ART. XXXIX.—*Diversity of the Glacial Drift along its Boundary;* by WARREN UPHAM.*

Recency and probable Brevity of the Glacial period.—The recession of the ice-sheet at the end of the Glacial period in the northern United States and Canada and in Great Britain seems to have been separated from the present day by a Post-glacial or Recent epoch of only about 6,000 to 10,000 years, as made known by the observations and reasoning of N. H. Winchell, Gilbert, Andrews, Wright, Mackintosh, Prestwich, and others. This conclusion, and the uniqueness of the Ice age, standing quite alone as a strange episode of geologic history, unexampled besides in all the very long Cenozoic and Mesozoic eras, forbid our longer reliance upon the once generally accepted astronomic theory of Croll, Geikie, and Ball, that the accumulation of the ice sheets was due to terrestrial conditions springing from the earth's relations to the sun during a period of increased eccentricity of the earth's orbit from about 240,000 years to 80,000 years ago. Dr. Croll's theory supposed glacial epochs to recur alternately in the northern and southern hemispheres each 21,000 years during the astro-

* A paper presented before the Geological Society of America at the Boston meeting, Dec. 29, 1893.

nomic period mentioned, giving seven or eight epochs of glaciation and as many interglacial epochs when the ice-sheets were melted away; but continuous temperate conditions similar to those of the present would have prevailed during the past 50,000 years or more. The recency of the date marking the close of the Ice age is inconsistent with the astronomic theory. But under the fruitful incentive of that theory many glacialists in Europe and America have interpreted their observations as establishing the recurrence of glacial and interglacial epochs which it suggested; and some who distrust or reject astronomic causes for the Ice age continue to hold this interpretation of the records of the glacial drift.

Looking through the long past ages previous to the Pleistocene, we come to no time affording evidences of widely extended glaciation, probably affecting continental areas, till we pass back at least many million years. Only one earlier stage of the earth's changes was attended, so far as geology can tell us, with the envelopment of large land areas beneath ice-sheets, and this was in the Permian period, closing the Paleozoic era. It was a time of great orogenic and epeirogenic changes; and I think that then, as in the Pleistocene Ice age, the accumulation of thick sheets of land ice was due to great epeirogenic uplifts of those areas so high as to give them a cool climate and chiefly snowfall instead of rainfall throughout the year. If extensive glaciation has been so rare, shall we readily believe that during the geologically very short Quaternary or Psychozoic era there have been two or three or several Glacial epochs? More probably, as I think, we shall find all the diverse phases of our glacial drift referable to a single and continuous Ice age; and the very slight changes of marine molluscan faunas during this age implies its exceptional brevity in comparison with any of the preceding periods recognized by geologists.

Earlier and Later Drift near its boundaries in the Mississippi basin.—The admirable work of Profs. Chamberlin and Salisbury on the Wisconsin driftless area and farther south in the Mississippi basin discriminates earlier, mostly thin, and later, thick and morainic, varieties of the drift border. These differ widely in their volume of drift, in its constituent material, and in the times of its deposition. Along the greater part of the boundaries of the drift on those areas, it terminates in an attenuated border, slowly thinning out and presenting considerable difficulty for the recognition and mapping of its limits. Indeed, it is apt to occur on its outermost tracts in low and thin, smooth patches, more or less isolated, and these are thought to represent in large degree the original method of deposition, not being a result of subsequent erosion. These

drift deposits belong to the time of maximum ice advance, and are much earlier than the marginal moraines of thick and irregularly knolly and hilly drift which were accumulated when the ice-sheet terminated farther north. There was, however, in some districts, as Mr. Frank Leverett has found in Illinois, a special massing of the early drift upon a belt near its boundary. In general the drift border is attenuated, but occasionally its thickness in the outermost five miles attains a maximum of 50 feet; and several times as much drift is found on that belt as in the adjacent drift-bearing belt 5 to 20 miles farther back within the glaciated area.

In this great region of smoothly spread early till, comprising large expanses on both sides of the Mississippi River, there was very scanty glacial erosion of the bed rocks. An area of 16,500 square miles in northeastern Iowa, according to McGee, has nearly everywhere a small thickness of the preglacial residuary clay and decaying rock still remaining beneath the universal mantle of the drift, which is principally till, the product of an overriding ice-sheet. McGee further notes that nearly all of the bowlders and smaller rock fragments of that till in both its lower and upper deposits, and by inference also its finer sandy and clayey matrix, were derived from formations lying north of the limits of Iowa. Bringing much drift, the ice-sheet twice advanced upon this area. Its first advance did not erode even so much as the thin preglacial residuary products of secular rock decay and denudation, which are found to average about seven feet in depth on the adjacent Wisconsin driftless area. Between the two ice incursions a forest grew on the land, and its fallen trees and peaty swamps were left upon many townships almost intact, as is known by the forest beds found in digging wells, while the later ice advance covered them with a second sheet of till, which is mostly from 3 or 5 to 10 or 20 feet thick and in some places is probably as much as 80 feet thick.

The feeble eroding action of the ice-sheets depositing the smooth expanses of the outer and earlier drift is remarkably contrasted with the vigor of erosion displayed by the planed and striated rock surface of the areas enclosed by the later marginal moraines. When the ice-sheets heaped these morainic hills it wore into its adjacent rock bed and accomplished much rock erosion upon all the region of the later and uneven drift, which encloses lakes and lakelets, reaching northward from the outermost large and continuous moraine and covering the far greater part of our drift-bearing area.

Portions of the Drift Border formed by Marginal Moraines of the Later Drift adjoining the Wisconsin Driftless Area and in the eastern United States.—Along a distance of

about 80 miles on the east side of the driftless area in Wisconsin the magnificently developed Kettle moraine, belonging to a late part of the Ice age, forms the extreme border of the drift. Its correlation or continuation in Minnesota, Iowa, and South and North Dakota, is probably the Altamont moraine, the outermost of the series of twelve approximately parallel successive retreatal moraines which I have explored and mapped, under the direction of Prof. N. H. Winchell, for the Minnesota Geological Survey. Near Des Moines in central Iowa this Altamont or first moraine of the Minnesota series, there forming the southern extremity of an area of the later drift deposited by the Minnesota and Iowa lobe of the ice-sheet, lies 175 miles north of the southern boundary of the drift in its course through Missouri and northeastern Kansas. Within the Mississippi basin the ice sheet forming the Kettle and Altamont moraines occupied less area by 125,000 square miles than was enveloped by the ice forming the earlier drift. But while there had been in general this great decrease in the extent of the ice previous to the accumulation of the outer large moraine, it even advanced at that time farther than ever before upon the east side of the Wisconsin driftless area.

In the eastern United States, the outer moraine along an extent of about 700 miles, from the Scioto basin in Ohio to Martha's Vineyard and Nantucket, stands upon the boundary of the drift or very near it. At its time of maximum extension the ice-sheet in this region generally reached a short distance, from a few miles up to twenty miles or more, beyond the position of the moraine. Besides this remarkable difference from the drift of the Mississippi basin, it must be confessed that we cannot yet be sure that this outer moraine, at least eastward from the angle of the drift boundary in southwestern New York, is to be correlated with the Kettle and Altamont belt. Following a suggestion or query of Mr. Leverett, I incline to believe that quite as likely it may belong somewhere within the time of the very large Fergus Falls, Leaf Hills, and Itasca moraines, which are the eighth, ninth and tenth of the series in Minnesota.

Oscillations of the Boundary and Changes in the Thickness and Currents of the Ice-sheet during its general Recession.—The great contrast between the glacial retreat from northeastern Kansas to Des Moines and the contemporaneous encroachment of the ice upon the eastern side of the Wisconsin driftless area seems to be accounted for, in part or wholly, by interdependence of snowfall at the east with rains and ice melting at the west. While the ice was being melted away by rains and sunshine over its 125,000 square miles that had been uncovered south and west of central Wisconsin, the east-

wardly moving air currents, abundantly laden with moisture from that region, were chilled in their farther progress over the ice-sheet north and east of the driftless area, and there gave exceptionally heavy snowfalls, permitting that part of the ice-sheet to grow thick and high, with only slight recession. At last, when there came a temporary general reversal of the warm climate under which the ice-sheet had been mainly retreating, its halt or re-advance producing the first of the prominent moraines carried the ice-front in Wisconsin forward upon a part of the area which previously had no drift.

During the great recession of the ice in the Mississippi basin, it probably withdrew much less, perhaps mostly from ten to thirty or forty miles, in Ohio, Pennsylvania, northern New Jersey, and Long Island, and south of Rhode Island and eastern Massachusetts. Meanwhile, as in eastern Wisconsin, it had grown thicker than during its time of maximum area, and the sudden and short climatic changes leading to the formation of the moraines allowed the ice in the eastern states to flow out again almost to its earlier limit, and in some places even beyond it. Considering how nearly coincident the earlier and later drift boundaries are for this long distance from the Scioto River in Ohio eastward, we naturally feel much reluctance against referring them to distinct epochs of glaciation separated by a long interglacial time, as some have supposed, when the ice-sheet made a long retreat to the north or was wholly melted as now from this continent. It seems to me more reasonable to appeal, as Prof. James D. Dana has recently done,* to meteorological differences between the Mississippi basin and the eastern states, whereby comparatively long glacial retreats and re-advances could take place at the west while in the east the ice-border more steadily remained near the drift boundary.

What shall be said, consistent with this view, concerning the extra-morainic drift in New Jersey, some of which occurs more markedly in isolated patches than any of the early drift before noted in the Mississippi basin? Prof. Salisbury estimates that a very long time of ordinary subaërial erosion intervened between the times of deposition of the earlier and later drift in New Jersey, so that the denudation of the land had removed the greater part of the earlier drift, leaving only its present patches on the extreme boundary, before the late moraine-producing ice advance. If this is a needful explanation, it goes far toward establishing a longer and probably more complex history of the Ice age than the view taken in this essay. It seems to me, however, that the manner of transportation and deposition of that early drift may explain its

* This Journal, III, vol. xlvi, pp. 327–330, Nov., 1893.

uneven distribution. The early accumulation and advance of the ice to its extreme limits gave a comparatively thin ice-sheet with feeble erosive action on all the outer part of the drift-bearing area. Its drift there was nearly all brought from considerable distances at the north and was deposited in obedience to the glacial currents of the marginal portions of the ice-sheet. Now we have upon many districts of the thick later drift the remarkable aggregations of the till called drumlins, which appear to have been amassed by convergent currents of the ice-sheet during its retreat.* Similar selective action of the outflowing early ice advance close to its farthest limits I think to have amassed that outermost early till in the patches where it is now found, having received little change by later erosion.

The well oxidized and leached condition of the early outer drift everywhere is easily referred to its derivation chiefly from the preglacial residuary clays, decaying rocks, weathered rock cliffs and tors, and bowlders of secular disintegration. Again, its smoothed surface, without the inequalities of accumulation which provide basins for the myriad lakes and lakelets of the later drift, seems attributable to the gentle currents of the early thin ice-sheet, in contrast with which the late thick ice powerfully eroded its rock bed, even close to the boundary, and tumultuously heaped or very irregularly spread its drift with many lake-enclosing hollows.

Forest beds between deposits of till in northeastern Iowa, and in portions of other states of the Mississippi basin, testify of glacial recessions and re-advances, the ice-sheet probably recovering at some times marginal belts from 50 to 100 or 200 miles wide of its previously lost ground. These great oscillations, however, need not have required a very long time, certainly no more than a few thousand years for them all, as we may well learn from Prof. I. C. Russell's observations of the drift-enveloped and forest-clad borders of the Malaspina ice-sheet between Mt. St. Elias and the ocean.

Amid the waverings of the retreating ice, often large channels were cut in the early drift and became covered and partially filled by the later drift. In southern Minnesota these old water-courses are recognized as far northward as the Minnesota river valley, considerably to the north of all our recorded observations of forest and peat beds enclosed in the till sheet. They seem to have been probably rapidly eroded when the altitude of the country and its slopes of descent from north to south were greater than now. The few thousand years which are here regarded as the time of the fluctua-

* "Conditions of Accumulation of Drumlins," Am. Geologist, vol. x, pp. 339–362, Dec., 1892.

tions of the ice-front recorded by the forest beds appear to be ample for the attendant stream channelling.

Farther northward, along the 700 miles of length of the glacial lake Agassiz the retreat of the ice-sheet, with the formation of numerous large moraines, was demonstrably very rapid, occupying apparently no more than one thousand years.* In all, I believe that a duration of five thousand years is sufficient to account for the records of the waning and closing stages of the Ice age, from the time of the maximum area of the ice-sheet depositing the early drift to the time when Lake Agassiz was drawn off into Hudson Bay and the northern United States and Canada were freed from their glacial mantle and occupied by hunting and fishing tribes of the red race, who have abode here with many intertribal wars and migrations during the 5,000 years or more since the departure of the ice. A very large part of my belief that these oscillations and important changes of the currents of the ice-sheet during its recession were comprised within a time geologically so short, comes from my studies of the shore erosion and beach accumulations of Lake Agassiz, and of great changes in the relations of the northeastern and northwestern convergent ice-currents in Minnesota during the deposition of the later drift.† These, I am convinced, took place fast, in a geological sense, and I am persuaded also that the ice oscillations and varying conditions causing the diversity of the drift near its boundaries were not of great duration and are referable to a continuous and brief Ice age, not divided by interglacial epochs.

Loess deposition mainly continuous from the time of maximum ice extension to the time of formation of the Moraines of the Later Drift.—On the drift border in southern Illinois and Indiana, Prof. R. D. Salisbury finds that the deposition of the loess ensued immediately after that of the early till and was in part contemporaneous with the till. As soon as the ice-sheet retired from its farthest limit the glacial drift was covered by this fine silt of the modified drift supplied by streams that flowed from the melting and retreating ice.‡

In the northeastern part of Iowa Mr. W J McGee similarly finds the loess to have been deposited while the ice-sheet that spread the upper portion of the early till was melting away. The very remarkable paha of that district, which are eskers of loess, were accumulated while the waning ice-sheet walled them in on each side.§

* Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, vol. iv, for 1888–'89, pp. 50, 51E.

† Proc. A. A. A. S., vol. xxxii, for 1883, pp. 231–234.

‡ Geol. Survey of Arkansas, Ann. Rep. for 1889, vol. ii, "The Geology of Crowley's Ridge" (1891), pp. 228, 229.

§ U. S. Geol. Survey, Eleventh An. Rep., for 1889–'90, pp. 435–471.

That the later part of the loess deposition was contemporaneous with the formation of the prominent Altamont moraine of the later drift, I ascertained in northwestern Iowa, where this moraine along a distance of 75 miles, from Guthrie County northwestward to Storm Lake, is bordered on its west side by an expanse of loess as high as the crests of the morainic hills, while its elevation above the expanse of till eastward is from 50 to 75 feet. During the time of deposition of this part of the loess the ice-sheet reached to the Altamont moraine and was a barrier preventing the waters by which the loess was brought from flowing over the lower area of till that reaches thence east to the Des Moines river.*

These observations in three widely separated regions prove that the loess, like the coarser portions of the modified drift forming sand and gravel plains, was in progress of deposition upon successive areas as fast as the ice-sheet supplying these stratified drift beds receded. Immediately after the land was bared by the retreat of the ice, and even while the ice itself occupied the adjoining land, the loess was being laid down, contemporaneous successively with the earliest till on the southern limit of the drift, with the till of intermediate age in northeastern Iowa, and with the later till enclosed by the Altamont moraine.

Such being the well demonstrated origin of the loess and its relations with the earlier and later glacial drift, it seems impossible that the rock gorges described by Mr. Oscar H. Hershey upon the area of the early drift in northwestern Illinois can have been eroded, as he supposes, between the times of deposition of the drift and of the loess.† Instead, I think that the early drift there and its closely ensuing loess so filled the valleys and raised the streams above the beds of the deep preglacial channels that in the places noted by Mr. Hershey the streams were turned aside into preglacial courses of small tributaries or across cols of plateau tracts which had become isolated alongside the valleys by the processes of ordinary land erosion and general weathering with rain, rill, and stream sculpture. This view brings harmony with Prof. Salisbury's assignment of the loess upon the early drift region to a time contemporaneous with the retirement of the ice-sheet from its farthest boundaries.

* Geol. and Nat. Hist. Survey of Minnesota, Ninth An. Rep. for 1880, pp. 307–314, 338.

† Am. Geologist, vol. xii, pp. 314–323, Nov., 1893.