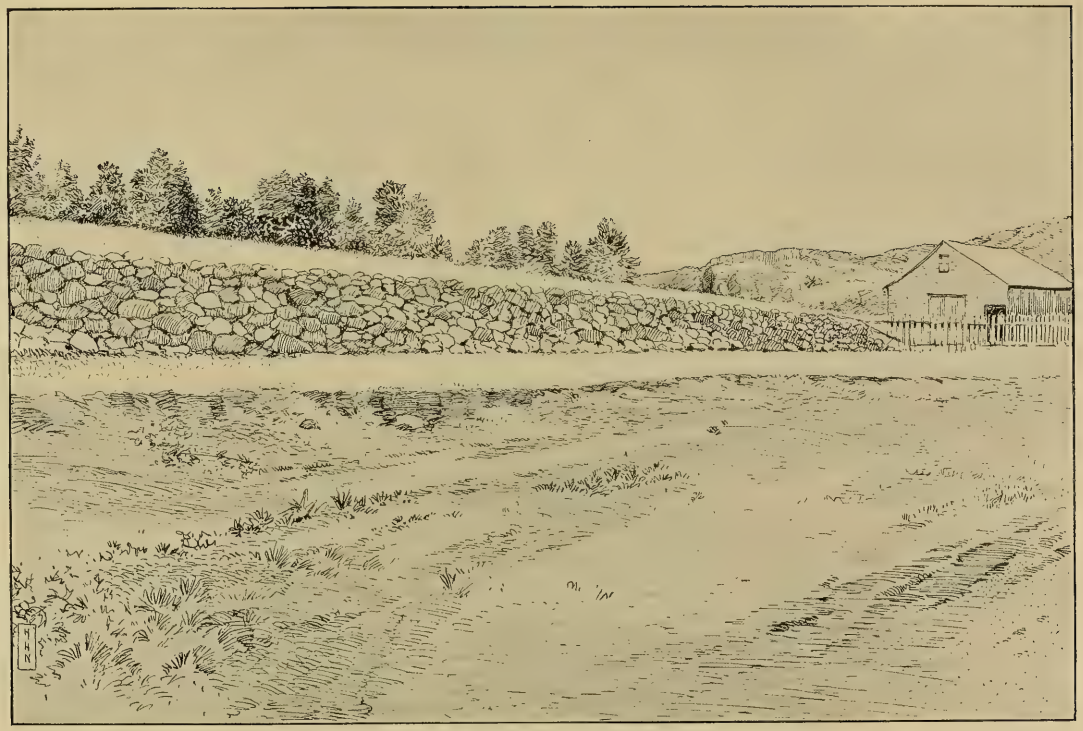
In many places the osar-plains have been much eroded by small streams and boiling springs. Invariably the erosion has been most rapid toward the sides of the plain, leaving a central uneroded ridge resembling an osar in external form. In some cases the central ridge is composed of much coarser material than the ground on each flank, but I have not been able to find sections satisfactorily showing the nature of the stratification of the central and lower parts of the ridges. At the tops of the ridges and in the plain at their sides the strata are nearly horizontal, or somewhat cross-bedded, dipping a little toward the south.

Fig. 34 shows a section across the osar-plain in Rumford and Milton. The central ridge is here known as the "Whalesback," and has about the same height as the uneroded terraces at the sides of the valley.

FIG. 35.—Diagrammatic section across osar-plain; valley of Bog Brook, Canton.

Fig. 35 shows a section across the valley of Bog Brook in Canton and Livermore. The broad osar has here been eroded by two brooks, one on each side of the central ridge, and they flow in opposite directions. The central ridge here rises several feet higher and the material is much coarser than the terraces of sand and gravel that are found on each side of the valley.

There must be a reason why the central ridge invariably resists erosion better than the matter at its sides. In most cases the ridge is plainly composed of much coarser matter. I have found no sections showing that an ordinary narrow osar with arched cross section lies along the axis of the osar-plain, though this is probably the case where the central ridge rises



WALL ON BROAD OSAR; WOODSTOCK.

The bowlders are water-rolled and show the coarseness of the osar matter. The place is near the top of a col over which the glacial river flowed

above the terraces. But the broad osar can easily be differentiated into the following tracts: (1) An axial belt of coarse composition and with the material very much waterworn. (2) Bordering terraces, sometimes not so high as the central ridge, composed of finer materials and often not so much waterworn.

These facts point to the following interpretation: that first there was an ordinary narrow osar channel in which more or less coarse gravel accumulated, and that as the channel subsequently broadened the original osar was more or less washed away and incorporated with the growing marginal terraces. These conclusions are strengthened by the fact that in several cases an osar expands for several miles into a broad osar and subsequently narrows again into the ordinary osar type of ridge. The broad osar or osar terrace is thus seen to differ in no essential character from the narrow osar except that it has advanced a stage farther in its development. The history of this development was in part as follows:

First there was an ordinary narrow osar river. Whether this had begun to deposit gravels within its channel previous to the great enlargement of the channel is to be determined in each case separately, for these rivers appear to have had different histories. We need not here inquire whether the narrow rivers flowed in subglacial vaults or in superficial canyons open to the air. The flow of water increased, and so gradually that the ice at the sides of the original channel could be melted and eroded at a corresponding rate. I defer the question whether the enlargement took place retreatally. While the channels remained comparatively narrow only coarse matter could be dropped in them, and as the channel widened the central osar was more or less washed away and spread laterally into the sides of the broadening channel. The broader the channel the finer the sediments that were deposited in it, unless there was a corresponding increase in the supply of water. It is due to a gradual broadening, accompanied by rapid currents, that the central osar is not abruptly differentiated from the bordering terraces of finer sediments.

Were the broad osar channels roofed with ice? Two facts can be named as especially bearing on this question.

1. The rarity of till on or within the broad osars.

In the northern part of Baldwin are a number of bowlders very little if in any degree polished by water, yet situated upon and within the sand

and fine gravel of a broad osar. They are exceptional, and the question of their origin is discussed elsewhere.

In general we find in the broad osar terraces no unpolished stones or bowlders that can be regarded as till dropped from the roof of an ice arch, though near the borders of these plains the stones have received much less attrition from water rolling than have the stones of the osars or central parts of the broad osars.

2. The great breadth of the terraces.

If the broad osar channels were roofed with ice, the size of the terraces demands ice arches of great lengths of span, numbers of them up to one-fourth of a mile, several one-half of a mile, and a few three-fourths of a mile. These would be very long spans for bridges of high-grade iron and steel. If the arches sagged and were supported on the gravels or on abutments of ice, we ought to find the terrace uneven on its surface, with kettleholes and reticulated ridges. The sizes of the subglacial channels would be so restricted, too, that only coarse sediment would be deposited all the way out from the central ridge to the margins. We now and then find reticulations and hummocky ridges in the midst of osar terraces that may have had such a history, but the broad osars proper are very level in cross section and contain such fine sediments that they must have been deposited in large channels where the flow of the water was moderate.

The interpretation of these facts is further discussed below.

FORMATION OF THE BROAD OSAR CHANNELS.

Among the methods whereby the ordinary osar channel might become broadened, we may mention the following, premising that these channels had somewhat parallel sides:

1. Subglacial channels were enlarged laterally and subglacially to the full breadth of the channel.

This theory would require us to assume that the larger bowlders, at least over most of the State, were contained in the basal ice. For the broad osar is composed, as a rule, of rather fine material, and does not carry bowlders such as ought to have fallen from the roofs of so broad tunnels if the englacial bowlders were high in the ice.

The difficulties of this hypothesis are very great if not insuperable.

The breadth of these broad channels (one-eighth of a mile to one-half mile or more) is such that it seems inadmissible to postulate ice arches of such dimensions without their roofs collapsing. Russell reports the roof of a stream of the Lucia glacier collapsing. This stream is about 150 feet wide.[1] Now, although the subsidence of the roof in this case appears on the ice surface only so long as the roof is not very thick, it by no means follows that there is not also an inward flow of the roof and walls with increasing depth. But the roofs of the broad osar channels would be from ten to twenty times as broad as this stream of the Lucia glacier. To postulate self-supporting roofs is an enormous demand. I do not see even one feature of the gravels or any property of ice that warrants the assumption. Locally we can conceive of such arches floating on the slack water north of hills crossed by the osar rivers, but the broad osars are also found on southern slopes where there could be no slack water.

Perhaps the principal question involved in the problem is this: Where are we to find the supply of heat necessary to melt and enlarge such great channels? For I assume that melting is a greater cause of enlargement than erosion. The channels in which were deposited the broad osars, the osar bowlder clay, the narrow marine deltas, also the lake-like enlargements in which were deposited the peculiar formation elsewhere named "lacustrine massives," are all a connected series of phenomena. Any complete theory must account not only for these very broad channels but also for the narrow ones. If we assume that the broad osar channels were formed subglacially, we may as well assume that lacustrine massives 5 to 10 miles long and 1 to 2 miles wide were also formed subglacially. But if we assume that these very broad channels were subglacial, how are we to account for the narrowness of the osars proper? Ordinary subglacial streams depend for the heat with which they enlarge their tunnels chiefly on waters of superficial melting, slightly warmed before the plunge down the crevasses. This supply of heat is small and only moderately enlarges the tunnels. This accounts for the narrowness of the earlier tunnels. We

[1] Nat. Geog. Mag., vol. 3, p. 107, May, 1891. "The course of the stream below the mouth of the tunnel may be traced for some distance by scarps in the ice above, formed by the settling of the roof. Some of these may be traced in the illustrations. When the roof of the tunnel collapses so completely as to obstruct the passage, a lake is formed above the tunnel, and when the obstruction is removed the streams draining the glacier are flooded."

This description refers to the tunnel by which the stream descends beneath the ice after having risen to the surface and flowed a mile and a half on the ice.

can assume that during the decay of the ice-sheet this enlargement went on at a somewhat uniform rate, so that at last they attained the dimensions of the broad osar channels. But if so, how can we, on the subglacial hypothesis, account for the discontinuous gravels, where the channels connecting the successive lake-like enlargements were so narrow and the resulting velocity was so great that for long distances no sediment was deposited? Besides, wear of surface streams ought to enlarge the channels somewhat uniformly—that is, produce ordinary osar channels; but I see no method of wear by which these extraordinary local enlargements would be produced.

On the other hand, if we postulate a body of water open to the sunlight, we at once find a sufficient local supply of energy to produce these local enlargements, in the heat absorbed directly from the sun by the water of the channel, pool, or lake. We are also saved from a self-destructive assumption of so great power of the ordinary superficial waters of the glacier—such as are exposed for only a short time to the sun and then plunge beneath the ice—in enlarging their channels, as would make it impossible to account for the narrow tunnels.

On the subglacial hypothesis the broad osar channels originated as ordinary narrow osar rivers, the roofs of whose tunnels subsequently disappeared. Were these, then, superficial streams? In my earlier writings they were so interpreted, and formed one of the principal arguments for the belief that superficial streams were able to cut canyons down to the bottom of the ice and deposit stratified sediments within them resting on the till or rock. Professor Chamberlin suggests that they were neither subglacial nor superficial. It is probable the water that flowed in them was in other portions of the glacier a part of the subglacial drainage. They are in general equally consistent with either the subglacial or the superglacial hypothesis, and therefore must certainly be withdrawn as evidence of superglacial streams. On the subglacial hypothesis all tunnels at some time lost their roofs, but these are supposed to have lost theirs before osar deposition was completed.

2. Another hypothesis would be about as follows:

As the subglacial tunnels attained considerable breadth, and the ice became thin, sagging or collapse of the roofs became more rapid and the cross section of the tunnel became a more and more flattened arch. In

process of time the middle of the arch might rest on the previously deposited osar, where there was one, but in any case there would often be more enlargement of the tunnel laterally than in height. Where the course of the glacial river was approximately parallel to the ice flow, the slow settling of the roof of the tunnel would continue to modify the same mass of ice in its progress for a term of years and cause a somewhat continuous depression of the surface. In this depression or valley surface waters would collect and melt more or less ice before reaching a crevasse. Many conditions, such as the extension of the névé line northward, might cause an increased supply of waters with flooding of the subglacial tunnels. Collapse of the roof or clogging of the channel would cause the water to rise into englacial or superficial channels, and the latter would follow the depression caused by the settling of the roof and often cause the formation of temporary surface lakes. Where the waters rose in crevasses or went down again into them after passing an obstruction, deep pools would form if the overflow was long continued or often repeated. When one or more pools were formed or openings were made through the roofs, the heat of the sun would be absorbed in increasing amount by the subglacial waters, the separate pools would gradually become confluent in a continuous channel open above to the sun, and this channel would then rapidly broaden till it sometimes came to extend across a whole valley. Many of the conditions for oversupply of water as compared with tunnel capacity would depend on purely glacial conditions, such as rate of melting, rate of ice flow, etc. When the falling of a single block of ice into a tunnel may have changed the course of a glacial river overflowing on the ice into a new valley in the ice surface, it will not be expected that we shall be able to trace all the accidents of broad-channel formation. North of hills crossed by the osar rivers this process was probably often, perhaps always, assisted by the pool of slack water there collected, and here the enlargement may have often proceeded as the extension of a fringing or marginal lake formed north of the hill.

This hypothesis, postulating the change in the development of an osar system from a narrow to a broad osar and again to the narrow type, demands that we shall not regard the broadening of the channel as extending recessively northward. Rather it took place locally, leaving reaches of narrow osar in the course of the same system. We can admit a

considerable enlargement as taking place at the base of the crevasse where a superficial stream pours beneath the ice; but I do not see how we can admit local supplies of ordinary superficial waters in such quantities as would account for the disappearance of the roofs. The overflow theory postulates known processes, and seems to be sufficient for the work accomplished. Local stoppages of the tunnels here and there would cause the local disappearance of the roofs, with the consequent broadening of the channels.

When we come to apply the hypothesis to the enlargement of the narrow marine delta channels and those of the border-clay channels that were beneath the sea, we find special difficulties. The ebb and flow of the tide and the temperature of the sea would introduce new elements into the analysis, but their quantitative significance is uncertain.

Applying these principles to both the up and the down slopes of the land as we go south along the courses of the osar rivers, I have failed to find any constant relation between the land slopes and the enlargements of broad osar channels, at least such as would warrant the prediction of their occurrence at particular places or slopes. If there is such a rule it is that in most cases a broad osar extends for some distance north of the tops of hills crossed by the osars. On the steeper down slopes there may have been the same broad channels, but quite often no gravel was left for 1 to 3 miles south of the hilltops, and we have only inferential evidence of the breadth of the channel. Also the alternation of broad-channel deposits having a horizontal surface in cross section with the area of reticulated ridges will require more detailed study before correlation of these deposits with topographical features can be asserted. Indeed, they may often have had no connection with the land surface and have depended on ice conditions alone.

RETICULATED ESKERS OR KAMES.

In external appearance these uneven and hummocky complexes, which show an endless variety of ridge and hollow, are perhaps the most remarkable of all the deposits left by the glacial rivers. They afford all gradations of complexity from the simple branching of a ridge into two ridges which soon come together again, up to the great plexus 3 or 4 miles broad, its surface covered with a jumble of heaps, mounds, cones, and ridges, inclosing all forms of hollows, funnels, hopperholes, kettleholes, basins, and

RETICULATED KAMES: PORTER.

"Roman theaters," many of which are so deep as to inclose lakelets without visible outlets.

Probably the phenomena of all the glaciated countries will have to be compared before we are able to explain these interesting formations in all their details.

The most important facts concerning the reticulated ridges are the following:

1. Their geographical distribution. The most remarkable of these plains are situated in southwestern Maine, where they are connected with the Conway-Ossipee kame plains of New Hampshire. Almost all the osars and other gravel systems here and there expand into a plexus of reticulated ridges, but they are not large except in the granitic areas. The granite outcrops of eastern Maine are much smaller than those of western Maine, and the general slope of the land is not so steep. For these and perhaps other reasons the reticulated eskers of that part of the State do not cover so broad areas.

2. Their relations to long gravel systems. The reticulated kames are not a distinct class of systems, but a peculiar form into which the longer gravel systems here and there expand. They were deposited by the same glacial rivers that left the osars and other types of gravels.

3. Their relations to relief forms of the land. All the longer gravel systems at some part of their course pass from one basin of natural drainage to another, and most of them do so repeatedly. In the interior of the State the areas of reticulated ridges into which the osars and broad osars expand are rather small. They are situated variously with respect to the slopes of the land, being found on both up and down slopes and in level regions. Thus going up and over the hills and across the valleys, the great river at last penetrated all the higher transverse ranges of hills along the low passes and came out into a region of broad valleys which soon merge into the sea-border plain, a rolling region extending 30 to 40 miles from the sea. In the hill country the gravels usually take the form of osars or osar terraces, but when they reach the broad valleys of gentler slope they expand into great plains or tracts of reticulated ridges. These are mostly situated between the contours of 230 and 500 feet.

4. The forms of the ridges. In western Maine the ridges are usually

rather narrow at the north end of the plexus, and have rather steep lateral slopes. Going southward we find the ridges on the average becoming higher and correspondingly massive till we arrive within a few miles of the contour of 230 feet. The ridges then grow broader as we still go southward, the lateral slopes more gentle, and the hollows shallower. In the more level country of eastern Maine there is an analogous but less-marked change of form.

5. Their relations to marine deltas of glacial origin. All the deltas left by glacial streams in the sea, both the broad, fan-shaped deltas deposited in the open sea and the narrower ones left in bays or broad channels of the ice, end at the north in reticulated ridges inclosing kettleholes and other basins of various sizes and shapes.

6. Their relations to lacustrine deltas of glacial origin. Numbers of deltas were deposited by glacial streams in lakes inclosed wholly or in part by ice. In the larger of these the deltas are more or less reticulated toward their northern extremities.

7. Their relations to overwash or frontal deltas of glacial origin. In the interior of the State, as the ice retreated northward it often happened that the glacial streams poured out from the ice front into valleys sloping southward. Their sediments spread out and filled the valleys like the sediments of Alpine glaciers. Their stones have been worn and rounded by the glacial streams more than they could have been worn by ordinary streams, and often they were carried farther by the glacial streams than by the river of the open valley beyond the ice front. Yet at the place of final deposition the water was in no way confined by ice and was practically an ordinary river. These overwash or fluviatile deltas of glacial streams sometimes show a rolling, uneven surface with shallow hollows, but no deep kettleholes or conspicuous reticulations, except in the valley of the Androscoggin River between Gorham, New Hampshire, and Gilead, Maine. The character of the alluvium of this valley is elsewhere described.

8. The material of the reticulated eskers. In general, the kame material is coarser in the hilly regions and becomes finer southward. In the western part of the State the reticulated ridges contain multitudes of bowlderets and bowlders, many of them much rounded, others with only a little polish, as if carved by sand and gravel without having traveled far.

LARGE OSAR BOWLDERS ON HILLSIDE RIDGE; PORTER

All over the State the reticulated ridges are usually rather coarse. In western Maine the ridges transverse to the general course of the glacial river are on the whole rather finer in material than the ridges parallel with the course of the river; but this rule is not universal. Indeed the reticulated kames seem to defy all rules.

9. Their internal structure. Many of the reticulated ridges, especially near the north end of the plexus, have the steep slopes and roof-like top characteristic of the pellmell ridge. All the excavations in Maine which I have examined show more or less distinct stratification. No very distinct layers can be expected where the materials are very coarse, and the thickness of the beds formed by a single flood might be many feet.

WAYS IN WHICH A RIDGE OF AQUEOUS SEDIMENT CAN BE FORMED.

1. Subaerially, in the way in which streams carrying much sediment build up delta channels. Thus, the Mississippi River, the Po, etc., near their mouths are flowing on top of a ridge composed of their own sediments. This ridge is really composed of two ridges which form the banks of the stream, but when the amount of sediment is great the ridges coalesce at the bottom and the river flows in a depression on the top of a single broad ridge. They seldom rise very high before the stream abandons the old channel and makes for itself a new one at the side of the old, thus spreading out in the well-known fan shape.

2. Wholly within channels of the ice, either subglacial or superficial, the subsequent melting of the ice leaving the sediments rising above the adjacent ground.

3. At the sides of rapid streams where they enter comparatively still water. A good modern instance of this kind of ridge may be seen at Kingman (see p. 98). This is, in fact, only a subaqueous example of the same process as that by which a subaerial stream in its delta builds up two-sided channels. The rapid glacial streams, both subglacial and superficial, would form large ridges on each side of them as they entered the sea or a lake. This is well exemplified by the gravels near East Monmouth (see p. 189).

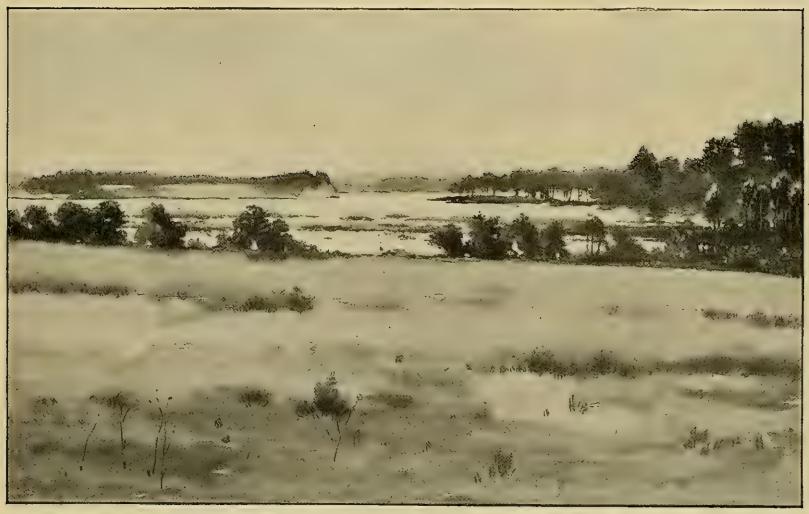
4. When a small stream bearing much sediment entered a body of still water, the two ridges formed at the sides would soon coalesce at the

bottom, and then the stream might, under favorable circumstances, build up a single ridge having a shallow channel on its top, an exaggerated subaqueous form of the ridge built above the sea by rivers at their deltas. The buoyancy of the water would enable such a ridge to have much steeper slopes than if formed above the water. As a glacial stream under these conditions entered the sea or a lake it would naturally, as the flow became less rapid in autumn, fill up the channel or channels in which it had previously flowed, so as to leave the ridge with a broad flattish or uneven top, or sometimes even rounded. If such a ridge were beneath the sea, the subsequent action of the waves would round off the summit to the lenticular or rounded form.

5. A ridge forms in the lee of an island, rock, mass of ice, or other obstruction situated in the midst of a sediment-bearing stream. Such a ridge has previously been described as forming in the Presumpscot River below a bridge pier.

All the above cases are instances of the general property of running water to drop its sediments as its velocity decreases. The distance to which the glacial rivers could extend ridges after issuing from the mouths of their channels depended on the size and velocity of the rivers. At Litchfield Plain the different ridges become confluent and are lost in the sand plain within one-fourth of a mile, and at the small marine delta in Amherst the sand passes into clay within the same short distance. On the other hand, in the larger deltas it is 3 to 5 miles northward from where the ridges become confluent to where they plainly were deposited in ice channels. It is difficult to determine the line between the ridges deposited in the sea in front of the ice and those within channels near the margin, if for no other reason than that the ice must have been retreating while the delta was forming and the one formation would follow and overlie the other in the retreat. If this retreat was for any great distance, the later sands ought to overlie the earlier gravel ridges deposited near the ice front of the earlier times. Thus far I have found no field evidence of such an order of deposition, and it is doubtful if we can admit more than 1 to 3 miles of retreat while the larger deltas were in process of formation. In addition to the retreat of the ice front, we have to consider also the possibility that the sea was at the same time rising or falling.

A. KETTLEHOLE IN MARINE DELTA; NEAR MONROE VILLAGE.



B. LAKE BORDERED ON ALL SIDES BY TERRACES OF GLACIAL GRAVEL; HIRAM.

The place where the lake is now situated was probably occupied by an island of ice when the gravel was deposited.

FORMATION OF KETTLEHOLES AND OTHER BASINS INCLOSED BY RIDGES OR BY PLAINS OF AQUEOUS SEDIMENTS.

I. Such hollows or basins may be formed above sea level.

1. In the channels of glacial streams either above or beneath the ice. This could happen if the streams branched like rivers at their deltas and subsequently came together again, or became connected by cross channels, thus inclosing islands of ice or covering the ice to an unequal depth with sediment.

2. In case glacial sediments are deposited on the ice and in process of the unequal melting part of the sediment slides one way and part another, or settles in channels of streams.

3. In the process of delta formation where a number of streams are each building up its own ridge. These streams as they radiate outward will here and there meet or approach one another and their respective ridges will inclose basins.

4. By unequal fluviatile erosion of previously deposited sediments, such as the deep pools in the beds of streams at the base of rapids or waterfalls.

5. By subterranean waters in the form of boiling springs. As the waters boil upward they carry off the finer matters of the soil in suspension, and even the matter contained in solution may in time come to have geological importance. In some cases small lake basins may have been formed in this way, such as those near Fryeburg and in the upper Kennebec Valley.

6. By the unequal filling of previously existing channels. The half-moon lakes of the delta of the Mississippi River are instances of this class, and perhaps some of the small lakelets of the alluvial plain of the Kennebec River between the Forks and Embden have the same origin.

7. By ice dams. Before ice gorges give way streams sometimes shoot out through them with sufficient velocity to erode deep holes in the valley alluvium. During the flood which accompanies the breaking of the dam, sediments are sometimes deposited over heaps of ice, and the subsequent melting of the ice blocks leaves a hollow where the thickest ice was.

II. Such hollows or basins may be formed beneath relatively still water.

1. By glacial streams flowing into a lake or the sea. Judging from the ridges formed below the dam at Kingman, each stream issuing from the

ice into the still water would form a ridge on each side of it, and these lateral ridges would be connected by a cross ridge at a distance from the mouth of the stream depending on the size and velocity of the stream, the depth of still water, the size of the transported stones, etc. This transverse ridge is due largely to the whirl of the water where the swift water enters the still water. If a number of parallel streams of different sizes entered a body of still water, the transverse ridges would be formed at different distances from the mouths of the streams. The result would be the same if a stream abandoned its former channel for a new one. As the ice melted and the ice front receded, new transverse ridges would be formed from time to time. Perhaps it would describe the phenomena better to state that the two lateral ridges bend their courses so that they unite, rather than to use the term "cross ridge," as if this ridge were distinct from the lateral ridges, for it is only a deflection of them, formed in a curve on the outside of the whirl where the swift water is checked and set to whirling by the mutual action of the still and the rapid water.

When small glacial streams build up each its own delta ridge beneath still water, the radiating ridges may approach one another and thus inclose basins.

2. By glacial streams in ice channels beneath the level of comparatively still water. This would more often happen in case of subglacial streams. The method would be substantially the same as when basins are formed above the sea.

3. In the lee of a broad obstruction situated in the midst of a flowing stream. Bars of gravel extend from each side of the obstruction, which curve convergently so as to leave a crescentic basin between the coalescent bars and the obstruction. I have seen such basins in the lee of small islands in the salt-water fiords and inside "rivers" along the coast. In case of glacial rivers entering lakes or the sea, this may have been an important condition for the forming of basins.

4. By the unequal filling of subaqueous channels. The shifting bars of the Western rivers must often leave portions of partly filled channels as deep pools, which would become kettleholes or other-shaped basins if raised above water. The terraces of valley drift are in general very level on the top, showing that they were deposited under very different conditions from those of the reticulated ridges on the alluvial plain of the Androscoggin

A. BASIN CONTAINING LAKELET IN THE MIDST OF A BROAD GRAVEL-PLAIN, NORTHERN PART OF WINDSOR

B GRAVEL MESA; SOUTHERN PART OF CHINA

The cirque containing the trees was not eroded; the gravel was deposited in practically its present condition

River above Gilead or the channel of such a river as the Platte, if it could be drained dry.

5. Where large quantities of sediment are being carried downward by a rapid stream, transverse bars naturally form across the stream, in which the grains or stones that are behind pass to the front, one after another, like the grains in a dune of blowing sand or in a ripple-mark. Bars of this kind, so far as I have observed them, are not large enough to be considered the correlatives of the large transverse ridges so common among the plains of reticulated kames.

The influence of tides in causing the formation of ridges and hollows by checking the glacial streams has not been formally included in this list, since it is doubtful how far tidal influence was felt by them. Yet the tides may in certain cases have had some effect of this kind. The tides would help to a horizontal stratification of the finer sediments.

In 1878 I suggested in the American Naturalist[1] that certain ridges that project like tongues from the side of the alluvial plain of the Androscoggin near the line between New Hampshire and Maine were due to the overflow of the river in time of flood into a lateral valley containing a lake during high water. It is still a question whether there is not a particular size of sediment fragments which, with a proper depth and velocity of stream, will tend to form an uneven bed covered by shifting bars and hollows, while if the fragments become smaller than this the stream will fill up the inequalities of its own production and flow over a level plain. The drift of the upper Androscoggin Valley is perhaps the key to this problem, if one only knew how to use the key.

ORIGIN OF THE GLACIAL GRAVEL COMPLEX AND ITS RELATION TO MARINE AND LACUSTRAL DELTAS.[2]

PLEXUS SITUATED AT ONE END OF A MARINE GLACIAL DELTA.

Here there is a gradual horizontal passage of sediments from coarse at one end of the delta to fine sand and finally clay, all having the same level as the adjacent beds. At the end where the coarser sediment is, the plain

[1] Note on the Androscoggin glacier, Am. Naturalist, vol. 14, pp. 299–302, 1880.

[2] The theory that the kames were deposited in the sea was enunciated in a paper by Prof. N. S. Shaler, in Proc. Boston Soc. Nat. Hist., vol. 23, pp. 36–44, and to Professor Shaler is due the credit of first publication. My own views were worked out independently by a study of the ridges formed below dams, as elsewhere described.

is always uneven and contains kettleholes and basins of various depths. Sometimes a few kettleholes or hollows in what would otherwise be a rather level plain are all the signs of reticulation that we find. Here the ridges are so broad and plain-like as to obscure their origin as reticulated ridges. Where the reticulated ridges are best developed there is a pretty regular gradation in the forms of the ridges. At the landward side of the delta, usually the north and northwest, the gravel is coarse and the ridges are high and have rather steep lateral slopes. The basins are correspondingly deep, and the transverse ridges are well defined. As we go away from the place where the mouths of the glacial rivers were the ridges become broader, though still with arched cross section. Soon the ridges are so broad as to be plain-like, and so nearly coalesce that the kettleholes are only shallow hollows, and there is a gently undulating plain of fine gravel. When the area of sand is reached, the plain becomes nearly level on top and shows hardly a trace of separate ridges. The stratification is here nearly horizontal, and so continues into the region of clays, where all signs of the separate ridges are lost. The broad osars sometimes pass into marine deltas by only a few reticulations (as in New Gloucester; see pp. 227-228).

1. The existence of glacial potholes and the phenomena of the noncontinuous gravels prove that subglacial streams existed in the coastal region, and that they were concerned in osar formation, as has previously been pointed out.

2. But glacial marine deltas occur in the course of the osars as a regular part of their development, sometimes more than once in the course of a single river. They mark epochs in the history of the osar rivers, showing where the ice front stood at particular epochs. They are thus retreatal phenomena, not changing the character of the rivers in any way, but merely the conditions of sedimentation. If the discontinuous gravels were deposited by the subglacial rivers, so were the marine deltas. Here there can be no compromise between the rival subglacial and superglacial hypotheses. Superglacial streams must account for all the coastal phenomena, including the deltas, noncontinuity of deposition, decrease in quantity toward the south, the petering out of the streams near the northern ends of the "rivers" or fiords of the coast, the lenticular shape of the gravel masses, the underlying terminal moraines, etc., or they must be ruled out of the coastal region altogether, except in the subsidiary form of

overflow channels where the subglacial streams found their tunnels closed and were forced for a time to rise into englacial or superglacial channels.

3. The heaviest burden that the superglacial hypothesis has to bear is the basal character of almost all the kame and osar drift. By far the greater part of the glacial gravels is stratified and shows no sign of having been deposited on ice, where it would have to fall as the ice melted. It has the appearance of having been deposited on the ground where we now find it, and this is the natural place for subglacial deposits. It remains to be proved that superglacial streams can cut canyons or enlarge lakes so deep that they penetrate to the bottoms of the ice, except near the ice margin, where crevasses are strongest. This reasoning, however, applies only to deposits within channels in the ice. Beyond the ice front the delta ridges of both kinds of streams would manifestly rest on the till or rock and can be accounted for by either hypothesis.

4. Some of the marine deltas are very broad at their northern ends, as in the northern part of Alna, where one ends in a broad transverse bar or ridge showing no horizontal assortment of sediments from the center toward the ends. In other places there are two or more short ridges projecting here and there toward the north, as if several streams, not one, had contributed to the formation of the delta. But these deltas are a part of an osar system, and except in these places we have no signs of more than a single glacial river. All this is easily accounted for on the subglacial hypothesis, since those streams can force new channels when their old ones are blocked, or they can rise into englacial or superglacial channels. But how can a single superglacial stream, after cutting a channel down or nearly down to the bottom of the ice, wander into other channels parallel to the old one, all of them also cutting to the bottom of the ice, which was considerably below sea level and only a short distance back from the ice front? The supposed superficial streams would sometimes have to cut 100 or more feet beneath sea level, and yet abandon these channels for others, unless we suppose that there were more than one superficial stream tributary to the delta; but elsewhere in the course of the gravel system we have proof of only a single river. The broad osar channels, including the retreatal channels and lakes north of hills, the massive plains or mounds deposited in glacial lakes, also the osar border clay, all point to a rapid enlargement of a glacial-stream channel or a pool when once they became open to the

sunlight. This makes it all the more difficult to account for the wanderings of a single superglacial river when it has cut a channel to the bottom of the ice, or nearly so, and that, too, very near the ice front. The narrow marine delta could, perhaps, sometimes be accounted for on the superglacial hypothesis, for the melting would probably be most rapid near the mouth of the main river, thus prolonging a narrowly deltoid bay or channel back into the ice and open to the sea in front. Ice gorges might possibly bar a superficial channel so as to cause an overflow into a new channel, but it is difficult to suppose that a dam of loose blocks would last long enough to enable a new channel to be cut to the bottom of the ice. If we assume that the channel became blocked by the coarsest sediment where it entered the sea, what are we to do about the sediment at the distal end of the delta, which evidently went over this supposed bar on its way south?

On the whole, the difficulties of the superglacial hypothesis are greatly increased by the breadth of the northern ends of some of the marine deltas and the certainty that they were enlarged, not by radiate transportation in the sea beyond the ice front, but by a single glacial river issuing from the ice by several mouths, the more distant being a half mile or more from each other. How far the flow of these different streams was simultaneous, and how far successive, is left an open question.

Usually marine deltas are a part of the discontinuous portions of osars; hence often there are intervals to the north of them without gravels. Here we have the same problem of noncontinuity as in the case of the other discontinuous deposits. Some of the deltas, perhaps, began as massive bars or mesas in gradually enlarging glacial lakes into which the sea subsequently advanced as the ice front retreated, after which time the deltas proper were deposited.

5. Were all the reticulated ridges at the landward ends of the glacial marine deltas deposited in the sea?

As above noted, there are sometimes gaps in the systems north of the deltas. In these cases I conceive that the rapidity of the streams was here sufficient to keep their channels free from sediment. These conditions probably prevailed all the way to the ice front, and in such cases all the reticulated ridges were formed in the sea.

But where long ridges extend northward from the proximal ends of the deltas, especially complexes continuing up to considerable heights above

the highest level of the sea and for 20 miles or more, as happens in southwestern Maine, the gravel was undoubtedly being deposited in stream channels in the ice at a distance back from the front at the same time the deltas were forming. While the delta was forming the ice would be retreating, and the retreat of the ice would uncover the ice-channel ridges, to be at once covered by gravels poured out by the glacial streams which now flowed into the sea at some point northward. In these cases I infer that ice-channel and frontal ridges are both represented in this class of marine deltas. The case would be still more complicated if the delta began as a glacial lake or broad channel deposit. The history of each delta is to be deduced from the local conditions, and probably in the various delta complexes we have every variety and combination of ice-channel sedimentation, with that which takes place in bodies of water in front of the ice.

RETICULATED RIDGES AT THE PROXIMAL ENDS OF THE GLACIAL LACUSTRINE DELTAS.

Elsewhere are described what appear to be lake deltas at East Brownfield, in North Shapleigh, in Unity and Thorndike, in Dixmont, in Newburg, and in other places. Two or three are possibly below the highest level of the sea and may be marine, or partly marine. All are north of hills, where fringing lakes would be formed during the retreat of the ice down the northern slopes. I see no points bearing on their origin other than those applying to the marine deltas.

RETICULATED RIDGES AS A PART OF GLACIAL LACUSTRINE MASSIVES.

These are the massive or solid mounds and mesas of coarse sediments, showing little horizontal assortment, which I assume to have been deposited in gradually enlarging lakes within the ice. They sometimes contain hollows or kettleholes and basins, inclosed by broad, flattish-topped ridges or plains. Some of the basins may have formed where the gravel was deposited over masses of ice or around ice islands. If deposited on the ice, I infer that the gravel would lose its stratification during the melting of the ice. More often probably the basins in this class of gravels are unfilled portions of the lake, left where broad reticulating ridges failed to coalesce completely. This sort of sedimentation would result from the stream pouring into the lake from different points, either simultaneously or in succession.

RETICULATED RIDGES WITHIN ICE CHANNELS.

Near Dover South Mills the Moosehead Lake osar divides into two branches, each not more than 100 to 250 feet wide at the base. They continue a few rods apart for about a half mile southeastward, when they unite to form a single ridge which presently expands into a broad, almost delta-like plain of sand and gravel near The Notch. Both ridges have rather steep slopes on each side, and they inclose a long, narrow hollow or ravine.

I have before described the three small gravel plains in the northeastern part of Monmouth. They are about one-fourth of a mile, or somewhat less, in diameter. Each is crossed by a central ravine flanked by terraces about one-eighth of a mile wide. My interpretation is that here a rapid stream flowed into a small glacial lake, dropping its sediment on each side and leaving the ravine where its bed was. Can we apply this interpretation to such a case as that at Dover South Mills?

If a body of still water existed at each outer flank of the two ridges, there ought to be a broad flanking terrace on each outer side; if swift streams, there ought to be two parallel ridges outside of the two existing ridges. The outer flanks of each ridge must, therefore, have been flanked by ice, and we are compelled to suppose that a single swift river flowed through the central hollow or ravine, dropping a ridge on each side, and its size and velocity were such for half a mile on a gentle up slope that it was able to keep its channel clear of sediment while building up ridges on each side from 10 to 30 feet in height. Now in Monmouth the central ravines, which I infer mark the beds of the streams, are not more than 20 feet deep in any place, and generally are rather less than 10; their length is only half that of the ridge in Dover, and the beds consist of gravel; hence in the process of deposition it is evident that the streams built up a plain of sediment beneath them, though the finer sediment passed out obliquely into the bordering lake. In Dover the ridges are in places confluent at their bases, but at the deeper hollows the ravine goes down to the till, or nearly. I leave the interpretation an open question until other cases are examined.

At the Whalesback, Aurora, we have two and sometimes three ridges extending for 3 miles or more, and nearly parallel. In places the hollows between the ridges are filled with gravel nearly to the top of the ridges; in

other places they are so broad and deep that they contain lakelets and must reach very nearly to the till. If we suppose that the central parts were kept clear of sediment by swift streams, these transverse bars of gravel connecting the main ridges are still to be accounted for.

In southwestern Maine we find in the complexes large steep-sided ridges extending for long distances (1 to 3 miles) without noticeable change in average size and without becoming confluent, except by occasional transverse bars or low ridges and many terraces. The contrast in structure between the ridges of the delta, which become broader and more confluent at their bases and show horizontal classification of sediments, and the ridges of the large plexus, which show little assortment of sediments but continue for miles of nearly uniform sizes and with steep lateral slopes, is very great indeed. The delta plexus is an intelligible formation; why should not all these ridges broaden toward the south and become finer in composition if they were all deposited in the sea or other large body of water? Think of the enormous rivers required to flow between two ridges 50 to 100 feet high and one-fourth of a mile apart and yet keep the space between them so clean of sediments that the deeper hollows are 100 feet deep, alternating with transverse bars rising almost to the tops of the lateral ridges; and all this, too, without the ridges broadening or the sediments becoming finer southward over distances as great as the breadth of the reticulated plexus of even the largest marine delta. The theory that the reticulated ridges were formed by unequal deposition in open bodies of water accounts well for the plexus at the proximal ends of marine or lacustral deltas, and for some of the reticulations in lakes or broad channels relatively small to the flow of the river, where there was no horizontal classification of sediments, or only an imperfect one, but it breaks down in face of the larger complexes and those not connected with deltas, such, for instance, as those occurring in the course of the osars on northern slopes and at considerable distances from the sea. Here the reticulated ridges were often as plainly deposited between ice walls as were any of the osars.

Let us now take the case of the most complex and best-developed plains of reticulated ridges to be found in the State—those lying west of the Saco River in southwestern Maine. They are situated in a region where the rocks are mostly granitic and the till is consequently abundant. The country is hilly, hence probably favorable to the englacial till getting up

into the ice to considerable distances. The region is crossed by two series of valleys nearly at right angles. The principal streams flow eastward along one series of valleys, and their lateral tributaries flow north or south in the other series. The larger gravel series extend from north to south, and thus are constantly going up and down hills, crossing the east-and-west valleys, or following up the north-and-south valleys to a divide and then descending into another drainage basin. Many of the cols they cross are more than 200 feet higher than the land to the north. For 20 or 25 miles the channels of these glacial rivers would for about half their length be filled with slack water on the northern slopes and in the lower parts of the valleys.

As we trace the gravels southward we find them occasionally taking the form of a broad two-sided ridge with arched cross section, but for most of the distance they have either the form of the broad osar terrace or that of the plexus of reticulated ridges. These different developments alternate with each other in the course of the same gravel series, proving that they were the work of a common river and are merely different types of sedimentation. Toward the south the hills become lower and the valleys broader. Here the plains of reticulated ridges widen and become the prevailing type of gravels; yet here and there are small delta-plains in the midst of the kame complex or at their flanks, while here and there the gravel forms level plains—osar terraces. Often in this district the central ridge of the plexus is very massive, rising 50 to 100 feet above the smaller ridges that cover the plain at its flanks. The lateral slopes of the ridges are here rather steep and the kettleholes so deep that in the forest they are very dark and gloomy. Many of them are more than 100 feet deep. Still going southward, we find on the average the ridges becoming broader, lower, and more plain-like, while the kettleholes become shallow. Not far above the contour of 230 feet the ridges become confluent, as an undulating plain, which toward the south becomes more and more level and the material becomes finer until it ends in a sand plain which in turn passes into sedimentary clay. The belt of transition between the conspicuously reticulated ridges and the plains of marine clay varies from a half mile up to 2 or 3 miles. In the narrower north-and-south valleys the gravels more often take the form of the osar terrace than the plexus of

reticulated ridges, and when the latter is present the reticulations are not so complex as in broad valleys or on level plains. The problem of the reticulated kames is, then, closely related to that of the broad osar. In the one case a single channel became very much enlarged and a continuous plain of rather horizontally stratified gravel was deposited over the bottom of the whole broad channel. In the other case the sediment took the form of a series of two-sided ridges, more or less confluent by their bases or by cross ridges. And there are in a few cases transition forms between the two types, as of a terrace or plain having a wavy surface. Furthermore, the same glacial river could in different parts of its course deposit both these forms. We must infer, then, that no special amount of water, or of increase or decrease in quantity of flow, was needed. The process depended not upon the stream so much as upon the ice and the other conditions of sedimentation. These conditions are so numerous that it can with some confidence be affirmed that the details of the process would vary in different localities.

ORIGIN OF THE LARGER COMPLEXES.

The general process by which the larger plains or complexes of reticulated ridges were formed appears to be about as follows:

North of these plains are regions of steep average southward slope. The rapid streams (mostly subglacial in southwestern Maine) brought down great quantities of sediment from the north. As they reached the more level country their velocity became less and the coarser sediment was dropped. In the case of the broad osar channel the deposit of sediment did not proceed faster than the lateral enlargement of the channel and no new channels were formed. A broad, rather level and continuous plain was deposited across the whole of this channel, which was often as broad as the plexus of reticulated kames adjacent. If the water could flow into and through this broad channel, producing a level plain, not an uneven plexus of ridges, how can we admit that the reticulated ridges were deposited in a body of open water as broad as the osar channel? The osar-plain or terrace, it seems to me, is the answer to our questions as to what would happen in a single gradually enlarging broad channel—not a jumble of ridges, but a rather horizontally stratified plain. The evidence here distinctly favors the hypothesis that the ridges of the complexes under discussion are not

such as were formed at the sides of swift streams entering a body of rather still water, and where the hollows between the ridges represent portions of the channels in which the rivers flowed or unfilled parts of the surface which was then covered by open water. Here the ridges were in greater part caused by the filling up of channels formed between ice walls, and the hollows and basins represent ice which separated the different channels or lay beneath the sediments as they were dropped. The following discussion assumes that these plains of steep-sided reticulated ridges, except as they pass into marine or lake deltas, were formed between ice walls in most cases. The gist of the problem lies in accounting for the formation of so many new longitudinal and transverse channels. Some cause must be adduced for the streams acting in this manner here at the reticulated kame tracts, while elsewhere they got along with only a single channel.

All the field phenomena, as we have seen, favor the hypothesis that there were rapid streams and consequently great transportation from the regions lying north of the great complexes of reticulated eskers. So also all the causes of sedimentation combine to retard the streams and cause deposition at the areas of reticulated ridges. Many of them were in the region of backwater north of the hills. The slopes were less steep than farther north. The subglacial drainage had been extended north over the area in question, and many of the subglacial channels had come to be very large. During each fall and winter the existing channels would become more or less clogged with sediment brought down from the steeper slopes. A time would come when the stream would no longer be able each summer to sweep away the débris accumulated during the preceding cold season. At the time of the spring floods the water, under great pressure from behind, would collect in the tunnels. If it found transverse and longitudinal crevasses reaching deep down in the ice, it would follow them laterally, and thus in course of time a new subglacial channel would be formed parallel to the old. Where the new subglacial outlets proved insufficient to carry off the waters, they would rise through crevasses and escape over the surface. The situation of many of the larger plains of reticulated kames is rather favorable to the formation of crevasses, and a large part of these overflow channels were probably subglacial. But when the summer floods came and found the old channels clogged the emergency was press-

ing. The floods must find instant escape in some way, and the natural result would be a complicated system of surface channels. These supposed surface channels probably served for the escape of the waters only for a short time each year—during the time of highest floods—yet they would contain some sediment. Thus probably streams both above and beneath the ice contributed to the formation of such ridges as were formed in channels between walls of ice.

While it is true that the situation of the large complexes of western Maine is in general favorable to a free flow of ice and the production of crevasses, yet the reticulated ridges often do not expand to fill a whole valley, as they would if the ice were so shattered that the subglacial waters could freely pass along crevasses in any direction. They cross valleys and go over cols in a way impossible unless the ice at the sides of the system formed solid barriers.

These considerations bear on the question whether the overflow channels were all subglacial Admitting that the huge central ridges were deposited in subglacial tunnels, the question recurs whether so many additional channels could be formed subglacially. The answer depends on the number and arrangement of the crevasses. If the ice was solid at the sides of a clogged subglacial channel, I see no physical process whereby the stream could form new subglacial outlets. The facts showing considerable solidity of the ice at the sides of the glacial rivers are many. These facts favor the hypothesis that a portion of the overflow channels were superficial. Probably the water would rise through crevasses onto the surface only after the ice had become rather thin. It has been noted before that the transverse ridges are sometimes composed of finer matter than the main longitudinal ridges. This is consistent with the hypothesis that the former were deposited in superficial channels, but the question can only be settled by examining their stratification.

During the time of formation of the kames the ice must in many places have been in motion. Many of the plains have no transverse hills in front of them and the ice motion could continue up to the last. If at this time the ice had power to push forward subglacial sediments, the transverse ridges which had to bear from their sides the force of the sea, ought to be of great breadth and of gentle slopes, like the lenticular ridge of till.

The point did not occur to me while in the field and was not specially studied, but I have no note of transverse ridges having a different contour from the longitudinal ridge adjacent.

Moreover, we must assume that the ice front was retreating. When in the retreat the ice had receded to a given point, the streams at that point were ready to cease to be, as hitherto, glacial, and were about to become frontal. The matter poured out from the front of the ice would overlie the previously deposited sediments. In the case of a narrow subglacial channel changing to a broad osar channel, the retreat of the ice would in part be equivalent to the gradual and recessive melting of the roof of the vault, and then the subsequent lateral enlargement of the canyon thus formed. In this case there are two retreats to be considered—one of the ice over the channel and the other of the ice at the sides of the channel. When, as is true in many cases, there is a ridge of coarse matter in the midst of the osar-plain, we may consider it deposited in a subglacial channel. There are many ways in which such a channel could change to a broad channel open to the air. Perhaps as plausible a theory as any is that often the roof melted recessively northward at the same rates. If so, the matter of the broad plain would be, with respect to the receding subglacial stream, frontal matter, and this would account well for its rather horizontal stratification and level surface. But though frontal with respect to the roof of the subglacial stream, it was contained between walls of ice in whole or in part, and hence was glacial with respect to the regions over which the ice had all melted.

Now, as in the retreat of the ice as a whole the glacial streams had continued to pour out their sediments from the ice front over the previously deposited reticulated gravels, they would at once begin to fill up the kettle-holes and change the ridged to a level plain. The fact that the ridges over large areas still preserve their individuality proves that but little frontal matter was deposited upon them. This in many cases can readily be accounted for, and when a good relief map is obtained perhaps all the cases can be explained. In the region of southwestern Maine under discussion the north-and-south series of gravels are connected by a number of east-and-west series. The latter probably date from the last part of the kame period, when the glacial water could escape eastward by subglacial or englacial channels or over the ice of the valleys more easily than over the hills to the

south. Thus the main supply of water from the north would be cut off before the ice at the sides of the reticulated ridges melted, and in this region of short hills the supply of frontal or overwash matter was small and due to local action. But in the valley of the Saco River from Hiram to Steep Falls the sedimentary plain that borders the river presents in certain places just such a structure as would result if reticulated ridges were subsequently overlain by much frontal matter, at the same time being more or less washed away and reclassified. The valley is inclosed by such high hills from Steep Falls northwestward that there was no late diversion of glacial waters out of the valley, while numerous glacial rivers have left gravels showing that they flowed into it. These are true ice-channel gravels, not overwash, and the plain of the Saco is therefore an intermediate formation between the frontal or overwash apron and the reticulated ridges, and contains both of those formations.

One method of the formation of reticulated ridges has been observed by Professor Wright at the Muir glacier and by Professor Russell at the Malespina glacier—one form of the overflow gravels suggested above. A frontal or overwash sheet of gravel is first deposited over the thin marginal ice. During the subsequent melting, channels are cut in the ice beneath the gravel by streams, apparently of local origin, and the overlying gravel tumbles from both sides into the channel, where it is more or less water-washed and stratified. It is highly probable that ridges having a pellmell internal structure often originated in substantially this manner, and it is one of the means employed to produce the mounds and hollows of the moraines. The clogging of the mouths of subglacial tunnels would bring the streams to the surface of the terminal slope, like those of the Malaspina glacier, when they would deposit on the marginal ice a more or less ridged sheet of gravel, which would become a jumble of ridges, mounds, and hollows during the unequal melting of the subjacent ice. But while admitting this as one of the methods of the formation of reticulated ridges and kettle-holes not forming a part of the delta plexus, I regard it as subordinate in rank to sedimentation in connecting ice channels by the great osar rivers themselves, for most of these ridges are stratified and must have been formed basally, not on the ice. Where large ridges are composed of coarse material and are stratified, we can evoke only the largest and most rapid of glacial rivers, not local brooks undermining sheets of clay.

OSAR BORDER CLAY.

This interesting deposit is so fully discussed in connection with the Anson-Madison system[1] that little need here be added. The general conception which I have formed of it is as follows:

First an osar was deposited in a narrow channel, just as the other ridges were. This channel was subsequently broadened by lateral melting and erosion of the ice so as to become one-eighth to one-fourth of a mile wide, and in some cases wider. If a large glacial river flowed in this broad channel, an osar terrace was formed within it. If the supply of water was small, its motion in so broad a channel was necessarily slow, and even the fine clay could be precipitated This clay is as truly a glacial sediment as the sand and gravel, yet the titles "eskers" and "osars" have come to be applied to ridges of coarser matter, and hence I give a special name to the plain of clay that borders the central ridge. Structurally I can not distinguish it from the plain of sand and gravel that borders the central ridge of the broad osar. The character of the sediments depended simply on the velocity of the stream that flowed in the broad channel. The evidence is conclusive that this border clay was contained in a channel inclosed wholly or in part by ice. This evidence is stated elsewhere and need not here be repeated. The border clay is found only in level regions below the elevation of about 400 feet, and the slow velocity of the water may in several or most cases have been due to the sea backing into the channels.

In several places below the highest sea level what appears to be border clay contains marine fossils. This is the case unless reaches of clay deposited in the open sea alternate with border clay in the course of the same system. But the border clay has in these cases been covered by more or less clay deposited in the open ocean after the melting of the ice at the sides of the broad ice channel. It will require a more detailed field examination than I have been able to give these deposits in order to determine what proportion of the clay was deposited in the open sea after the melting of the ice of the whole region, and what was left in the bottom of broad channels and formed long fiords by which the sea penetrated for considerable distances, perhaps several or many miles, into the thin ice-sheet of late glacial time. It was in such broad channels that the narrow marine deltas were

[1] See p. 180; also Clinton system, East Vassalboro branch, p. 170.

formed. I have no proof of any such fiords extending into the ice that did not proceed from the broadening of the channel of a glacial river. Nor is it here assumed that they were at all times filled with salt water. They were perhaps more nearly estuarine, with brackish water.

The border clay is here and there strewn with nonpolished bowlders which have typical till shapes. They must either have been transported by floating ice or have dropped from glacier ice. In this case, as well as in that of similar bowlders in the marine clays, I prefer the interpretation of floating ice. I can not perceive any way of regarding these as proof of an advance of glacier ice after the deposition of the clays. They do not constitute a sprinkling of till, much less such a sheet as would be left if the ice readvanced over the clays, or if the border clay were formed subglacially. I see no admissible interpretation but that the osar terraces and the border clay were both laid down in channels open to the air. The angular bowlders overlying the border clays are found up to 400 feet. In part they must be due to floating ice of the sea, but there must have been ice floes or little bergs floating in these broad glacial channels, which, as they melted, dropped their burden upon the clay. Some of these bowlders are 8 or 10 feet in diameter.

The narrow marine deltas, the broad osars, the border clay, the broad solid or plain-like massives, all unite with the lake deltas and the kames, eskers, and osars themselves to prove the gradual enlargement of the channels and pools within the ice. Both subglacial and superficial streams could not only hold their own against the inflow of the ice tending to close the channels but could enlarge them.

DELTAS DEPOSITED BY GLACIAL STREAMS IN FRONTAL GLACIAL LAKES.

The best examples are situated in Dixmont and Unity and are described elsewhere.[1] All are small, only 5 or possibly in one case 10 miles long. Regarding the frontal lakes, it is here only necessary to remark: (1) They mark stages in the retreat of the ice northward. (2) They collected between the ice front on the north and hills situated to the south. Thus on a small scale they were equivalent to the lakes that fringed the southern border of the ice-sheet in central New York and Ohio. (3) They differ in no essential

[1] See pp. 141, 146.

respect from the dead water that occupied the glacial channels north of the hills, except that they were not confined within so narrow limits. (4) Thus far I have not been able to find fossils in their sediments. Maine is so far from the terminal moraines of southern New England that it will not be surprising if it shall be found that the ice front retreated northward faster than the land plants and terrestrial invertebrates could advance. Moreover, these organisms had just been wholly driven out of New England, unless possibly on a few of the higher mountains and islands. West from Staten Island the plants could follow the retreating ice by the shortest lines, i. e., at right angles to the ice front. In New York and Pennsylvania it would be much easier for them to accompany the ice in its retreat than for them to travel obliquely after the ice northward and eastward all the way from New Jersey to Maine. Prof. B. K. Emerson has recently found fossils in sediments of late glacial or early postglacial age situated in central Massachusetts. It would require only a third as long for terrestrial plants and animals to travel to that place as to Maine, and probably the ice was all melted before they reached the latter place. If there was any retreat for these plants and animals from the ice in eastern British America it has not been reported. Reference is here of course not made to algæ naturally inhabiting snow and ice.

VALLEY DRIFT.

VALLEY DRIFT OF PURELY FLUVIATILE ORIGIN.

In a country of hills and rather level valleys, like most of Maine, the surface waters erode the uplands, carry their load down the steeper slopes of the hills, and then may or may not drop the coarser portion as they reach the more moderate slopes of the valleys. In Maine the hills are usually diversified by numerous small lateral valleys, sometimes due to inequalities in the distribution of the till, but more often to the accidents of preglacial weathering and erosion. Most of the surface waters of the uplands are thus soon converged into valleys and ravines. Erosion by surface waters must always have been most active in these smaller valleys.

If the deep sheets of alluvium which cover the bottoms of the broader valleys are composed of material eroded from the uplands by surface waters after the melting of the ice, we ought now to find a system of ravines comparable in volume to the valley drift. The brooks that form

on the hillsides have eroded channels in the till, sometimes 10 to 20 or even 30 feet deep, but in general they are small and their united volumes insignificant compared to the great sheets of valley drift. The surface of the land is such that there never could be a great diffused or general ablation, but the erosion must have been chiefly confined to the hillside ravines.

While, then, there must have been considerable erosion of the upland till since the disappearance of the ice, especially immediately after the melting, while the till was still unprotected by vegetation and the upper till somewhat unconsolidated, yet this furnished only a small part of the valley drift.

The impossibility of thus accounting for the valley drift is still further emphasized by the relatively short time in which this supposed erosion of the uplands must have been accomplished. The upper stratum of the valley drift often extends beneath the sea level of that time as deltas deposited by the rivers in the sea. No matter what origin we assign to the valley drift, the great mass of the deposit must have been laid down between the time of the melting of the ice at the place of deposit and the retreat of the sea to its present level. The limited erosion by the sea during this time proves it to be geologically a very brief period.

Furthermore, we must remember that the till resists erosion far better than the sedimentary drift. For a large part of postglacial time the streams have been able to erode and transport the sediments of the valleys more rapidly than the upland erosion. This is proved by the great size of the valleys of erosion which the streams have excavated alike in the marine clays, in the valley drift, and in the glacial sediments proper. Only here and there locally has deposition exceeded transportation in the lowland valleys. Any such relation of the comparative difficulty of erosion of the till and the sediments, or of land slopes to rainfall, as now exists, could plainly never have caused the great accumulation of alluvium in the valleys. When once the tenacious till was eroded, the streams would have been able to transport most of the loosened matter direct to the sea. Only the coarser matter would be left in the valleys, and a fine clay, like the lowest layer of the valley drift, would be impossible under the conditions assumed.

Moreover, we must account for the coarse residual matter that would

be left on the uplands, if there had been so great an erosion of the till after it had become bare of ice that it furnished the material for such thick sheets of finer sediment. The till contains material of all sizes from bowlders down to rock flour. Any large erosion of the surface till, especially where it would largely be localized in the smaller upland ravines and valleys, ought to have left a mass of residual matter composed of the bowlders and larger stones. This ought now to be either in the ravines of the hills where it would be left when the finer matter was carried away, or to form alluvial cones in the larger valleys near the mouths of the steeper hillside brooks. In the mountains such cones are noticeable, but they at once show themselves to be composed of different material from most of the valley drift, and they add very much to the difficulties of the hypothesis that the valley drift is derived from fluviatile erosion products. Conclusion: Unless locally in the mountains, there is no such body of residual coarse matter left on the hillsides, or as alluvial cones at the mouths of brooks, as testifies to any great erosion of the till since it was deposited by the ice, still less such a vast quantity as would be required by the fluviatile hypothesis. Indeed, the small sizes of the brook channels of the uplands is surprising. I have known near the base of Pikes Peak a channel one-fourth of a mile long eroded in a single storm to a larger size than many a large perennial brook in Maine has been able to erode in all the time since the melting of the ice.

One class of fluviatile residual gravels here deserves further notice. The larger streams and rivers have not infrequently excavated canyons in the till or rock since the melting of the ice. This most often occurs in east-and-west valleys, where the ice often left deep morainal sheets or ridges across the valleys. Here rapids and waterfalls were formed. The rivers excavated a channel in the till barrier and carried the coarser matter down a short distance below the foot of the swift water, where it was left as terraces of valley drift. The stones are usually subangular, and are easily traceable in the midst of the original valley drift. Such a deposit at Kingman is elsewhere described (see p. 98). Now if large rivers have left the residual matter from channels formed in the till, much more ought the brooks to show such proofs of any large erosion of the till.

Another consideration is this: Most of the east-and-west valleys contain less valley drift than north-and-south valleys, and it is on the average of

finer composition. No reasons for greater fluviatile erosion in one class of valleys than in the other, other things being equal, have as yet suggested themselves.

The quantity of the valley drift in valleys is very greatly dependent on the positions of the glacial rivers, and is to some extent independent of the drainage surface.

While, then, we must assume a certain amount of rain wash and erosion of till by streams as having helped to bring down sediment that is now in the valleys, this process can account for only a small part of the valley drift.

Was the valley drift deposited in the sea? If so, it might be under the following conditions:

1. The valley drift was deposited, in part, by glacial streams pouring into the sea. It is plainly a different formation from the marine glacial delta as ordinarily developed. It is possible that in narrow valleys the structure would be modified by tidal wash and scour, yet I see no way to account for the total absence of the reticulated ridges formed at the landward ends of the deltas.

2. We may attribute the alluvium to erosion by the sea waves. If so, the residual beach gravels left after so much of the finer matter was washed away ought to be recognized, and such are not found. Even in the most exposed coasts the till was not all washed away. Still less can we postulate in the interior valleys, which the rise of the sea would change into landlocked fiords, any such erosion as the valley drift calls for.

3. Sheets of valley drift comparable in most or all respects to the valley drift of the higher parts of Maine are found in the vicinity of the Green and the White mountains, and thence extend south through northern New England far above any admissible or alleged former level of the sea. Even if we admit that a part of the valley drift is marine, it is certain that the larger part was deposited above the sea.

4. The valley drift was deposited in the sea by ordinary rivers. This, I think, is true for a portion of the valleys, but only below the former level of the sea, say 450 or possibly 500 feet in the interior valleys. This structure will be referred to hereafter, and the limits wherein found.

I conclude, as the result of this discussion, that the valley drift extends above the former level of the sea. It is a subaerial formation, as a whole, though it locally passes into fluviatile deltas deposited by the ordinary rivers in the sea.

VALLEY DRIFT OF SEMIGLACIAL ORIGIN.

The evidence that the valley drift was derived from the drainage of the ice-sheet is as follows:

1. The valley drift can not be due to the erosion of till after it has become bare of the ice, either by meteoric and fluviatile waters or by the sea. We have no other assignable origin than glacial.

2. The shapes of the stones of the valley drift are in general those of the glacial gravels after they have been rolled several miles by the glacial streams. The stones are in most cases much more worn and rounded than those contained in the channels excavated in the till by existing streams, except on the steeper slopes of the mountains. The stones of the gravel of the valley drift are often as much worn as stream gravels known to date from Tertiary time, but this they can not be, since the stream gravels of preglacial age were removed by the ice or incorporated with the till. We have no machinery for the production of such great masses of rounded gravel, acting within valley-drift time, except glacial streams.

3. We find in the valley drift here and there masses of coarse matter bearing no relation to the local land slopes. Now coarse matter collects near the ice where the subglacial streams emerge from the ice. The lingering of the ice front at a given place would cause local accumulation of coarse matter near that point. The occurrence within the valley drift of such a mode of assortment of sediments as does not depend on the slopes of the land requires us to postulate glacial conditions. An instance like this is found near North New Portland. (See p. 188.)

4. The last-named argument would be strengthened if at the same time with the local coarseness of material it was found that the body of coarse matter formed a low bar or ridge across the valley and rose above the level of the valley drift both to the north and to the south of it. This is the condition at North and East New Portland. In various places lakes within the valley drift have probably been formed in this manner.

5. The glacial origin of the valley drift would be confirmed if near the supposed overwash plain of sediment terminal moraines were found. Such occur at East New Portland, in the valley of the Androscoggin River, at the State line, and near the Katahdin Iron Works.

6. In several cases an osar broadens southward and passes by degrees

into a sheet of gravel extending across the valley from side to side and not distinguishable from other valley drift. To the south this does not take the form of an osar terrace (broad osar), but is true frontal matter, passing by degrees into finer sediments and finally into marine clays. Here the glacial origin of the valley drift is unmistakable.

7. That the valley drift is usually more abundant in north-and-south than in east-and-west valleys appears to be due wholly to the fact that this was the prevailing direction of the glacial streams. In other words, the law appears to be that where the glacial streams were most active there we find the most valley drift. This gives a distinctly glacial facies to the valley drift. The sizes of the drainage basins, especially of the smaller valleys, often bear no relations to the quantity of the drift. This points distinctly away from the fluviatile hypothesis and toward the glacial.

Summary.—These facts abundantly prove that overwash plains of glacial sediments formed in front of the ice, and that they are typical valley drift. If the glacial hypothesis thus accounts for that portion of the valley drift directly associated with moraines, osars, and other unmistakable glacial phenomena, we need no other hypothesis to account for those sediments that were deposited at longer distances from the ice front of that time, since the latter are what should be expected on that hypothesis.

RELATIONS OF THE VALLEY DRIFT TO THE OTHER GLACIAL AND THE MARINE SEDIMENTS.

Comparing the valley drift to the other glacial sediments, we find the following relations:

Origin.—They all were at one time transported by glacial streams.

Places of deposition.—Deposits within ice channels include all the eskers, kames, osars, and border clay of the varieties elsewhere described.

Deposits poured out in front of the ice by the glacial streams include the following: The marine deltas with most of the marine clays and sands, deposits in fringing or marginal lakes, and overwash aprons or valley drift poured out on land sloping away from the ice front.

I pause in passing, however, to note that erosion of the till by the sea waves contributed to the marine sands and clays; so, also, water wash from the till contributed to the valley drift. But in both cases the glacial sediments so greatly exceed in quantity the eroded till that practically we may speak of both deposits as of glacial origin.

HISTORICAL RELATIONS.

In a preceding chapter the manner of the retreat of the ice has been discussed and the lines of the front have been marked on the map (Pl. XXXI) as they are supposed to have been at various periods. The lines of retreat seem to indicate not only that the melting took place from above downward but that it was most rapid at the margin. They furnish no proof that any large bodies of stagnant ice were isolated from the main body by the melting of the ice to the north of it, unless the ice situated south of east-and-west glacial rivers be so considered. Thus, near Oxford there is proof that, at a time when a broad plain of sand was being deposited, it was kept from spreading into Thompson Pond by the presence of ice in the basin of that lake. The valley of the Little Androscoggin River may at this time have formed an arm of the sea from Oxford or Norway to Auburn. (See p. 225.) In the Androscoggin Valley in Gilead and Shelburne, New Hampshire, also in the Kennebec Valley from Embden northward, and elsewhere, the valley drift often does not spread into lateral valleys. This suggests that these laterals were filled by ice at the time the central plains were being deposited. While thus there are indications that glacial channels often broadened till they covered all the valleys in which they were situated, and thus the purely glacial sediments deposited in channels back from the ice front passed by degrees into frontal bodies of overwash, the probability is that the retreat of the ice as a whole took place from the margin and the glacial stream channels were bordered by ice until the retreat of the general frontal line back to that place.

1. In valleys containing osars the larger glacial rivers were already established, draining areas 5 to 10 or more miles in width. The same processes that collected the glacial gravels with so few visible ravines of erosion in the ground moraine or till sufficed to accumulate the material of the valley drift in the channels of the glacial streams. In all cases the smaller tributary subglacial streams seldom left gravels, except for short distances near the main osars. This indicates that their channels were small as compared to the flow of water. Most of their work, including tracts of erosion of the ground moraine, glacial potholes, etc., has been covered out of sight by the euglacial till. In a word, we have in the glacial streams a machinery for diffused erosion without the ravines required by the hypothesis of till erosion by rains and streams after the melting of the ice.

The phenomena of delta or diverging branches of glacial rivers prove that from time to time these streams found their channels clogged or were for some other reason diverted to new channels. Admitting that these accidents were liable to happen at any time, still I can see no especial liability of their happening during the very last of the ice at a particular place except on account of the rising of a hill in front. Transverse hills crossed by glacial rivers might often force the streams to escape either east or west after the ice sank to the tops of the hills. In continuous north-and-south valleys containing gravels deposited in ice channels the retreat would cause sediments to be carried beyond the ice front, where they would overlie or be mixed with the previously deposited ice-channel gravels. Cases of this sort of deposition are found in the valley of the Saco River for many miles above Steep Falls, in the upper Kennebec Valley, and elsewhere.

Where the very latest conditions favored the formation of the broad osar, the channel might often continue to widen till it extended across a whole valley. The marginal part of the plain of sediments that would extend across the valley might be valley drift, and we should hardly be able to distinguish it from the osar terrace proper. But where we find the narrow osars or reticulated ridges we could not fail to distinguish them from a later deposit of overwash matter, which would necessarily border or overlie them. In general, it is astonishing to note how suddenly sedimentation ceases. Kettleholes and ridges of coarse matter are found with their shapes clearly defined. Often there has been but little postglacial erosion to fill up the bottoms of the kettleholes. We must, therefore, account not only for the valley drift, but also for its absence from long reaches of the osars and reticulated kames right on the lines of glacial rivers, where, on the glacial hypothesis of the valley drift, its presence would be expected.

In many cases the relief forms of the land would naturally cause the flow of a glacial river to cease at a given place before the ice front had retreated to that point. Thus, where the ice flowed over transverse hills there would be local deflections of ice movement during the last days of the ice. This would make it increasingly easy for the subglacial streams to find new channels east or west along the valley north of the transverse hills, at the same time that the lowering of the level of the ice would make it increasingly difficult to maintain the flow south over the tops of the hills. Often we can trace the new channels by transverse series of gravels. Thus,

in the hills of Oxford and northern York counties three great north-and-south osar series are connected every few miles by transverse lines of gravels, several of which follow the east-and-west valleys. But in general we must suppose that the latest channels of deflection were in use for too short a time to become enlarged sufficiently to permit within them the deposition of gravels.

For various reasons, then, the waters of the longer osar rivers often did not form frontal or overwash gravels in front of the ice during the retreat. If they had continued to flow up to the last, the gravels previously deposited within channels in the ice ought to have been covered or flanked by matter poured out in front of the ice during the retreat. That this did not happen is best explained by supposing the streams to have been diverted to new channels at some time not long previous to the final melting of the ice at those places. Below the level of the sea it would facilitate interpretation if we could assume that some of the rivers ceased to flow in consequence of the pressure of the rising sea, also if we could assume that toward the last the melting of the ice in the far interior valleys of the State was more rapid below sea level than above it. This would be equivalent to the formation of bays of the sea penetrating into the ice beyond the general frontal line, a condition that would facilitate interpretation at Oxford and elsewhere. Such an outline would not be inconsistent with the lines of frontal retreat as set forth elsewhere, but thus far I do not find direct proof of it, unless through the evidence furnished in some cases by the osar border clay.

2. The absence of osars in north-and-south valleys proves that the channels of the glacial streams had not become sufficiently enlarged to permit deposition within them. The streams must have transported all their sediments to the ice front and poured them out as frontal overwash or valley drift. Where these streams were united into one main river we would find the coarsest matter arranged along the course of the stream, and the sediments would grow finer on each side. The coarser mass would not have a definite border or arched cross section. Where there were several glacial streams there would be a corresponding number of coarser belts. Under some conditions these might form reticulations and inclose lake basins and kettleholes, like those in the valley of the Androscoggin River in Shelburne, New Hampshire. These would often be filled later by other drift, but

might survive in very broad valleys. In some cases these reticulated ridges may have been deposited in ice channels near the front.

Obviously the slopes of the land, the breadth of the valleys, the size of the streams, etc., would determine the development of the gravels after passing out of the ice.

3. In numerous cases there are north-and-south valleys or passes leading southward to low cols of transverse hills. In late glacial time they contained lobes of ice which were practically local glaciers. Here we not seldom find, a short distance north of the top of the col, a short esker and small terminal moraines. In a number of such valleys there is considerable sediment along the northern slope for several miles. The most probable interpretation is that a fringing lake formed between the ice and the hill in front, and that the glacial streams continued to pour into this during several miles of ice retreat.

4. Some valleys contain terminal moraines of considerable size. This implies that the ice front remained stationary, or nearly so, for a time. Such moraines are found in the valley of the Androscoggin near the line between Maine and New Hampshire, near East New Portland, and elsewhere.

In such a case we ought to find a very deep overwash apron near where the ice stood or paused, and it might even form a dam across the valley and inclose a lake. From this point the sediments would become finer in composition down the valley, and might even pass into the marine clays.

5. Some east-and-west valleys do not contain osar gravels. Near the end of glacial time the waters of these valleys could not escape southward over the hills bounding the valleys on the south, and the ice would be rather stagnant. There is here no direct proof showing the courses by which the local waters escaped. Some of them would flow in subglacial channels, some might escape between the ice and the hill to the south, or superficially or englacially. It has already been remarked that such of the east-and-west valleys as contain no osar gravels, or were simply crossed by them, contain valley drift which is but little waterworn. This points to small local streams, mostly subglacial and transverse to the ice flow. Such directions would often cause the streams to transport sediments into arms of the sea or into distant north-and-south valleys. After the ice front had

retreated northward to the bottom of an east-and-west valley, all the sediments derived from the drainage of the ice on the north side of the valley would be swept into the stream, which then would flow in the bottom of the valley substantially parallel with the ice front of that time. As the ice retreated northward up the hill more or less sediment would be poured out on the open hillside below the ice, whence much of it would be carried down the hill to the bottom of the valley.

6. In some east-and-west valleys hillside eskers are found. These were deposited by glacial streams that flowed down the southern slopes of rather high hills and left their coarser sediments on the sides or near the bases of the hills. Sometimes here they are lost and the streams must have escaped superglacially or in channels too narrow to permit sedimentation. In other cases this class of gravels expand into deltas and finally merge into the alluvium of their valleys. Evidently this valley drift differs in no essential from that not associated with the osar gravel, except that we can trace its glacial origin more directly.

RELATION OF THE VALLEY DRIFT TO THE MARINE BEDS.

We now approach a series of phenomena very difficult to interpret. In a paper read at the Boston meeting of the American Association for the Advancement of Science, in 1880, I estimated the elevation of the sea in the interior of Maine at 300 to 350 feet. The highest fossils I had been able to find in the interior valleys were at 215 to 230 feet in Palmyra. I had also discovered certain high deltas, as that at Curtis, Leeds, that were from 300 to 350 feet in elevation. My estimate was based on the deltas, assuming that the higher marine beds were nonfossiliferous. Later, when I discovered (1885–86) that the elevation of the beaches along the outer coast-line did not exceed 200 to 230 feet, I became quite doubtful where to place the limit in the interior. It even seemed possible to interpret the highest deltas as formed in lake-like bodies that toward the south opened on land bare of ice, while the basal clay of the valleys would on this hypothesis be a form of valley drift analogous to the loess.

The observations of Baron De Geer, made in 1891, cover most of the area of the elevated marine beds. They make it evident, in a way that local observations could not do, that the apparent rise of the sea in late glacial time was due to a general subsidence of the glaciated area. From

observations in Maine alone I have not felt justified in maintaining the subsidence on our coast and that in the St. Lawrence Valley as contemporaneous.

Accepting the general conclusions of De Geer, I assume that the post-glacial elevation of the land in the interior of Maine has been about three times that of the coast.

FORMER HEIGHT OF THE SEA.

To determine the highest elevation of the sea in the valleys of the interior of the State, we have to depend on the following means:

1. The elevation of fossils. Possibly the time may come when this method will be applicable, especially by means of microscopical examinations. Thus far I have found no macroscopical fossils in large areas of the marine clays, and do not find the absence of fossils in the glacial marine sediments fatal to their being deposited in the sea.

2. The elevation of raised beaches. On those portions of the coast region where the hills were exposed directly to the surf, with few or no protecting islands lying to seaward, we readily find such beaches. Even near the coast the presence of hills toward the south that would form islands has often so diminished the force of the waves that the beaches are inconspicuous and are traceable with difficulty. At the time the sea stood at its highest elevation the interior valleys contained landlocked bays or fiords of the sea. In the Sebasticook and Penobscot and others of the broader valleys it is possible that the waves had sufficient force to leave traceable beaches, though I have not traced them. But these places are not where the valley drift meets the marine beds. These two formations meet in the valleys where the crooked fiords were usually less than 5 miles in breadth and where we can not expect to find distinct beaches.

3. The projection of lines of equal elevation. By projecting the elevations of the highest raised beaches on the exposed coasts, selecting points at different distances from the outer coast line, we find the rate of differential subsidence. Assuming this rate to have been the same over the interior as near the coast, we can then calculate the positions of the lines of equal elevation. Following this method, Baron De Geer calculates that the isobases, or lines of equal elevation, would take the following courses:

* * * An isobase drawn through points which have been upheaved 300 feet passes probably from near Niagara Falls, by Albany, New York, and Augusta, Maine,

to Moncton, New Brunswick, whence it turns backward, running northwesterly and northerly, crossing the St. Lawrence estuary about halfway between Cape Gaspe and the Saguenay.

The 600-foot isobase is probably to be drawn from Georgian Bay past the outlet of Lake Ontario, through the southern part of the Adirondacks, and thence east-northeast nearly to Moosehead Lake. Here it makes an abrupt bend to the north and west, similar with the loop of the 300-foot isobase at Moncton, and runs first westward to some point not far from Three Rivers, and thence, turning again northeastward, it passes along the north shore of the St. Lawrence estuary.[1]

Manifestly this method is not complete until the elevations of all the traceable beaches are accurately determined, and thereby the amount of local warping, if any.

The position of the shore line in any of the inland valleys would, according to this method, lie where the profile of the valley, drawn in a plane perpendicular to the lines of equal elevation, intersects the horizontal line marking the old sea level. Thus in the diagram the line *acb* represents the profile of a valley supposed to be normal to the lines of equal elevation. At *b* and *c* are raised beaches, and the profile is at these points depressed below the horizontal line distances proportional to the heights of the beaches at those points. This determines the position of the point *a*, which marks the former shore.

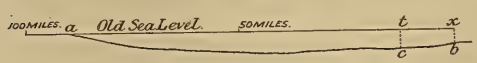


FIG. 36.—Diagram illustrating the method of finding the highest sea level in an interior valley.

4. The elevation of marine deltas. The deltas of the interior at 300 to 350 feet are now interpreted by me as marine, but possibly this point may be disputed. They certainly do not bear such relations to the fossiliferous clays as the deltas nearer the coast. But sheets of clay and sand are found extending from the deltas up to considerably higher elevations, and therefore under no conditions do the deltas mark the highest level of the sea. Indeed, it should be expected that deltas would be formed in front of the ice, often at a considerable depth beneath sea level. The higher deltas are more than 100 feet above the highest fossil thus far found. Marine fossils are found in Lewiston, Winthrop, Norridgewock, Skowhegan, Palmyra, Unity, and other interior towns. The highest deltas are found only a few miles beyond the fossils. Both together constitute valuable collateral evidence of the presence of the sea in the interior valleys, but do not give the extreme limit.

[1] Am. Geol., vol. 9, p. 248, April, 1892.

5. The deeper interior valleys now occupied by streams and rivers. The main valleys are often connected by cross or transverse valleys or low passes. Up to the highest level of the sea we should expect these transverse valleys to have been occupied by straits forming a complex system of reticulating channels surrounding numerous islands. A corresponding series of sands and clays would mark these old channels or straits. Up to the height of these transverse plains of fine sediments it is at least possible that the sea extended. Yet it is also possible that the floods of rivers might rise above the divides between neighboring valleys, and thus an overflow might take place from one to the other. It thus becomes necessary to distinguish a possible form of valley drift from marine beds before it becomes certain whether the transverse plains of fine sediments mark the presence of the sea.

6. The character and structure of the sediments. This constitutes another method of distinguishing between the valley drift and the marine beds. Into the main marine bays of the time when the sea stood at its highest level poured large rivers which to the north were fed by waters of the melting ice-sheet. Above sea level they were depositing valley drift; within the sea, fluviatile marine deltas. Estuarine deposits would form the transition between the two. The determination of the points of transition would be rendered difficult by the rise and fall of the tides, and especially by any general rise or fall of the sea level whereby at successive periods the fresh and salt waters met at different places. If we should find a great change in the coarseness of the sediments taking place within narrow vertical limits, proving considerable slowing of the waters at that point, and especially if this were observed in several valleys at the same relative position to the lines of highest elevation as determined by observation of the coast beaches, we should have probable proof that the streams of the land poured into the sea at those points. Thus far I have not been able to apply the method satisfactorily, in part owing to the rarity of known elevations in these valleys. Where the streams were large compared to the breadth of the valleys it is doubtful if this method can be applied with certainty. The broader and shorter valleys, off the lines of the glacial rivers, are the most promising cases for the application of the method.

The following data give approximate elevations of the highest shore in

several of the valleys. The list could have been considerably extended if the elevations were known:

Elevations of seashore in valleys of Maine.

Name of valley.	Place of highest admissible seashore.	Character of deposit passing into marine fluviatile delta.		Approximate elevation, in feet.
		Marine delta.	Valley drift.	
Saco	Standish, below Steep Falls	×		200 to 250
Presumpscot	Near Sebago Lake	×		250 to 260
	North Windham	×		250+
Little Androscoggin	South Paris		×	400
Twentymile River	Sumner and Buckfield		×	350?
Androscoggin	Livermore Falls, or Jay		×	375+
Sandy River	Farmington		×	440+
Carrabassett	New Portland		×	450?
Kennebec	Bingham or Moscow		×	450 to 500

The Kennebec, because it occupies a deep depression and penetrates far north and west, is better situated than any other of the valleys for containing high-level marine beds. It presents many difficult questions of interpretation which it will require detailed study to solve. The sands and clays admitted as possibly marine in the above table have heretofore been interpreted by me as valley drift laid down at the sides of a broadening osar. The history of this interesting, because difficult, valley must largely be left an open question.

It has been before stated that the upper or rarely fossiliferous marine clay passes up the valleys as the basal layer of what appears to be valley drift. Even if we grant the highest elevations given above for the sea, we do not reach the limits of the basal clay, which in places extends up to 600 feet or more.

Probably the most important feature of the valley drift is that the basal layer is of finer composition than the upper, at least until we reach the steep mountain valleys. Sometimes it is a fine gray clay, at other times a silt, but almost always it has a finer composition than the gravels and sands that overlie it. This condition extends considerably below the old sea level and is widely shown by beds undoubtedly marine. The valley of the Penobscot River west from Medway shows little of the basal clay,

but there appear to be local reasons for the peculiar alluvial drift of this valley, such as its direction, its passing through so many lakes that would arrest its sediments, its large ravines or gorges of postglacial erosion both in rock and till, with terraces composed of the coarser eroded matter extending for some miles below the gorges, etc.

CAUSES OF THE RELATIVE FINENESS OF THE LOWER STRATA OF THE VALLEY DRIFT AND THE MARINE BEDS OF THE INTERIOR VALLEYS.

The valley drift passes into the marine beds by not easily distinguishable gradations. They are here treated together in order to avoid the necessity of absolute determination or distinction of one from the other in the field.

THE LOWER STRATUM, COMPOSED OF CLAY, SILT, OR FINE SAND.

1. We have already given proof that this sediment was chiefly of glacial origin.

2. The average composition of the till is such that great quantities of fine glacial sediment demand the existence of great quantities of the coarser matter also, although it must be admitted that in some of the interior regions, as the upper Kennebec Valley, the local slates would cause the till to have a finer than average composition.

The inference follows that at the time the finer basal clays and silts which cover the bottoms of the valleys were being deposited, there was also a body of coarser sediments being deposited higher up in the valleys, or in part, perhaps, in channels within the ice. The smaller glacial streams, perhaps, then carried little beyond the ice front except Gletschermilch and the finer débris.

3. Fineness of sediment implies the presence either of the sea or of a lake, or, if above their level, a very gentle slope. Some of these basal fine sediments pass above any level of the sea that now appears at all admissible. The interpretation is thus preferred that the land slopes were very gentle at the time the basal fine sediments were deposited. Such low gradients must have marked the time of deepest subsidence of the land, and I see no other assignable cause—remembering that the subsidence in northwestern Maine was three or more times that of the coast, or, rather, that the postglacial elevation has been such.

THE COARSER UPPER STRATUM.

1. The fact that the till was only partially eroded from the outer islands proves that the retreat of the sea was geologically rapid, especially if, as is probable, the surf beat against the ice all the time of the retreat to the sea margin and only once on the land situated beneath the sea at its highest level, and that during the time of elevation of the land.

2. While we do not know the amount of early glacial subsidence, we do know approximately the amount of postglacial elevation. I assume that this elevation has been about three times as great in northwestern Maine as at the outer coast line. The moment this differential elevation began, the gradients of the valleys leading southward became steeper, and grew more and more so during all the time the land was rising (the apparent retreat of sea) to its present position.

3. Marine glacial deltas are formed at the ice front. The presence of such deltas in the interior of the State within 100 feet or less below the highest admissible level of the sea in their respective localities, and that, too, at elevations of about 100 feet above the highest marine glacial deltas that lie nearest the coast, proves that the ice still covered all the northern part of the State at the time the sea had reached its highest elevation, or nearly. Indirectly they furnish proof that the greater subsidence to the north had at this time been already accomplished.

4. The inference follows that at the time the sea reached its highest level (i. e., when the subsidence of the land was arrested) glacial sediments were still being poured down the valleys in front of the retreating ice. Above the sea of that time these glacial sediments formed valley drift; below that level, fluviatile marine deltas. During the differential elevation of the northern lands this delta would recede southward with the shore of the sea. The steeper gradients would now enable the coarser glacial sediments to be transported to longer distances from the ice, where they would be deposited over the beds of finer sediments already spread over the bottoms of the valleys. Moreover, there would be more or less erosion of the coarse sediments previously deposited farther up the valleys than the basal clays extend, and the eroded matter would be transported nearer to the sea and often might reach it and help form a fluviatile delta where the rivers flowed into the sea.

As elsewhere noted, these fluviatile deltas can be traced in all the larger valleys. The delta of the Androscoggin reaches to the sea, or nearly, as ought to be the case where a large stream continues to pour sediment into the sea during the whole time of the retreat. The delta of the Kennebec covered not only the basal clay of the valley with coarse gravel and cobbles from Bingham for many miles southward, but also all the fossiliferous clays from Norridgewock south to a breadth of several miles. From Madison south the delta consisted of sand; northward it became coarser. The delta sand is not traceable south of Waterville. The fluviatile delta of the Penobscot is indistinct south of the mouth of the Piscataquis River. I have not been able to trace definitely the clays which naturally belong to a fluviatile delta of sand, but undoubtedly the finer sediments were swept out to sea and helped form the upper or sparingly fossiliferous clays.

5. South of where the fluviatile deltas of the Kennebec and Penobscot rivers disappear as broad sheets there are low plains or lateral valleys which would be covered by sea water up to the time when the sea had nearly sunk to its present level. If these rivers continued to bring down the same quantity of sediment as formerly, I do not see why the fluviatile deltas should not be prolonged all the way to the sea, or at least they should spread laterally into these broader bays of that time.

Various reasons can be assigned for these deltas failing to be extended all the way to the sea. Thus, as the ice receded toward the north a larger proportion of the sediment might be dropped at a distance from the sea. The supply of glacial sediments would diminish as the ice melted. The flow of water may have diminished as the elevation advanced. As the gradients became steeper the sediment would be carried out farther to sea and would tend less to spread into the lateral bays. Parts of deltas may have disappeared by erosion. The net result was that the deltas were narrow, no longer extended back from the rivers, and are hardly distinguishable from the flood plain.

The existence of Merrymeeting Bay has a bearing on the history of both the Kennebec and Androscoggin rivers. Into this large lake-like body of water both these rivers flow. Both have formed delta flats near where they enter it. If there had been any such transportation of sediments when the sea stood, say, 30 feet above its present level, as took place

while the sea stood at high level, the two rivers combined would have filled up the bay, as I conceive. Yet the land slopes at this time must have been almost as steep as at present, and were much steeper than when the sea stood at its highest level. The conditions would be favorable to transportation from up the valleys, yet the late deltas are comparatively small. The most reasonable interpretation is that the supply of sediment fell off greatly as soon as the ice had melted.

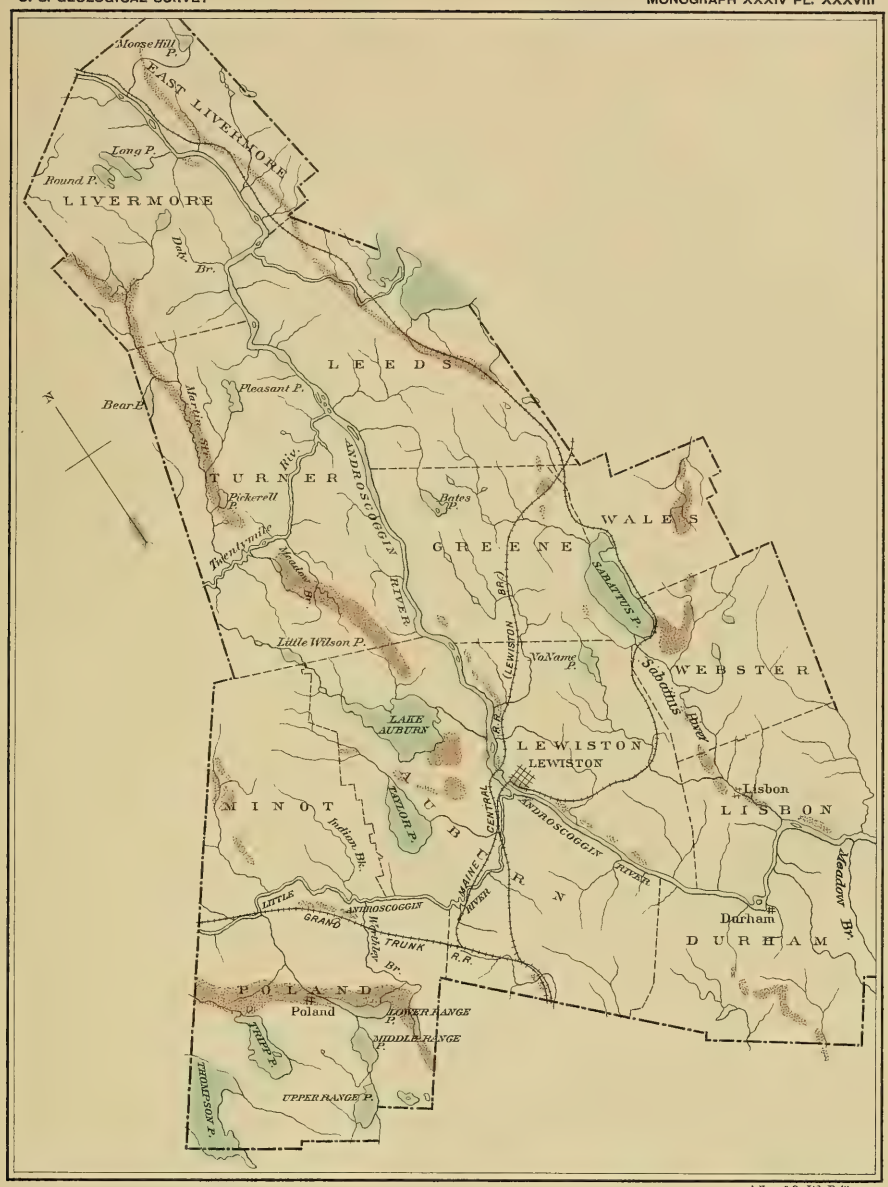
SIZES OF THE VALLEY-DRIFT RIVERS.

Professor Dana postulates in the Connecticut Valley a river large enough to fill all the space between the terraces—a condition inadmissible in Maine. The broad osars and the uneroded valley drift all point to sedimentation by the rivers open to the air, as taking the form of rather level plains, not as high terraces bordering a deep central channel.

The hypothesis that there was a greater elevation of the interior than of the coast region of Maine helps clarify some heretofore very doubtful points of interpretation. At elevations extending from 350 to 450 or 500 feet are plains of valley sediments up to 5 miles in breadth, and in a few cases they are somewhat wider. If these great sheets are valley drift, they demand very large rivers. But if they are in large part marine beds, i. e., fluviatile deltas formed offshore in bays or fiords, we do not need so large streams to account for them. From the sea margin back to the ice these rivers were dependent, like ordinary rivers, on the annual precipitation. Within the ice-covered area their waters were glacial. But the drainage systems of the ice-sheet did not conform to those of the land. Any attempted comparison of the sizes of the valley-drift rivers with the present rivers must take into account the amount of glacial waters that was diverted from one of the present valleys by glacial streams, or that was brought into it. Such calculations are necessarily difficult. The valley drift is more abundant in valleys that once contained the larger glacial rivers—that is about all we know.

Valley-drift time was relative. In each valley it lasted from the melting of the ice until the supply of glacial water was all cut off. Whatever may have been the annual precipitation, the flow of the valley-drift rivers was not only that due to this precipitation, but also that due to the net melting or wastage of the ice-sheet.

Below Moscow and Bingham the sedimentary plain of the Kennebec is from 1 to 6 or 7 miles wide. The overflow stream from Bethel southward into Albany was a fourth of a mile wide or more. This was an overflow of the Androscoggin River. Even if we admit the alluvium of the broader valleys to be fluviatile marine deltas, still we need streams capable of acting over great breadth and with velocity sufficient to transport gravel and cobbles. The breadth and character of the deposits demand large rivers, but I am not prepared to submit a quantitative comparison between them and those of to-day. It is probable that there was a greater rainfall then than now, if we correlate valley-drift time with a part of the career of lakes Bonneville and Lahontan. But we know neither the cause of the glacial epoch nor the cause of its termination. At present I leave open the question of the sizes of valley-drift rivers as compared with those of the present time.



A. Roen & Co. Lith. Baltimore.

MAP OF ANDROSCOGGIN COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893

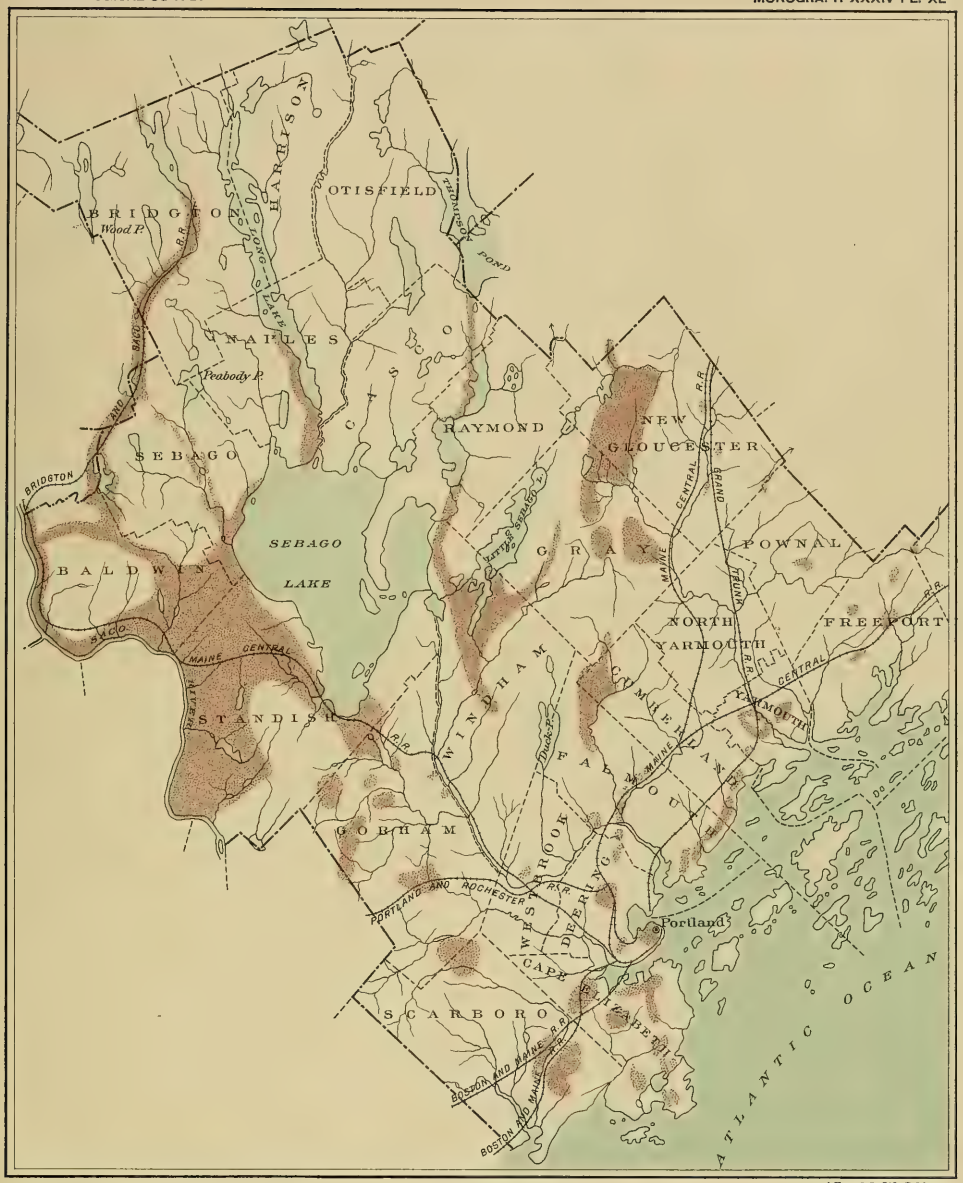
A. Hoen & Co. Lith. Baltimore.

MAP OF AROOSTOOK COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893



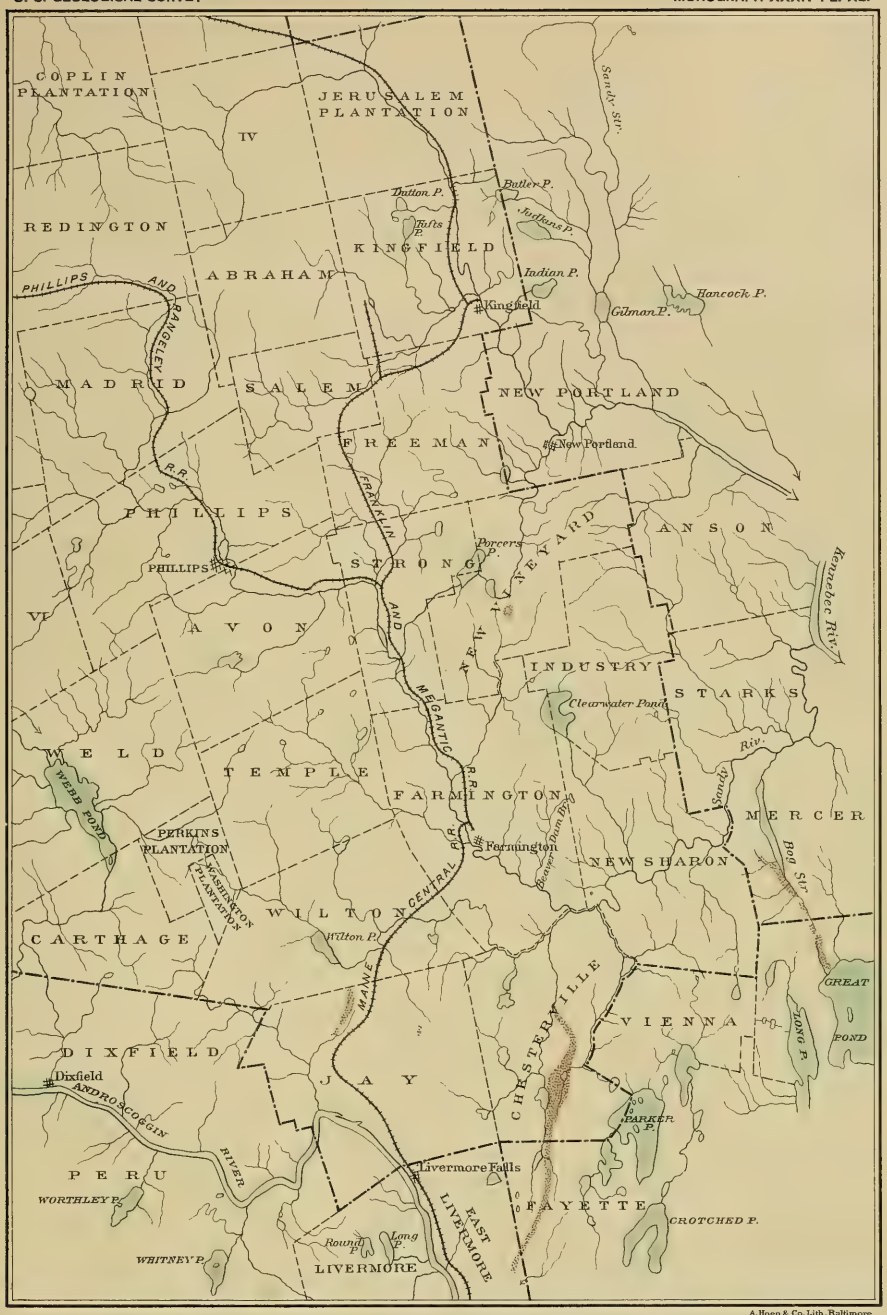
A. Hoen & Co. Lith. Baltimore.

MAP OF CUMBERLAND COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893



A. Hoen & Co. Lith. Baltimore.

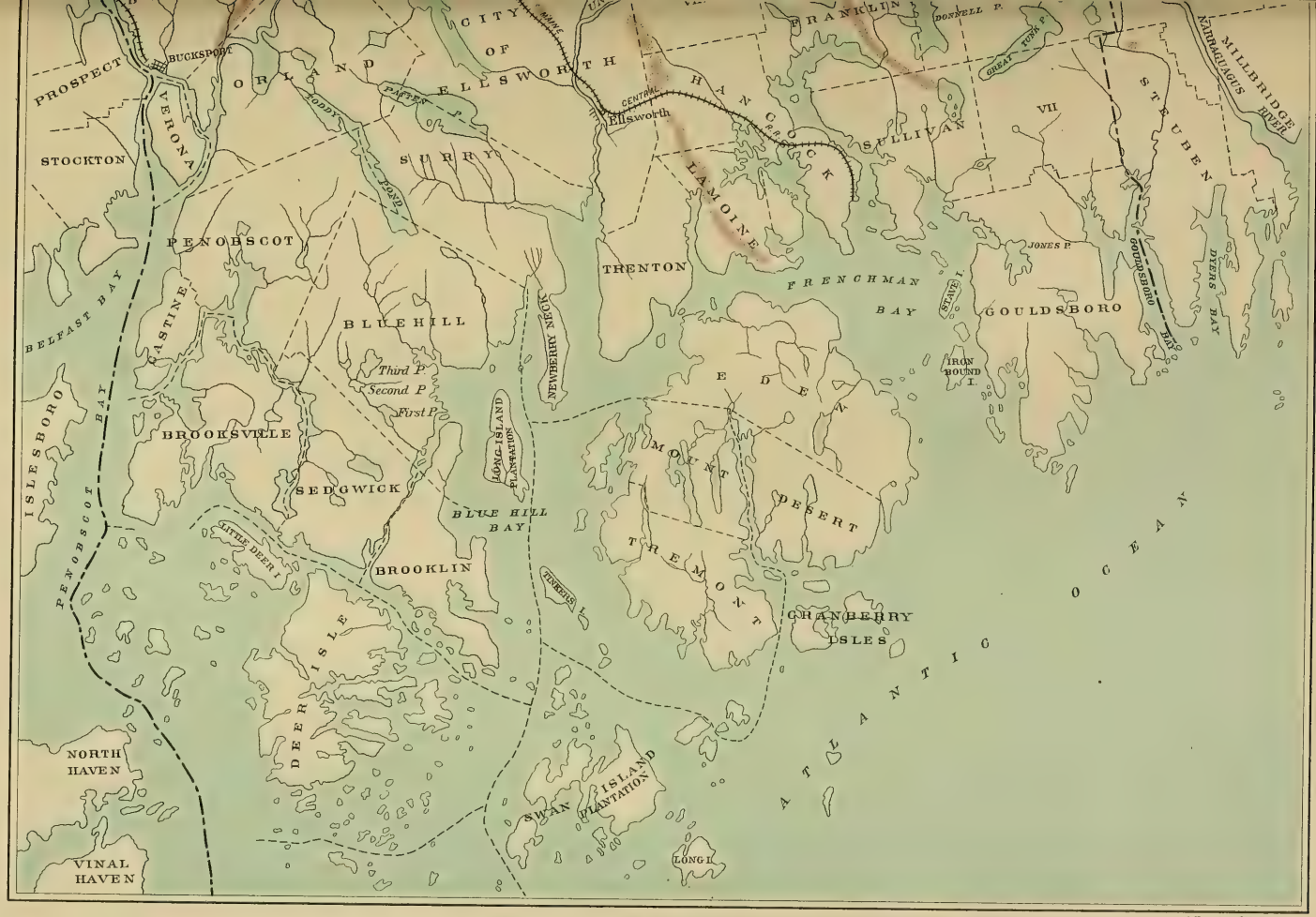
MAP OF FRANKLIN COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893


LOWELL
BURLINGTON
PASSADUMKEAG
Passadumkeag R.
Lords Br.
GREENBUSH
CENTRAL R.R.
GREENFIELD
MILFORD
Little
Buffalo Str.
Sunkhaze Str.
South Br.
West Br.
MAINE
RIVER
BRADLEY
Nichols Str.
Great Works Str.
AMHERST
Union R.
AURORA
EDDINGTON
NICHOLS P.
CLIFTON
BREWER
PENOBSCOT
DAVIS P.
MOUNT
HOLDEN
ORRINGTON
BREWER P.
DESERT
DEDHAM
OTIS
WALTHAM
EASTBROOK
ARIAVILLE
RIVER
East Branch
Middle Br.
Union R.
ROCKY P.
SPECTACLE P.
MOLASSES P.
Indian Str.
West Branch
Narraguagus R.
DEVEREAUX
Narraguagus
Burnham Br.
Gould Br.
Baker Brook Flowage
MOPANG L.
PLEASANT RIVER L.
SPRUCE MT. L.
S.W. Pond
BEDDINGTON
DEBLOIS
River
Machias
PISTOL LAKES
MACHIAS L.
THIRD L.
NICKATOUS LAKE
Machias Pond
FIFTH L.
Horseshoe L.
SABAO L.
West Branch
UPPER REEDS P.
BERRYFIELD
I
II
IV
V
XL
XLI
XLII
XXXIX
XXXVI
XXXV
XXXIV
XXXIII
XXXII
XXX
XXIX
XXVIII
XXIV
XXII
XXI
XVIII
XVI



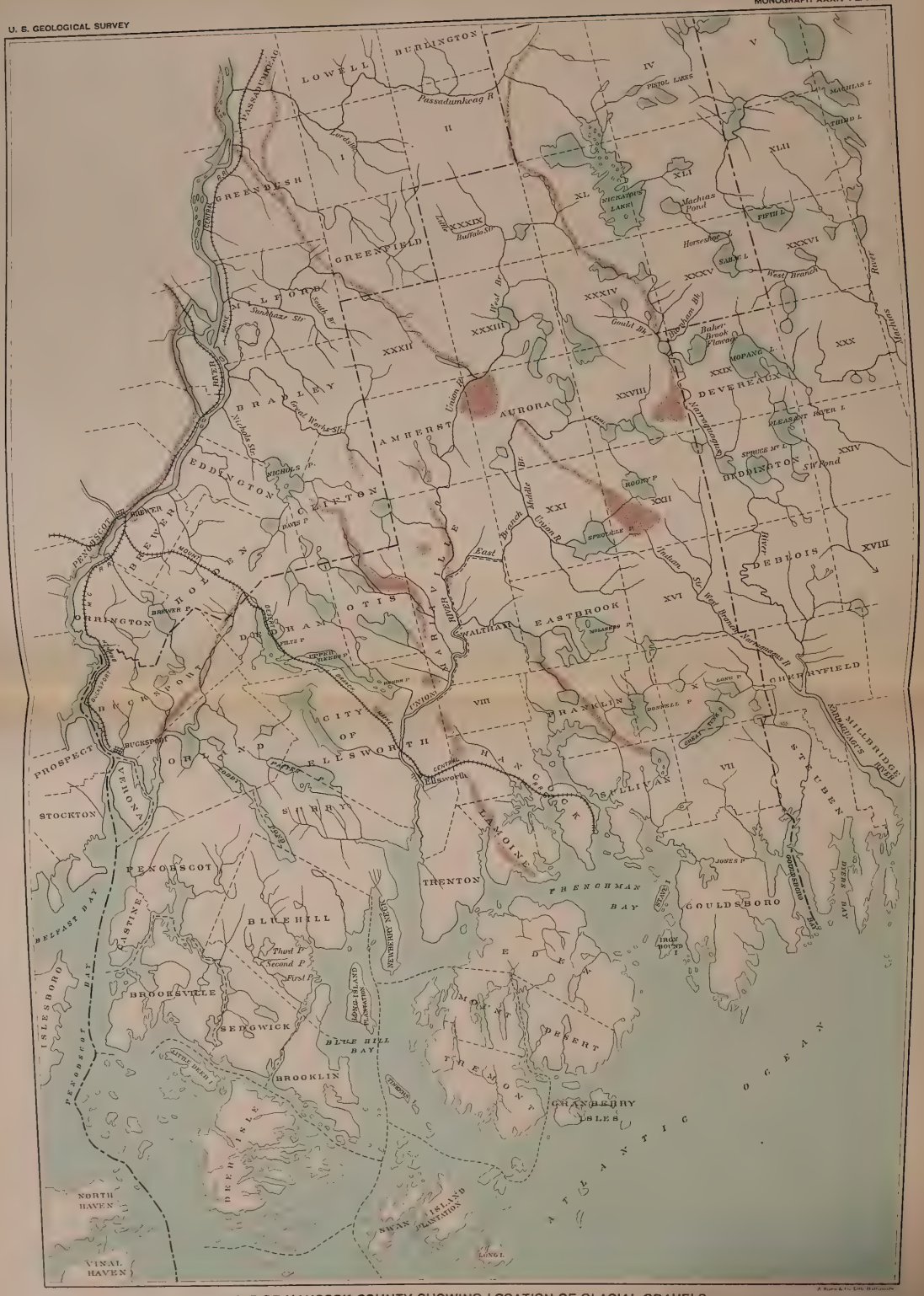
A. Hoen & Co. Lith. Baltimore.

MAP OF HANCOCK COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893

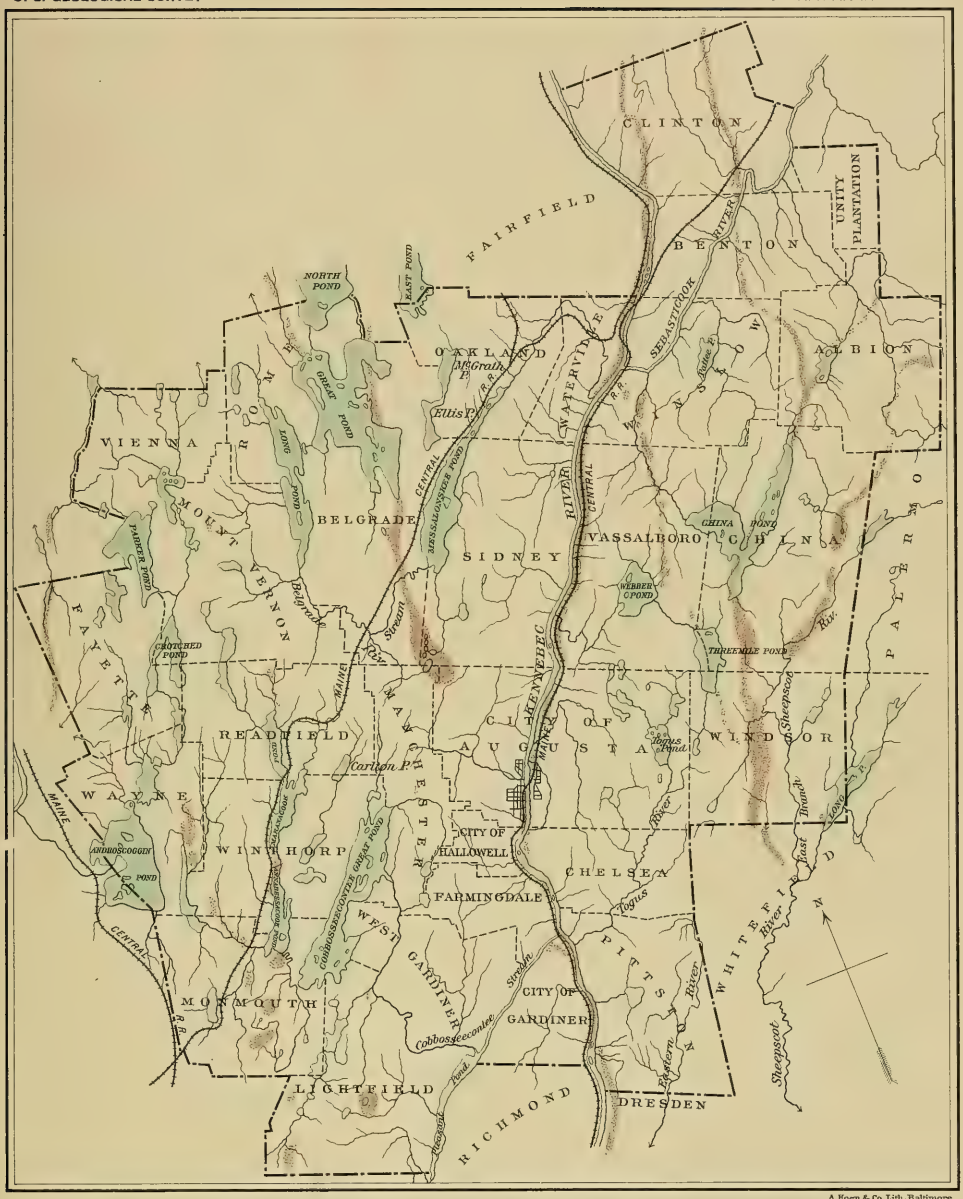


MAP OF HANCOCK COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

10 MILES

1893



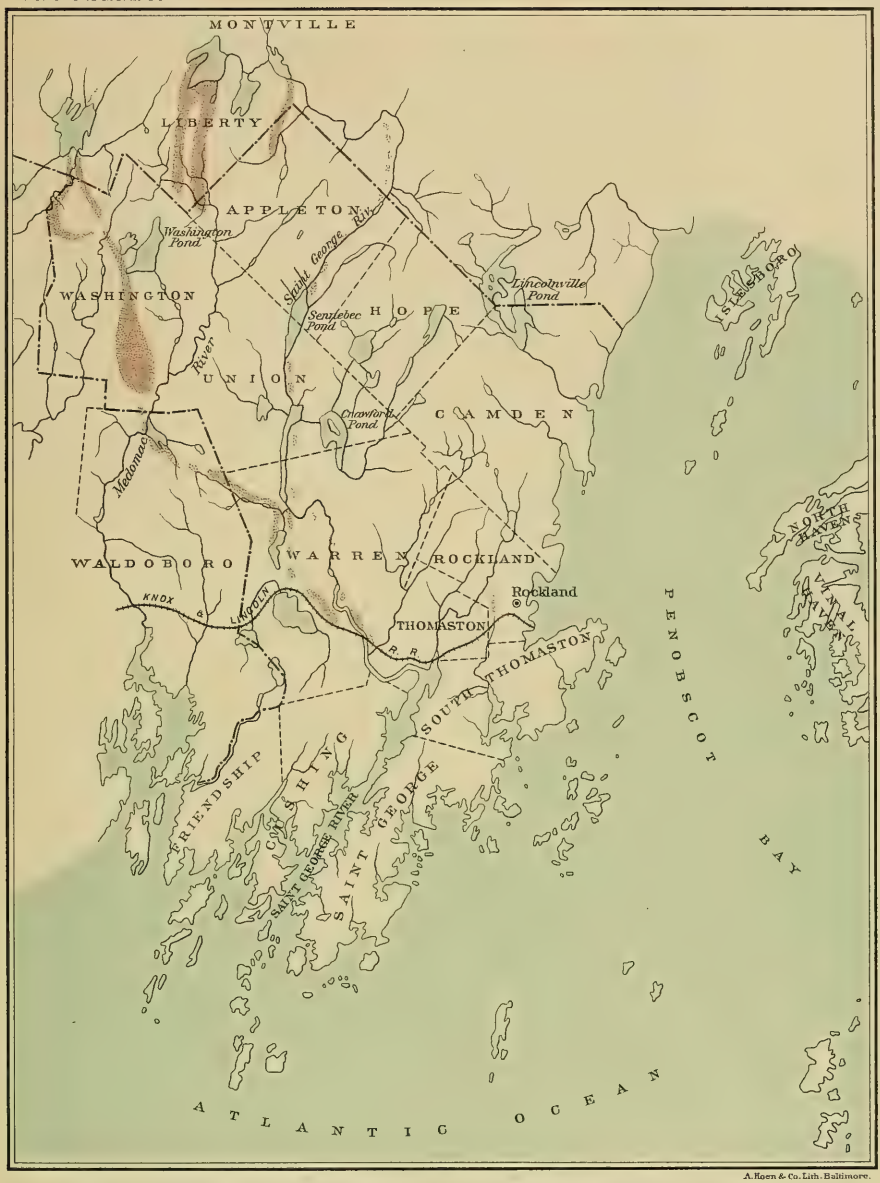
A. Hoen & Co. Lith. Baltimore.

MAP OF KENNEBEC COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 MILES

1893



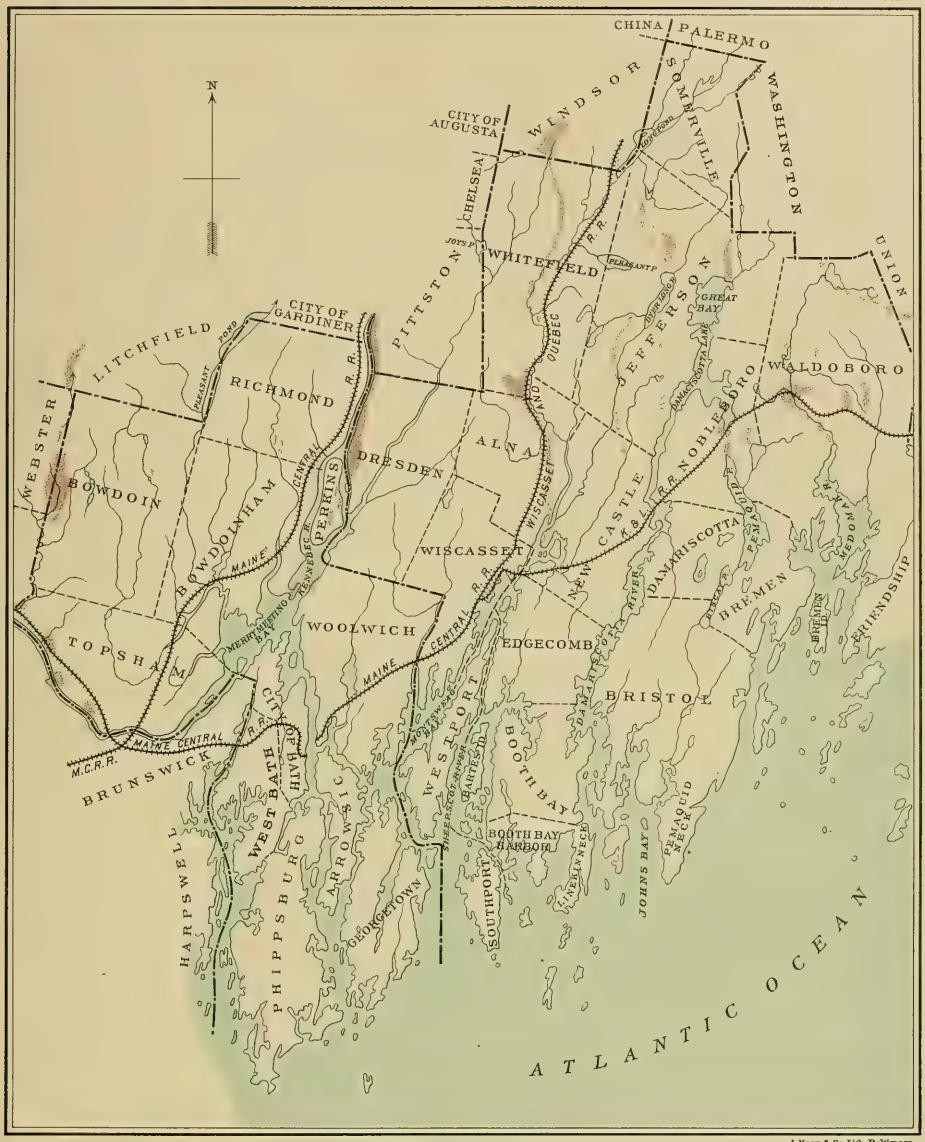
A. Hoen & Co. Lith. Baltimore.

MAP OF KNOX COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893



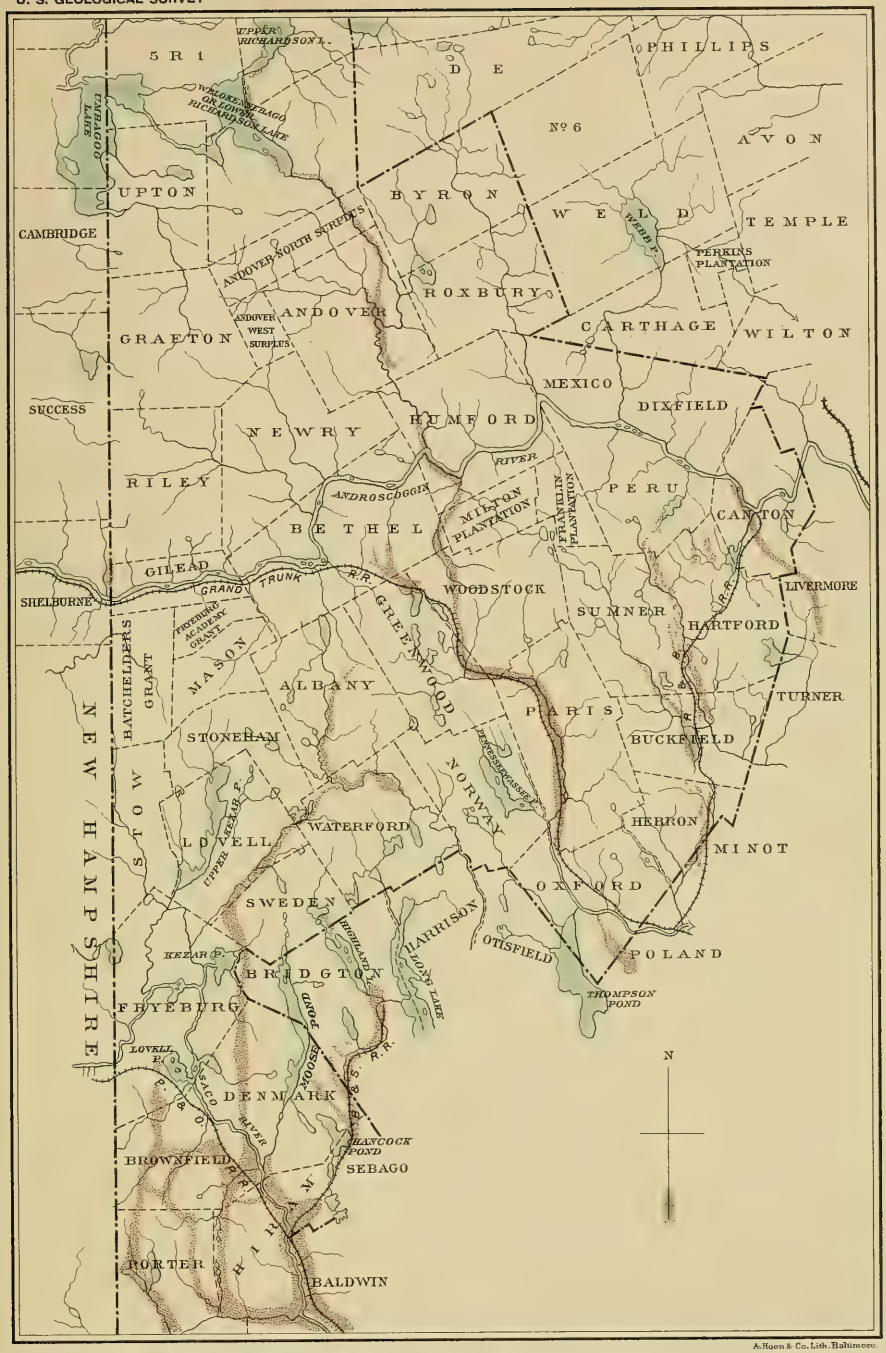
A. Hoen & Co. Lith. Baltimore.

MAP OF
LINCOLN AND SAGADAHOC COUNTIES SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893



A. Hoen & Co. Lith. Baltimore.

MAP OF OXFORD COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893

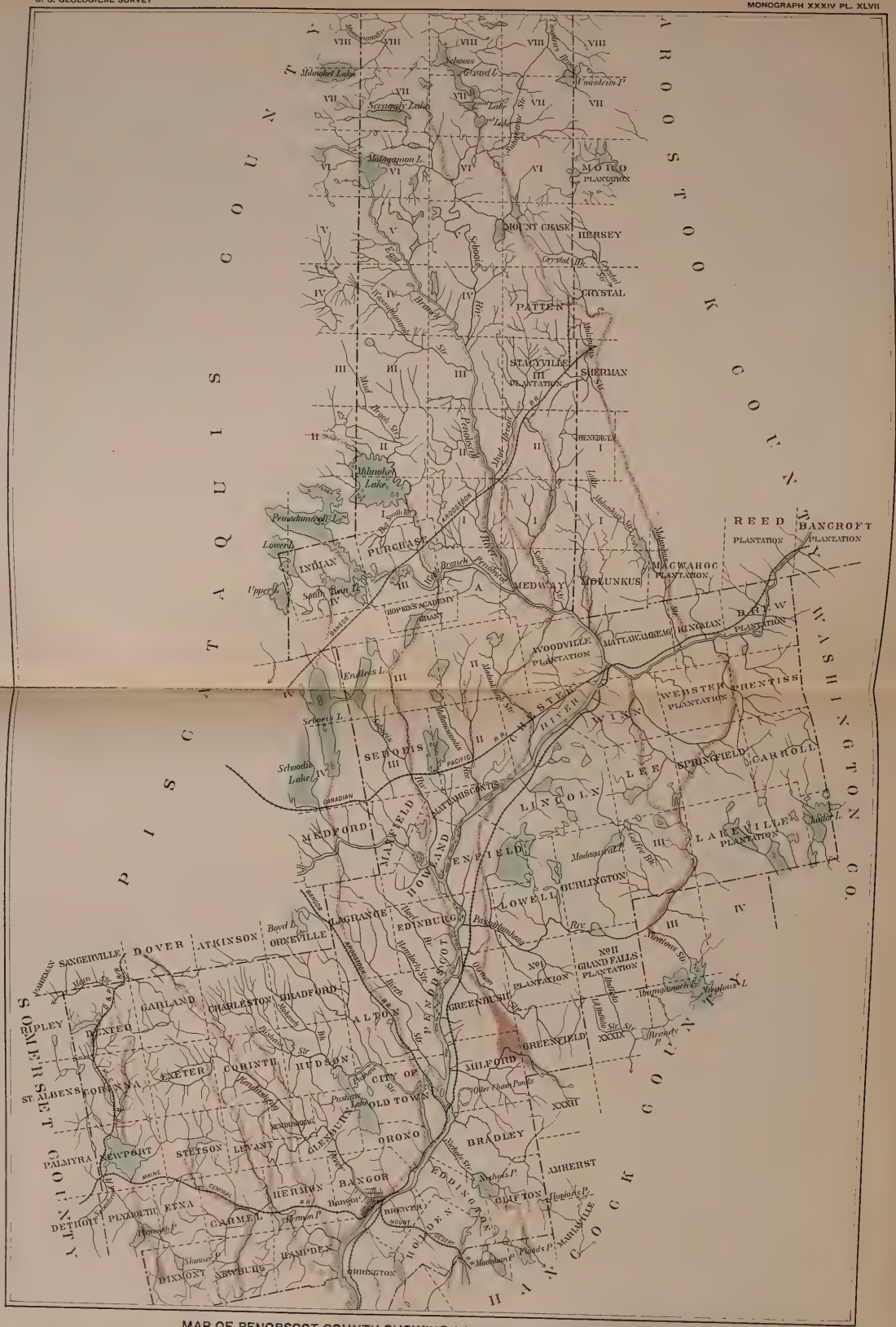

TAQUULS COUNTY
AROOSTOOK COUNTY
WASH
Milinoket Lake
Seboois Grand L.
Umcolcus P.
Scraggly Lake
2nd Lake
1st Lake
Matagamon L.
MORO PLANTATION
MOUNT CHASE
HERSEY
Crystal Br.
CRYSTAL
PATTEN
STACYVILLE PLANTATION
SHERMAN
BENEDICTA
Milinoket Lake
Pemadumcook L.
Lower L.
Upper L.
South Twin L.
INDIAN PURCHASE
HOPKINS ACADEMY GRANT
MEDWAY
MOLUNKUS
MACWAHOC PLANTATION
REED PLANTATION
BANCROFT PLANTATION
BREW PLANTATION
KINGMAN
MATTAWAMKEAG
WOODVILLE PLANTATION
Seboois River
Mud Brook
Penobscot River
Aroostook River
Molunkus Str.
Little Molunkus Str.
Wassataquoik Br.
East Br.
Mud Brook Str.
Mountain Str.
Umcolcus Brook
Manawanic Str.
Matagamon Str.
BANGOR

MAP OF PENOBSCOT COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893



MAP OF PENOBSCOT COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

S 0 5 10 15 MILES

1893

A. Hoen & Co. Lith. Baltimore

A. Hoen & Co. Lith. Baltimore

MAP OF PISCATAQUIS COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893

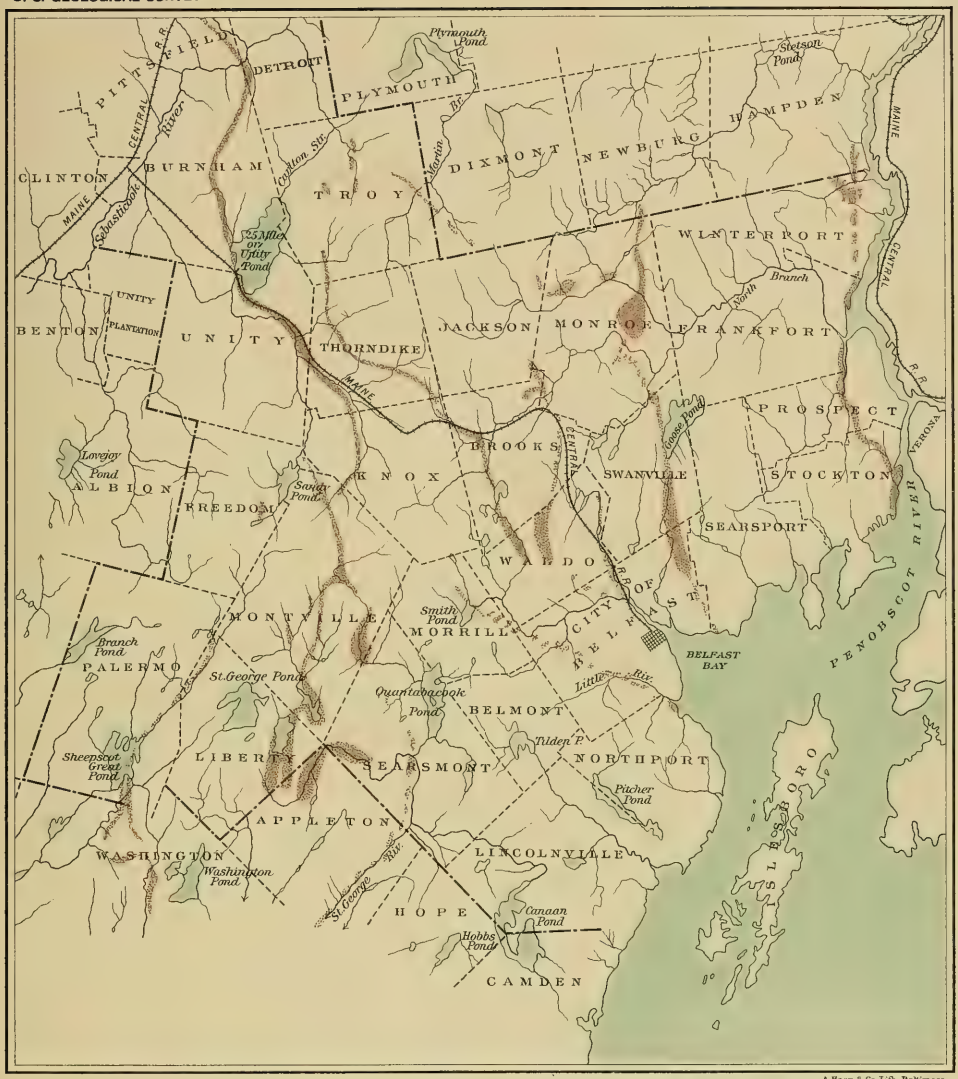
A. Boen & Co. Lith. Baltimore.

MAP OF SOMERSET COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893



A. Hoen & Co. Lith. Baltimore.

MAP OF WALDO COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893

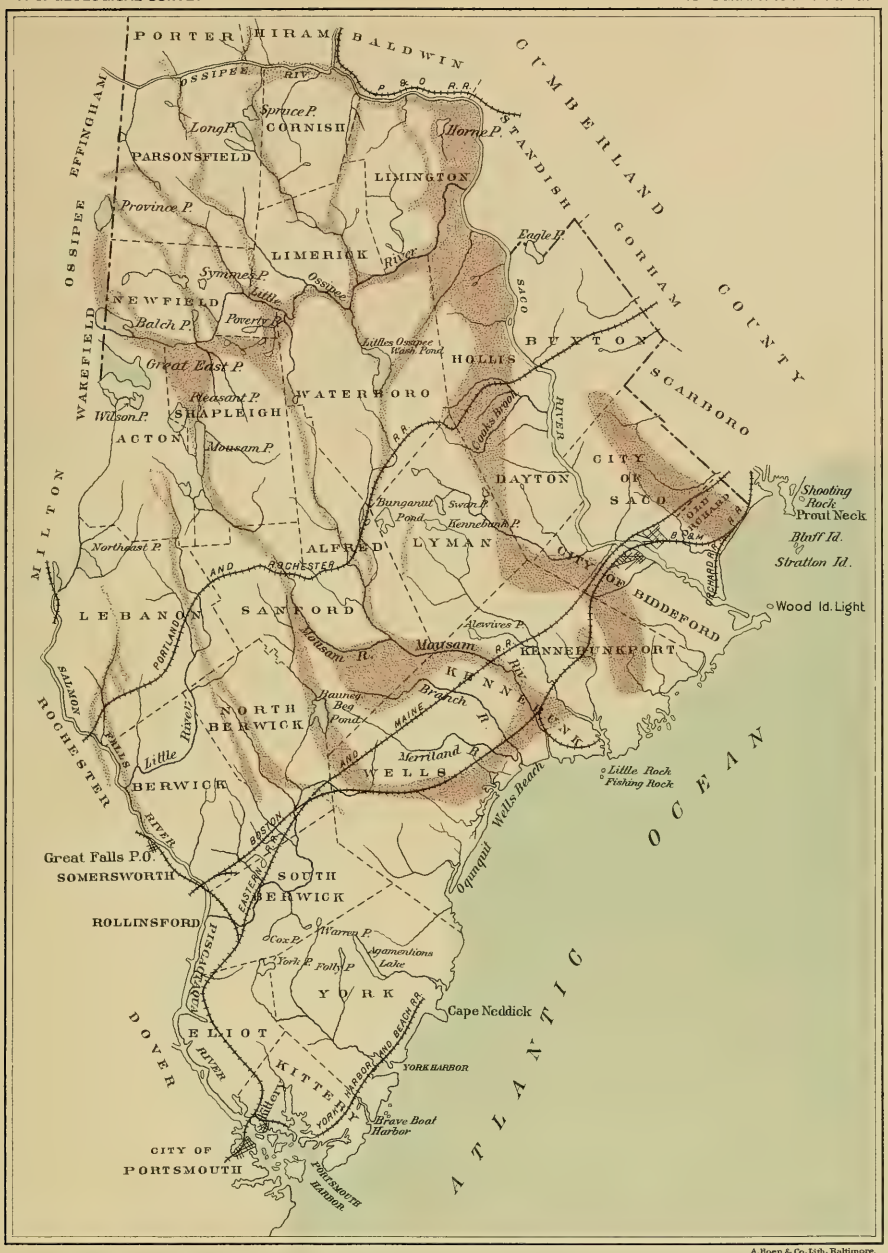
A. Hoen & Co. Lith. Baltimore.

MAP OF WASHINGTON COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 15 MILES

1893



A. Hoen & Co. Lith. Baltimore.

MAP OF YORK COUNTY SHOWING LOCATION OF GLACIAL GRAVELS

Scale

5 0 5 10 MILES

1893

INDEX.

M.

Y.

ADVERTISEMENT.

[Monograph XXXIV.]

The statute approved March 3, 1879, establishing the United States Geological Survey, contains the following provisions:

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

Except in those cases in which an extra number of any special memoir or report has been supplied to the Survey by special resolution of Congress or has been ordered by the Secretary of the Interior, this office has no copies for gratuitous distribution.

ANNUAL REPORTS.

I. First Annual Report of the United States Geological Survey, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 62 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884–'85, by J. W. Powell. 1885. 8°. xxix, 570 pp. 65 pl. and maps.

VII. Seventh Annual Report of the United States Geological Survey, 1885–'86, by J. W. Powell. 1888. 8°. xx, 656 pp. 71 pl. and maps.

VIII. Eighth Annual Report of the United States Geological Survey, 1886–'87, by J. W. Powell. 1889. 8°. 2 pt. xix, 474, xii pp., 53 pl. and maps; 1 prel. leaf, 475–1063 pp., 54–76 pl. and maps.

IX. Ninth Annual Report of the United States Geological Survey, 1887–'88, by J. W. Powell. 1889. 8°. xiii, 717 pp. 88 pl. and maps.

X. Tenth Annual Report of the United States Geological Survey, 1888–'89, by J. W. Powell. 1890. 8°. 2 pt. xv, 774 pp., 98 pl. and maps; viii, 123 pp.

XI. Eleventh Annual Report of the United States Geological Survey, 1889–'90, by J. W. Powell. 1891. 8°. 2 pt. xv, 757 pp., 66 pl. and maps; ix, 351 pp., 30 pl. and maps.

XII. Twelfth Annual Report of the United States Geological Survey, 1890–'91, by J. W. Powell. 1891. 8°. 2 pt., xiii, 675 pp., 53 pl. and maps; xviii, 576 pp., 146 pl. and maps.

XIII. Thirteenth Annual Report of the United States Geological Survey, 1891–'92, by J. W. Powell. 1893. 8°. 3 pt. vii, 240 pp., 2 maps; x, 372 pp., 105 pl. and maps; xi, 486 pp., 77 pl. and maps.

XIV. Fourteenth Annual Report of the United States Geological Survey, 1892–'93, by J. W. Powell. 1893. 8°. 2 pt. vi, 321 pp., 1 pl.; xx, 597 pp., 74 pl. and maps.

XV. Fifteenth Annual Report of the United States Geological Survey, 1893–'94, by J. W. Powell. 1895. 8°. xiv, 755 pp., 48 pl. and maps.

XVI. Sixteenth Annual Report of the United States Geological Survey, 1894–'95, Charles D. Walcott, Director. 1895. (Part I, 1896.) 8°. 4 pt. xxii, 910 pp., 117 pl. and maps; xix, 598 pp., 43 pl. and maps; xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl.

XVII. Seventeenth Annual Report of the United States Geological Survey, 1895–'96, Charles D. Walcott, Director. 1896. 8°. 3 pt. in 4 vol. xxii, 1076 pp., 67 pl. and maps; xxv, 864 pp., 113 pl. and maps; xxiii, 542 pp., 8 pl. and maps; iii, 543–1058 pp., 9–13 pl.

XVIII. Eighteenth Annual Report of the United States Geological Survey, 1896–'97, Charles D. Walcott, Director. 1897. (Parts II and III, 1898.) 8°. 5 pt. in 6 vol. 1–440 pp., 4 pl. and maps; i–v,

1–653 pp., 105 pl. and maps; i–v, 1–861 pp., 118 pl. and maps; i–x, 1–756 pp., 102 pl. and maps; i–xii, 1–642 pp., 1 pl.; 643–1400 pp.

XIX. Nineteenth Annual Report of the United States Geological Survey, 1897–'98, Charles D. Walcott, Director. 1898. 8°. 6 pt. in 7 vol.

MONOGRAPHS.

I. Lake Bonneville, by Grove Karl Gilbert. 1890. 4°. xx, 438 pp. 51 pl. 1 map. Price $1.50.

II. Tertiary History of the Grand Cañon District, with Atlas by Clarence E. Dutton, Capt., U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.00.

III. Geology of the Comstock Lode and the Washoe District, with Atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.00.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. The Copper-Bearing Rocks of Lake Superior, by Roland Duer Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. and maps. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William Morris Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph Story Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles Doolittle Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. 1 map. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1886. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. and maps. Price $1.75.

XII. Geology and Mining Industry of Leadville, Colorado, with Atlas, by Samuel Franklin Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

XIII. Geology of the Quicksilver Deposits of the Pacific Slope, with Atlas, by George F. Becker. 1888. 4°. xix, 486 pp. 7 pl. and atlas of 14 sheets folio. Price $2.00.

XIV. Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by John S. Newberry. 1888. 4°. xiv, 152 pp. 26 pl. Price $1.00.

XV. The Potomac or Younger Mesozoic Flora, by William Morris Fontaine. 1889. 4°. xiv, 377 pp. 180 pl. Text and plates bound separately. Price $2.50.

XVI. The Paleozoic Fishes of North America, by John Strong Newberry. 1889. 4°. 340 pp. 53 pl. Price $1.00.

XVII. The Flora of the Dakota Group, a Posthumous Work, by Leo Lesquereux. Edited by F. H. Knowlton. 1891. 4°. 400 pp. 66 pl. Price $1.10.

XVIII. Gasteropoda and Cephalopoda of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1891. 4°. 402 pp. 50 pl. Price $1.00.

XIX. The Penokee Iron-Bearing Series of Northern Wisconsin and Michigan, by Roland D. Irving and C. R. Van Hise. 1892. 4°. xix, 534 pp. Price $1.70.

XX. Geology of the Eureka District, Nevada, with an Atlas, by Arnold Hague. 1892. 4°. xvii, 419 pp. 8 pl. Price $5.25.

XXI. The Tertiary Rhynchophorous Coleoptera of the United States, by Samuel Hubbard Scudder. 1893. 4°. xi, 206 pp. 12 pl. Price 90 cents.

XXII. A Manual of Topographic Methods, by Henry Gannett, Chief Topographer. 1893. 4°. xiv, 300 pp. 18 pl. Price $1.00.

XXIII. Geology of the Green Mountains in Massachusetts, by Raphael Pumpelly, T. Nelson Dale, and J. E. Wolff. 1894. 4°. xiv, 206 pp. 23 pl. Price $1.30.

XXIV. Mollusca and Crustacea of the Miocene Formations of New Jersey, by Robert Parr Whitfield. 1894. 4°. 193 pp. 24 pl. Price 90 cents.

XXV. The Glacial Lake Agassiz, by Warren Upham. 1895. 4°. xxiv, 658 pp. 38 pl. Price $1.70.

XXVI. Flora of the Amboy Clays, by John Strong Newberry; a Posthumous Work, edited by Arthur Hollick. 1895. 4°. 260 pp. 58 pl. Price $1.00.

XXVII. Geology of the Denver Basin in Colorado, by Samuel Franklin Emmons, Whitman Cross, and George Homans Eldridge. 1896. 4°. 556 pp. 31 pl. Price $1.50.

XXVIII. The Marquette Iron-Bearing District of Michigan, with Atlas, by C. R. Van Hise and W. S. Bayley, including a Chapter on the Republic Trough, by H. L. Smyth. 1895. 4°. 608 pp. 35 pl. and atlas of 39 sheets folio. Price $5.75.

XXIX. Geology of Old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties, by Benjamin Kendall Emerson. 1898. 4°. xxi, 790 pp. 35 pl. Price $1.90.

XXX. Fossil Medusæ, by Charles Doolittle Walcott. 1898. 4°. ix, 201 pp. 47 pl. Price $1.50.

XXXI. Geology of the Aspen Mining District, Colorado, with Atlas, by Josiah Edward Spurr. 1898. 4°. xxxv, 260 pp. 43 pl. and atlas of 30 sheets folio. Price $3.60.

XXXII. Geology of the Yellowstone National Park, Part II, Descriptive Geology, Petrography, and Paleontology, by Arnold Hague, J. P. Iddings, W. Harvey Weed, Charles D. Walcott, G. H. Girty, T. W. Stanton, and F. H. Knowlton. 1899. 4°. xvii, 893 pp. 121 pl. Price ——.

XXXIII. Geology of the Narragansett Basin, by N. S. Shaler, J. B. Woodworth, and August F. Foerste. 1899. 4°. xx, 402 pp. 31 pl. Price ——.

XXXIV. The Glacial Gravels of Maine and their Associated Deposits, by George H. Stone. 1899. xiii, 499 pp. 52 pl. Price ——.

XXXV. The Later Extinct Floras of North America, by John Strong Newberry; edited by Arthur Hollick. 1898. 4°. xviii, 295 pp. 68 pl. Price $1.25.

In preparation:

XXXVI. The Crystal Falls Iron-Bearing District of Michigan, by J. Morgan Clements and Henry Lloyd Smyth; with a Chapter on the Sturgeon River Tongue, by William Shirley Bayley.

XXXVII. Flora of the Lower Coal Measures of Missouri, by David White.

XXXVIII. The Illinois Glacial Lobe, by Frank Leverett.

—Flora of the Laramie and Allied Formations, by Frank Hall Knowlton.

BULLETINS.

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross. with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl, Price 10 cents.

2. Gold and Silver Conversion Tables, giving the Coining Values of Troy Ounces of Fine Metal, etc., computed by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian, along the Meridian of 76° 30′, from Tompkins County, N. Y., to Bradford County, Pa., by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, in Geographic and Chronologic Order, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of Work done in the Washington Laboratory during the Fiscal Year 1883–'84. F. W. Clarke, Chief Chemist; T. M. Chatard, Assistant Chemist. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary Studies, by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Description of New Forms, by R. Ellsworth Call. Introduced by a Sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the Several States and Territories, with a Historical Sketch of the Territorial Changes, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, with Notes on the Geology of the District, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-Water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation; a Report on the Region between the Grand and Moreau Rivers, Dakota, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary Fossils and Recent Forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William Healey Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Maryland, by George Huntington Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-Water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles Doolittle Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel Hubbard Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Lists and Analyses of the Mineral Springs of the United States; a Preliminary Study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by J. S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the Relation of the Laramie Molluscan Fauna to that of the Succeeding Fresh-Water Eocene and Other Groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1886. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by J. S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1887. 8°. 10 pp. 4 pl. Price 5 cents.

41. On the Fossil Faunas of the Upper Devonian—the Genesee Section, New York, by Henry S. Williams. 1887. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1885–'86. F. W. Clarke, Chief Chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

43. Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson. 1887. 8°. 189 pp. 21 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

45. The Present Condition of Knowledge of the Geology of Texas, by Robert T. Hill. 1887. 8°. 94 pp. Price 10 cents.

46. Nature and Origin of Deposits of Phosphate of Lime, by R. A. F. Penrose, jr., with an Introduction by N. S. Shaler. 1888. 8°. 143 pp. Price 15 cents.

47. Analyses of Waters of the Yellowstone National Park, with an Account of the Methods of Analysis employed, by Frank Austin Gooch and James Edward Whitfield. 1888. 8°. 84 pp. Price 10 cents.

48. On the Form and Position of the Sea Level, by Robert Simpson Woodward. 1888. 8°. 88 pp. Price 10 cents.

49. Latitudes and Longitudes of Certain Points in Missouri, Kansas, and New Mexico, by Robert Simpson Woodward. 1889. 8°. 133 pp. Price 15 cents.

50. Formulas and Tables to Facilitate the Construction and Use of Maps, by Robert Simpson Woodward. 1889. 8°. 124 pp. Price 15 cents.

51. On Invertebrate Fossils from the Pacific Coast, by Charles Abiathar White. 1889. 8°. 102 pp. 14 pl. Price 15 cents.

52. Subaërial Decay of Rocks and Origin of the Red Color of Certain Formations, by Israel Cook Russell. 1889. 8°. 65 pp. 5 pl. Price 10 cents.

53. The Geology of Nantucket, by Nathaniel Southgate Shaler. 1889. 8°. 55 pp. 10 pl. Price 10 cents.

54. On the Thermo-Electric Measurement of High Temperatures, by Carl Barus. 1889. 8°. 313 pp., incl. 1 pl. 11 pl. Price 25 cents.

55. Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1886–'87. Frank Wigglesworth Clarke, Chief Chemist. 1889. 8°. 96 pp. Price 10 cents.

56. Fossil Wood and Lignite of the Potomac Formation, by Frank Hall Knowlton. 1889. 8°. 72 pp. 7 pl. Price 10 cents.

57. A Geological Reconnoissance in Southwestern Kansas, by Robert Hay. 1890. 8°. 49 pp. 2 pl. Price 5 cents.

58. The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by George Frederick Wright, with an Introduction by Thomas Chrowder Chamberlin. 1890. 8°. 112 pp., incl. 1 pl. 8 pl. Price 15 cents.

59. The Gabbros and Associated Rocks in Delaware, by Frederick D. Chester. 1890. 8°. 45 pp. 1 pl. Price 10 cents.

60. Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1887–'88. F. W. Clarke, Chief Chemist. 1890. 8°. 174 pp. Price 15 cents.

61. Contributions to the Mineralogy of the Pacific Coast, by William Harlow Melville and Waldemar Lindgren. 1890. 8°. 40 pp. 3 pl. Price 5 cents.

62. The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, a Contribution to the Subject of Dynamic Metamorphism in Eruptive Rocks, by George Huntington Williams, with an Introduction by Roland Duer Irving. 1890. 8°. 241 pp. 16 pl. Price 30 cents.

63. A Bibliography of Paleozoic Crustacea from 1698 to 1889, including a List of North American Species and a Systematic Arrangement of Genera, by Anthony W. Vogdes. 1890. 8°. 177 pp. Price 15 cents.

64. A Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1888–'89. F. W. Clarke, Chief Chemist. 1890. 8°. 60 pp. Price 10 cents.

65. Stratigraphy of the Bituminous Coal Field of Pennsylvania, Ohio, and West Virginia, by Israel C. White. 1891. 8°. 212 pp. 11 pl. Price 20 cents.

66. On a Group of Volcanic Rocks from the Tewan Mountains, New Mexico, and on the Occurrence of Primary Quartz in Certain Basalts, by Joseph Paxson Iddings. 1890. 8°. 34 pp. Price 5 cents.

67. The Relations of the Traps of the Newark System in the New Jersey Region, by Nelson Horatio Darton. 1890. 8°. 82 pp. Price 10 cents.

68. Earthquakes in California in 1889, by James Edward Keeler. 1890. 8°. 25 pp. Price 5 cents.

69. A Classed and Annotated Biography of Fossil Insects, by Samuel Howard Scudder. 1890. 8°. 101 pp. Price 15 cents.

70. A Report on Astronomical Work of 1889 and 1890, by Robert Simpson Woodward. 1890. 8°. 79 pp. Price 10 cents.

71. Index to the Known Fossil Insects of the World, including Myriapods and Arachnids, by Samuel Hubbard Scudder. 1891. 8°. 744 pp. Price 50 cents.

72. Altitudes between Lake Superior and the Rocky Mountains, by Warren Upham. 1891. 8°. 229 pp. Price 20 cents.

73. The Viscosity of Solids, by Carl Barus. 1891. 8°. xii, 139 pp. 6 pl. Price 15 cents.

74. The Minerals of North Carolina, by Frederick Augustus Genth. 1891. 8°. 119 pp. Price 15 cents.

75. Record of North American Geology for 1887 to 1889, inclusive, by Nelson Horatio Darton. 1891. 8°. 173 pp. Price 15 cents.

76. A Dictionary of Altitudes in the United States (Second Edition), compiled by Henry Gannett, Chief Topographer. 1891. 8°. 393 pp. Price 25 cents.

77. The Texan Permian and its Mesozoic Types of Fossils, by Charles A. White. 1891. 8°. 51 pp. 4 pl. Price 10 cents.

78. A Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1889–'90. F. W. Clarke, Chief Chemist. 1891. 8°. 131 pp. Price 15 cents.

79. A Late Volcanic Eruption in Northern California and its Peculiar Lava, by J. S. Diller.

80. Correlation Papers—Devonian and Carboniferous, by Henry Shaler Williams. 1891. 8°. 279 pp. Price 20 cents.

81. Correlation Papers—Cambrian, by Charles Doolittle Walcott. 1891. 8°. 547 pp. 3 pl. Price 25 cents.

82. Correlation Papers—Cretaceous, by Charles A. White. 1891. 8°. 273 pp. 3 pl. Price 20 cents.

83. Correlation Papers—Eocene, by William Bullock Clark. 1891. 8°. 173 pp. 2 pl. Price 15 cents.

84. Correlation Papers—Neocene, by W. H. Dall and G. D. Harris. 1892. 8°. 349 pp. 3 pl. Price 25 cents.

85. Correlation Papers—The Newark System, by Israel Cook Russell. 1892. 8°. 344 pp. 13 pl. Price 25 cents.

86. Correlation Papers—Archean and Algonkian, by C. R. Van Hise. 1892. 8°. 549 pp. 12 pl. Price 25 cents.

87. A Synopsis of American Fossil. Brachiopoda, including Bibliography and Synonymy, by Charles Schuchert. 1897. 8°. 464 pp. Price 30 cents.

88. The Cretaceous Foraminifera of New Jersey, by Rufus Mather Bagg, Jr. 1898. 8°. 89 pp. 6 pl. Price 10 cents.

89. Some Lava Flows of the Western Slope of the Sierra Nevada, California, by F. Leslie Ransome. 1898. 8°. 74 pp. 11 pl. Price 15 cents.

90. A Report of Work done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1890–'91. F. W. Clarke, Chief Chemist. 1892. 8°. 77 pp. Price 10 cents.

91. Record of North American Geology for 1890, by Nelson Horatio Darton. 1891. 8°. 88 pp. Price 10 cents.

92. The Compressibility of Liquids, by Carl Barus. 1892. 8°. 96 pp. 29 pl. Price 10 cents.

93. Some Insects of Special Interest from Florissant, Colorado, and Other Points in the Tertiaries of Colorado and Utah, by Samuel Hubbard Scudder. 1892. 8°. 35 pp. 3 pl. Price 5 cents.

94. The Mechanism of Solid Viscosity, by Carl Barus. 1892. 8°. 138 pp. Price 15 cents.

95. Earthquakes in California in 1890 and 1891, by Edward Singleton Holden. 1892. 8°. 31 pp. Price 5 cents.

96. The Volume Thermodynamics of Liquids, by Carl Barus. 1892. 8°. 100 pp. Price 10 cents.

97. The Mesozoic Echinodermata of the United States, by W. B. Clark. 1893. 8°. 207 pp. 50 pl. Price 20 cents.

98. Flora of the Outlying Carboniferous Basins of Southwestern Missouri, by David White. 1893. 8°. 139 pp. 5 pl. Price 15 cents.

99. Record of North American Geology for 1891, by Nelson Horatio Darton. 1892. 8°. 73 pp. Price 10 cents.

100. Bibliography and Index of the Publications of the U. S. Geological Survey, 1879–1892, by Philip Creveling Warman. 1893. 8°. 495 pp. Price 25 cents.

101. Insect Fauna of the Rhode Island Coal Field, by Samuel Hubbard Scudder. 1893. 8°. 27 pp. 2 pl. Price 5 cents.

102. A Catalogue and Bibliography of North American Mesozoic Invertebrata, by Cornelius Breckinridge Boyle. 1892. 8°. 315 pp. Price 25 cents.

103. High Temperature Work in Igneous Fusion and Ebullition, chiefly in Relation to Pressure, by Carl Barus. 1893. 8°. 57 pp. 9 pl. Price 10 cents.

104. Glaciation of the Yellowstone Valley north of the Park, by Walter Harvey Weed. 1893. 8°. 41 pp. 4 pl. Price 5 cents.

105. The Laramie and the Overlying Livingstone Formation in Montana, by Walter Harvey Weed, with Report on Flora, by Frank Hall Knowlton. 1893. 8°. 68 pp. 6 pl. Price 10 cents.

106. The Colorado Formation and its Invertebrate Fauna, by T. W. Stanton. 1893. 8°. 288 pp. 45 pl. Price 20 cents.

107. The Trap Dikes of the Lake Champlain Region, by James Furman Kemp and Vernon Freeman Marsters. 1893. 8°. 62 pp. 4 pl. Price 10 cents.

108. A Geological Reconnoissance in Central Washington, by Israel Cook Russell. 1893. 8°. 108 pp. 12 pl. Price 15 cents.

109. The Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and their Contact Phenomena, by William Shirley Bayley. 1893. 8°. 121 pp. 16 pl. Price 15 cents.

110. The Paleozoic Section in the Vicinity of Three Forks, Montana, by Albert Charles Peale. 893. 8°. 56 pp. 6 pl. Price 10 cents.

111. Geology of the Big Stone Gap Coal Fields of Virginia and Kentucky, by Marius R. Campbell. 1893. 8°. 106 pp. 6 pl. Price 15 cents.

112. Earthquakes in California in 1892, by Charles D. Perrine. 1893. 8°. 57 pp. Price 10 cents.

113. A Report of Work done in the Division of Chemistry during the Fiscal Years 1891–'92 and 1892–'93. F. W. Clarke, Chief Chemist. 1893. 8°. 115 pp. Price 15 cents.

114. Earthquakes in California in 1893, by Charles D. Perrine. 1894. 8°. 23 pp. Price 5 cents.

115. A Geographic Dictionary of Rhode Island, by Henry Gannett. 1894. 8°. 31 pp. Price 5 cents.

116. A Geographic Dictionary of Massachusetts, by Henry Gannett. 1894. 8°. 126 pp. Price 15 cents.

117. A Geographic Dictionary of Connecticut, by Henry Gannett. 1894. 8°. 67 pp. Price 10 cents.

118. A Geographic Dictionary of New Jersey, by Henry Gannett. 1894. 8°. 131 pp. Price 15 cents.

119. A Geological Reconnoissance in Northwest Wyoming, by George Homans Eldridge. 1894. 8°. 72 pp. Price 10 cents.

120. The Devonian System of Eastern Pennyslvania and New York, by Charles S. Prosser. 1894. 8°. 81 pp. 2 pl. Price 10 cents.

121. A Bibliography of North American Paleontology, by Charles Rollin Keyes. 1894. 8°. 251 pp. Price 20 cents.

122. Results of Primary Triangulation, by Henry Gannett. 1894. 8°. 412 pp. 17 pl. Price 25 cents.

123. A Dictionary of Geographic Positions, by Henry Gannett. 1895. 8°. 183 pp. 1 pl. Price 15 cents.

124. Revision of North American Fossil Cockroaches, by Samuel Hubbard Scudder. 1895. 8°. 176 pp. 12 pl. Price 15 cents.

125. The Constitution of the Silicates, by Frank Wigglesworth Clarke. 1895. 8°. 109 pp. Price 15 cents.

126. A Mineralogical Lexicon of Franklin, Hampshire, and Hampden counties, Massachusetts, by Benjamin Kendall Emerson. 1895. 8°. 180 pp. 1 pl. Price 15 cents.

127. Catalogue and Index of Contributions to North American Geology, 1732–1891, by Nelson Horatio Darton. 1896. 8°. 1045 pp. Price 60 cents.

128. The Bear River Formation and its Characteristic Fauna, by Charles A. White. 1895. 8°. 108 pp. 11 pl. Price 15 cents.

129. Earthquakes in California in 1894, by Charles D. Perrine. 1895. 8°. 25 pp. Price 5 cents.

130. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for 1892 and 1893, by Fred Boughton Weeks. 1896. 8°. 210 pp. Price 20 cents.

131. Report of Progress of the Division of Hydrography for the Calendar Years 1893 and 1894, by Frederick Haynes Newell, Topographer in Charge. 1895. 8°. 126 pp. Price 15 cents.

132. The Disseminated Lead Ores of Southeastern Missouri, by Arthur Winslow. 1896. 8°. 31 pp. Price 5 cents.

133. Contributions to the Cretaceous Paleontology of the Pacific Coast: The Fauna of the Knoxville Beds, by T. W. Stanton. 1895. 8°. 132 pp. 20 pl. Price 15 cents.

134. The Cambrian Rocks of Pennsylvania, by Charles Doolittle Walcott. 1896. 8°. 43 pp. 15 pl. Price 5 cents.

135. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1894, by F. B. Weeks. 1896. 8°. 141 pp. Price 15 cents.

136. Volcanic Rocks of South Mountain, Pennsylvania, by Florence Bascom. 1896. 8°. 124 pp. 28 pl. Price 15 cents.

137. The Geology of the Fort Riley Military Reservation and Vicinity, Kansas, by Robert Hay. 1896. 8°. 35 pp. 8 pl. Price 5 cents.

138. Artesian-Well Prospects in the Atlantic Coastal Plain Region, by N. H. Darton. 1896. 8°. 228 pp. 19 pl. Price 20 cents.

139. Geology of the Castle Mountain Mining District, Montana, by W. H. Weed and L. V. Pirsson. 1896. 8°. 164 pp. 17 pl. Price 15 cents.

140. Report of Progress of the Division of Hydrography for the Calendar Year 1895, by Frederick Haynes Newell, Hydrographer in Charge. 1896. 8°. 356 pp. Price 25 cents.

141. The Eocene Deposits of the Middle Atlantic Slope in Delaware, Maryland, and Virginia, by William Bullock Clark. 1896. 8°. 167 pp. 40 pl. Price 15 cents.

142. A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana, by T. Wayland Vaughan. 1896. 8°. 65 pp. 4 pl. Price 10 cents.

143. A Bibliography of Clays and the Ceramic Arts, by John C. Branner. 1896. 8°. 114 pp. Price 15 cents.

144. The Moraines of the Missouri Coteau and their Attendant Deposits, by James Edward Todd. 1896. 8°. 71 pp. 21 pl. Price 10 cents.

145. The Potomac Formation in Virginia, by W. M. Fontaine. 1896. 8°. 149 pp. 2 pl. Price 15 cents.

146. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1895, by F. B. Weeks. 1896. 8°. 130 pp. Price 15 cents.

147. Earthquakes in California in 1895, by Charles D. Perrine, Assistant Astronomer in Charge of Earthquake Observations at the Lick Observatory. 1896. 8°. 23 pp. Price 5 cents.

148. Analyses of Rocks, with a Chapter on Analytical Methods, Laboratory of the United States Geological Survey, 1880 to 1896, by F. W. Clarke and W. F. Hillebrand. 1897. 8°. 306 pp. Price 20 cents.

149. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1896, by Fred Boughton Weeks. 1897. 8°. 152 pp. Price 15 cents.

150. The Educational Series of Rock Specimens collected and distributed by the United States Geological Survey, by Joseph Silas Diller. 1898. 8°. 398 pp. 47 pl. Price 25 cents.

151. The Lower Cretaceous Gryphæas of the Texas Region, by R. T. Hill and T. Wayland Vaughan. 1898. 8°. 139 pp. 25 pl. Price 15 cents.

152. A Catalogue of the Cretaceous and Tertiary Plants of North America, by F. H. Knowlton. 1898. 8°. 247 pp. Price 20 cents.

153. A Bibliographic Index of North American Carboniferous Invertebrates, by Stuart Weller. 1898. 8°. 653 pp. Price 35 cents.

154. A Gazetteer of Kansas, by Henry Gannett. 1898. 8°. 246 pp. 6 pl. Price 20 cents.

155. Earthquakes in California in 1896 and 1897, by Charles D. Perrine, Assistant Astronomer in Charge of Earthquake Observations at the Lick Observatory. 1898. 8°. 47 pp. Price 5 cents.

156. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1897, by Fred Boughton Weeks. 1898. 8°. 130 pp. Price 15 cents.

160. A Dictionary of Altitudes in the United States (Third Edition), compiled by Henry Gannett. 1899. 8°. 775 pp. Price 40 cents.

161. Earthquakes in California in 1898, by Charles D. Perrine, Assistant Astronomer in Charge of Earthquake Observations at the Lick Observatory. 1899. 8°. 31 pp. 1 pl. Price 5 cents.

In preparation:

157. The Gneisses, Gabbro-Schists, and Associated Rocks of Southeastern Minnesota, by C. W. Hall.

158. The Moraines of southeastern South Dakota and their Attendant Deposits, by J. E. Todd.

159. The Geology of Eastern Berkshire County, Massachusetts, by B. K. Emerson.

WATER-SUPPLY AND IRRIGATION PAPERS.

By act of Congress approved June 11, 1896, the following provision was made:

"*Provided*, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed one hundred pages in length and five thousand copies in number; one thousand copies of which shall be for the official use of the Geological Survey, one thousand five hundred copies shall be delivered to the Senate, and two thousand five hundred copies shall be delivered to the House of Representatives, for distribution."

Under this law the following papers have been issued:

1. Pumping Water for Irrigation, by Herbert M. Wilson. 1896. 8°. 57 pp. 9 pl.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis. 1897. 8°. 97 pp. 31 pl.
3. Sewage Irrigation, by George W. Rafter. 1897. 8°. 100 pp. 4 pl.
4. A Reconnoissance in Southeastern Washington, by Israel Cook Russell. 1897. 8°. 96 pp. 7 pl.
5. Irrigation Practice on the Great Plains, by Elias Branson Cowgill. 1897. 8°. 39 pp. 12 pl.
6. Underground Waters of Southwestern Kansas, by Erasmus Haworth. 1897. 8°. 65 pp. 12 pl.
7. Seepage Waters of Northern Utah, by Samuel Fortier. 1897. 8°. 50 pp. 3 pl.
8. Windmills for Irrigation, by Edward Charles Murphy. 1897. 8°. 49 pp. 8 pl.
9. Irrigation near Greeley, Colorado, by David Boyd. 1897. 8°. 90 pp. 21 pl.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 8°. 51 pp. 11 pl.
11. River Heights for 1896, by Arthur P. Davis. 1897. 8°. 100 pp.
12. Water Resources of Southeastern Nebraska, by Nelson H. Darton. 1898. 8°. 55 pp. 21 pl.
13. Irrigation Systems in Texas, by William Ferguson Hutson. 1898. 8°. 67 pp. 10 pl.
14. New Tests of Certain Pumps and Water-Lifts used in Irrigation, by Ozni P. Hood. 1889. 8°. 91 pp. 1 pl.
15. Operations at River Stations, 1897, Part I. 1898. 8°. 100 pp.
16. Operations at River Stations, 1897, Part II. 1898. 8°. 101–200 pp.
17. Irrigation near Bakersfield, California, by C. E. Grunsky. 1898. 8°. 96 pp. 16 pl.
18. Irrigation near Fresno, California, by C. E. Grunsky. 1898. 8°. 94 pp. 14 pl.
19. Irrigation near Merced, California, by C. E. Grunsky. 1899. 8°. 59 pp. 11 pl.
20. Experiments with Windmills, by T. O. Perry. 1899. 8°. 97 pp. 12 pl.

21. Wells of Northern Indiana, by Frank Leverett. 1899. 8°. 82 pp. 2 pl.
22. Sewage Irrigation, Part II, by George W. Rafter. 1899. 8°. 100 pp. 7 pl.
23. Water-Right Problems of Bighorn Mountains, by Elwood Mead. 1899. 8°. 62 pp. 7 pl.
24. Water Resources of the State of New York, Part I, by George W. Rafter. 1899. 8°. 99 pp. 13 pl.
25. Water Resources of the State of New York, Part II, by George W. Rafter. 1899. 8°. 101–200 pp. 12 pl.
26. Wells of Southern Indiana (Continuation of No. 21), by Frank Leverett. 1899. 8°. 64 pp.
27. Operations at River Stations, 1898, Part I. 1899. 8°. 100 pp.
28. Operations at River Stations, 1898, Part II. 1899. 8°. 101–200 pp.

In preparation:
29. Wells and Windmills in Nebraska, by Edwin H. Barbour.
30. Water Resources of the Lower Peninsula of Michigan, by Alfred C. Lane.

TOPOGRAPHIC MAP OF THE UNITED STATES.

When, in 1882, the Geological Survey was directed by law to make a geologic map of the United States there was in existence no suitable topographic map to serve as a base for the geologic map. The preparation of such a topographic map was therefore immediately begun. About one-fifth of the area of the country, excluding Alaska, has now been thus mapped. The map is published in atlas sheets, each sheet representing a small quadrangular district, as explained under the next heading. The separate sheets are sold at 5 cents each when fewer than 100 copies are purchased, but when they are ordered in lots of 100 or more copies, whether of the same sheet or of different sheets, the price is 2 cents each. The mapped areas are widely scattered, nearly every State being represented. About 900 sheets have been engraved and printed; they are tabulated by States in the Survey's "List of Publications," a pamphlet which may be had on application.

The map sheets represent a great variety of topographic features, and with the aid of descriptive text they can be used to illustrate topographic forms. This has led to the projection of an educational series of topographic folios, for use wherever geography is taught in high schools, academies, and colleges. Of this series the first folio has been issued, viz:

1. Physiographic types, by Henry Gannett, 1898, folio, consisting of the following sheets and 4 pages of descriptive text: Fargo (N. Dak.-Minn.), a region in youth; Charleston (W. Va.), a region in maturity; Caldwell (Kans.), a region in old age; Palmyra (Va.), a rejuvenated region; Mount Shasta, (Cal.), a young volcanic mountain; Eagle (Wis.), moraines; Sun Prairie (Wis.), drumlins; Donaldsonville (La.), river flood plains; Boothbay (Me.), a fiord coast; Atlantic City (N. J.), a barrier-beach coast.

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geologic Atlas of the United States is the final form of publication of the topographic and geologic maps. The atlas is issued in parts, progressively as the surveys are extended, and is designed ultimately to cover the entire country.

Under the plan adopted the entire area of the country is divided into small rectangular districts (designated *quadrangles*), bounded by certain meridians and parallels. The unit of survey is also the unit of publication, and the maps and descriptions of each rectangular district are issued as a folio of the Geologic Atlas.

Each folio contains topographic, geologic, economic, and structural maps, together with textual descriptions and explanations, and is designated by the name of a principal town or of a prominent natural feature within the district.

Two forms of issue have been adopted, a "library edition" and a "field edition." In both the sheets are bound between heavy paper covers, but the library copies are permanently bound, while the sheets and covers of the field copies are only temporarily wired together.

Under the law a copy of each folio is sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Prepayment is obligatory. The folios ready for distribution are listed below.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
1	Livingston	Montana	110°–111°	45°–46°	3,354	25
2	Ringgold	Georgia Tennessee	85°–85° 30′	34° 30′–35°	980	25
3	Placerville	California	120° 30′–121°	38° 30′–39°	932	25
4	Kingston	Tennessee	84° 30′–85°	35° 30′–36°	969	25
5	Sacramento	California	121°–121° 30′	38° 30′–39°	932	25
6	Chattanooga	Tennessee	85°–85° 30′	35°–35° 30′	975	25
7	Pikes Peak (out of stock)	Colorado	105°–105° 30′	38° 30′–39°	932	25
8	Sewanee	Tennessee	85° 30′–86°	35°–35° 30′	975	25
9	Anthracite-Crested Butte	Colorado	106° 45′–107° 15′	38° 45′–39°	465	50
10	Harpers Ferry	Virginia West Virginia Maryland	77° 30′–78°	39°–39° 30′	925	25

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
11	Jackson	California	120° 30′-121°	38°-38° 30′	938	25
12	Estillville	Virginia Kentucky Tennessee	82° 30′-83°	36° 30′-37°	957	25
13	Fredericksburg	Maryland Virginia	77°-77° 30′	38°-38° 30′	938	25
14	Staunton	Virginia West Virginia	79°-79° 30′	38°-38° 30′	938	25
15	Lassen Peak	California	121°-122°	40°-41°	3,634	25
16	Knoxville	Tennessee North Carolina	83° 30′-84°	35° 30′-36°	925	25
17	Marysville	California	121° 30′-122°	39°-39° 30′	925	25
18	Smartsville	California	121°-121° 30′	39°-39° 30′	925	25
19	Stevenson	Alabama Georgia Tennessee	85° 30′-86°	34° 30′-35°	980	25
20	Cleveland	Tennessee	84° 30′-85°	35°-35° 30′	975	25
21	Pikeville	Tennessee	85°-85° 30′	35° 30′-36°	969	25
22	McMinnville	Tennessee	85° 30′-86°	35° 30′-36°	969	25
23	Nomini	Maryland Virginia	76° 30′-77°	38°-38° 30′	938	25
24	Three Forks	Montana	111°-112°	45°-46°	3,354	50
25	Loudon	Tennessee	84°-81° 30′	35° 30′-36°	969	25
26	Pocahontas	Virginia West Virginia	81°-81° 30′	37°-37° 30′	951	25
27	Morristown	Tennessee	83°-83° 30′	36°-36° 30′	963	25
28	Piedmont	Virginia Maryland West Virginia	79°-79° 30′	39°-39° 30′	925	25
29	Nevada City: Nevada City, Grass Valley, Banner Hill	California	121° 00′ 25″-121° 03′ 45″ 121° 01′ 33″-121° 05′ 04″ 120° 57′ 05″-121° 00′ 25″	39° 13′ 50″-39° 17′ 16″ 39° 10′ 22″-39° 13′ 50″ 39° 13′ 50″-39° 17′ 16″	11.65 12.09 11.65	50
30	Yellowstone National Park: Gallatin, Canyon, Shoshone, Lake	Wyoming	110°-111°	44°-45°	3,412	75
31	Pyramid Peak	California	120°-120° 30′	38° 30′-39°	932	25
32	Franklin	Virginia West Virginia	79°-79° 30′	38° 30′-39°	932	25
33	Bricevillе	Tennessee	84°-84° 30′	36°-36° 30′	963	25
34	Buckhannon	West Virginia	80°-80° 30′	38° 30′-39°	932	25
35	Gadsden	Alabama	86°-86° 30′	34°-34° 30′	986	25
36	Pueblo	Colorado	104° 30′-105°	38°-38° 30′	938	50
37	Downieville	California	120° 30′-121°	39° 30′-40°	919	25
38	Butte Special	Montana	112° 29′ 30″-112° 36′ 42″	45° 59′ 28″-46° 02′ 54″	22.80	50
39	Truckee	California	120°-120° 30′	39°-39° 30′	925	25
40	Wartburg	Tennessee	84° 30′-85°	36°-36° 30′	963	25
41	Sonora	California	120°-120° 30′	37° 30′-38°	944	25
42	Nueces	Texas	100°-100° 30′	29° 30′-30°	1,035	25
43	Bidwell Bar	California	121°-121° 30′	39° 30′-40°	918	25
44	Tazewell	Virginia West Virginia	81° 30′-82°	37°-37° 30′	950	25
45	Boise	Idaho	116°-116° 30′	43° 30′-44°	864	25
46	Richmond	Kentucky	84°-84° 30′	37° 30′-38°	944	25
47	London	Kentucky	84°-84° 30′	37°-37° 30′	950	25
48	Tenmile District Special	Colorado	106° 8′-106° 16′	39° 22′ 30″-39° 30′ 30″	55	25
49	Roseburg	Oregon	123°-123° 30′	43°-43° 30′	871	25
50	Holyoke	Massachusetts Connecticut	72° 30′-73°	42°-42° 30′	885	25

STATISTICAL PAPERS.

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Mineral Resources of the United States, 1888, by David T. Day. 1890. 8°. vii, 652 pp. Price 50 cents.

Mineral Resources of the United States, 1889 and 1890, by David T. Day. 1892. 8°. viii, 671 pp. Price 50 cents.

Mineral Resources of the United States, 1891, by David T. Day. 1893. 8°. vii, 630 pp. Price 50 cents.

Mineral Resources of the United States, 1892, by David T. Day. 1893. 8°. vii, 850 pp. Price 50 cents.

Mineral Resources of the United States, 1893, by David T. Day. 1894. 8°. viii, 810 pp. Price 50 cents.

On March 2, 1895, the following provision was included in an act of Congress:

"*Provided*, That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the Director of the Geological Survey."

In compliance with this legislation the following reports have been published:

Mineral Resources of the United States, 1894, David T. Day, Chief of Division. 1895. 8°. xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl. Being Parts III and IV of the Sixteenth Annual Report.

Mineral Resources of the United States, 1895, David T. Day, Chief of Division. 1896. 8°. xxiii, 542 pp., 8 pl. and maps; iii, 543–1058 pp., 9–13 pl. Being Part III (in 2 vols.) of the Seventeenth Annual Report.

Mineral Resources of the United States, 1896, David T. Day, Chief of Division. 1897. 8°. xii, 642 pp., 1 pl.; 643–1400 pp. Being Part V (in 2 vols.) of the Nineteenth Annual Report.

Mineral Resources of the United States, 1897, David T. Day, Chief of Division. 1898. 8°. viii, 651 pp., 11 pl.; viii, 706 pp. Being Part VI (in 2 vols.) of the Nineteenth Annual Report.

The money received from the sale of the Survey publications is deposited in the Treasury, and the Secretary of that Department declines to receive bank checks, drafts, or postage stamps; all remittances, therefore, must be by MONEY ORDER, made payable to the Director of the United States Geological Survey, or in CURRENCY—the exact amount. Correspondence relating to the publications of the Survey should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *June, 1899.*

[Take this leaf out and paste the separated titles upon three of your catalogue cards. The first and second titles need no addition; over the third write that subject under which you would place the book in your library.]

LIBRARY CATALOGUE SLIPS.

Series.

United States. *Department of the interior.* (*U. S. geological survey.*)
Department of the interior | — | Monographs | of the | United States geological survey | Volume XXXIV | [Seal of the department] |
Washington | government printing office | 1899
Second title: United States geological survey | Charles D. Walcott, director | — | The | glacial gravels of Maine | and | their associated deposits | by | George H. Stone | [Vignette] |
Washington | government printing office | 1899
4°. xiii, 499 pp. 52 pl.

Author.

Stone (George H.)
United States geological survey | Charles D. Walcott, director | — | The | glacial gravels of Maine | and | their associated deposits | by | George H. Stone | [Vignette] |
Washington | government printing office | 1899
4°. xiii, 499 pp. 52 pl.
[UNITED STATES. *Department of the interior.* (*U. S. geological survey.*) Monograph XXXIV.]

Subject.

United States geological survey | Charles D. Walcott, director | — | The | glacial gravels of Maine | and | their associated deposits | by | George H. Stone | [Vignette] |
Washington | government printing office | 1899
4°. xiii, 499 pp. 52 pl.
[UNITED STATES. *Department of the interior.* (*U. S. geological survey.* Monograph XXXIV.]