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ART. XXVIII.—*Weathering and Erosion as Time Measures* ;*
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THE writer presented a paper, under the above title, at the Baltimore meeting of the Geological Society of America, which set forth the advantages of estimates of weathering and erosion in making correlations between the drift sheets of Europe and America. Since the correlation of European with American drifts is to be presented as a special paper in the international glacial magazine, *Zeitschrift für Gletscherkunde*, the present paper will aim only to set forth the value of weathering and erosion in making correlations, and will be restricted mainly to our American deposits. The topographic sheets now published embrace each of the drift formations to a sufficient extent to enable the student to use them in comparing glacial formations of different age. They will thus serve a valuable purpose in the class room. The present paper will fulfill its mission if it helps to a proper understanding of topographic sheets illustrating each of the glacial drifts.

There are certain situations in which the student is able to determine, by erosion alone, the relative ages of the different drift sheets. This can be done where the surface of the drift was left in a flat or featureless condition so that the present reliefs are almost wholly the result of stream action, and it is especially valuable where the streams have been working under sufficiently high gradient to admit of the cutting of well-defined channels. There are places where stream gradients are so low that little or no deepening of the drainage lines has occurred. In such situations and in situations where the drift topography is of a ridged or complicated character, weathering naturally is made a leading criterion for judging of relative

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ages of the drift sheets under comparison. The rapidity of weathering is especially great in fragmental formations, such as the glacial and fluvial deposits, since a multitude of faces are exposed for attack. It is thus possible to distinguish lesser differences in age than would be detectible in the solid formations. Weathering of glacial material or of fluvial material will reach depths to be measured in feet and meters, while that in rock formations may reach only a few inches or centimeters.

There are certain complications in these studies resulting from differences in climatic conditions and differences in the constitution of the drift which have to be properly considered in forming the estimates. Leaching goes on so much more rapidly under humid conditions than under semi-arid that one may easily be misled if he depends entirely upon the depth to which the leaching extends. In the same way erosion studies are liable to be misleading if one does not take into account differences of rainfall, in stream gradient, and in the texture of the deposits. It is necessary also, in glaciated regions, to ascertain the work accomplished by the drainage from the ice sheet, in order to properly compare the work done by the present streams on drift sheets of different age.

In the glaciated portions of North America there are, fortunately, extensive plains of Kansan, Illinoian, and Wisconsin drift and of glacial lake beds, whose conditions of rainfall, stream gradient and texture of deposits, are sufficiently alike to afford excellent subjects for time estimates based on weathering and erosion. It is not claimed that these studies will give time measures definitely expressible in thousands of years, at least not in the present state of our knowledge; but it is thought that a sufficiently reliable measure of relative age is afforded to form a basis for wide correlations, such as those between the American and European drift sheets.

The table here presented gives the names applied to the several members of the glacial series in each prominent field of Pleistocene glaciation. Some of the lesser fields, west of the Rocky Mountains, may have a similar complexity, but this has not been so fully established. The Skandinavian field has had a great variety of interpretations and still awaits a satisfactory nomenclature. It will, perhaps, serve our purpose best to make use of the terms employed by the German geologists, though here it must be understood that the earlier literature is not fully in harmony with the later. The order of arrangement in the table is from younger to older in each field.

Table of drift sheets.

Keewatin	Labrador	Skandinavian	Alpine
Wisconsin	Wisconsin	Upper Diluvium	Würm
Iowan ?			
Illinoian ?	Illinoian	Middle Diluvium	Riss
Kansan	Kansan ?	Lower Diluvium	Mindel
Pre-Kansan*	Jerseyan		Gunz

Wisconsin Drift.

In the first attempts by Chamberlin and others to show the complexity of the glacial deposits but two drift sheets were recognized, the earlier and the later, and of these the later embraces what is now known as Wisconsin drift. Its aspect is everywhere much fresher or younger than that of the outlying and underlying drift sheets, so that it can easily be distinguished from them. With the progress of the study it became evident that considerable complexity of ice movement was involved in producing the many moraines of this later drift. The moraines do not form throughout a concentric series, such as one would expect to find had the ice made a simple retreat from its field, with halts at places where moraines occur. Instead, there are groups of concentric moraines which have a trend out of harmony with other groups, resulting in a partial overriding of the earlier by the later. From this it is inferred that the ice made shiftings in its directions of movement, such as call perhaps for some change in its center of accumulation.

The earliest group of these moraines of later drift has been termed the Earlier Wisconsin, while the remainder of the moraines are thrown together under the name Later Wisconsin. The principal exposure of the Earlier Wisconsin is in Illinois, but it has a slight extent beyond the Later Wisconsin in Indiana and Ohio and possibly also in Wisconsin. Whether it is exposed in states farther west has not been determined. The amount of weathering and erosion which the Earlier Wisconsin has undergone differs so little from that experienced by the Later Wisconsin that we may feel sure that no interval of great length separates them. The knolls and basins along the moraines of the Earlier Wisconsin are toned down by erosion and filling so that only the larger ones are well-defined, whereas in the Later Wisconsin the small hummocks and basins still preserve their sharpness of contour. But in the Earlier Wisconsin as in the Later there are wide areas not yet invaded by drainage lines, as may be seen by reference to the Danville, the Urbana, and the Mahomet,

* The Pre-Kansan is sometimes termed Sub-Aftonian.

Illinois, topographic maps. If one should place these maps besides those of quadrangles inside the Later Wisconsin, as for example the Marion, Sycamore, Upper Sandusky and Arlington sheets in northwestern Ohio, it would be difficult to discover any difference in the character of drainage. The amount of weathering, however, is perceptibly greater in the Earlier

FIG. 1.

FIG. 1. Part of the Wayne, Michigan, topographic sheet, illustrating the slight amount of erosion characterizing the beds of the great glacial lakes. Scale, 1 : 90000. Contour interval, 20 feet.

than in the Later Wisconsin, it being rare to find unleached till on the plains of the Earlier Wisconsin at a depth of less than a meter, whereas on the Later Wisconsin it is frequently found at $\frac{1}{2}$ meter or less, and the average depth of leaching in the Later Wisconsin scarcely reaches a meter. It is, therefore, chiefly by the weathering and by toning down of the slight inequalities that the Earlier Wisconsin is distinguished from the Later.

The erosion of the Later Wisconsin drift, compared with that of the beds of the large glacial lakes which occupied its surface during the recession of the ice from the St. Lawrence basin, is sufficiently more advanced to be perceptible on many of the topographic maps. The sections of the two maps here introduced serve to bring out this difference (see figs. 1

FIG. 2.

FIG. 2. Part of London, Ohio, topographic sheet, illustrating the amount of erosion ordinarily found on a plain of Wisconsin drift where the slope is sufficient to favor a somewhat rapid development of drainage lines. The incipient stage of development testifies to the recency of the Wisconsin glaciation. Scale, 1:93700. Contour interval, 20 feet.

and 2). Fig. 1, which represents a portion of the lake plain in southeastern Michigan, shows the drainage lines to have developed very few tributaries as well as to have cut only insignificant valleys. Fig. 2, which represents the Wisconsin drift in the western portion of Scioto basin in Ohio, shows a slightly deeper valley cutting and the beginning of numerous

tributary valleys. The tributaries, however, are in a very incipient state of development. This map near West Jefferson, Ohio, serves to indicate that fully nine-tenths of the drift plain still stands at its original level, and this is true over a large part of the surface of the Wisconsin drift. In fact there are considerable areas in which less than one-tenth of the surface has been lowered or reduced in any way by drainage lines.

Areas in which the topography of the Wisconsin drift and the Post-Wisconsin erosion may be studied without much complication with rock topography have already been mapped in nearly every state from Massachusetts to North Dakota. Thus a considerable part of southeastern Massachusetts, including the islands of Marthas Vineyard and Nantucket, much of Long Island in New York, as well as the greater part of the plain east and south of Lake Ontario, nearly all the northwest one-fourth of Ohio, the quadrangles mapped in southeastern Michigan, northeastern Illinois and southeastern Wisconsin (except the Broadhead, Janesville and Shoppiere sheets in Wisconsin), the area around Minneapolis and St. Paul, Minnesota, the area north and west of Des Moines, Iowa, certain sheets in the James River valley in South Dakota, and those in the eastern part of North Dakota, may be drawn upon for illustrations. It will be observed that the morainic areas of southeastern Michigan, southeastern Wisconsin, and in the vicinity of St. Paul, Minnesota, embrace much poorly drained land represented as swamp, whereas such swamp areas are of small extent in northwestern Ohio, northeastern Illinois, and in the region bordering Lake Ontario. This should not be interpreted to indicate that the less swampy areas owe their condition to greater age. It results instead from a more favorable original condition for shedding the water or from a different ground-water condition.

There are extensive areas in New England, as also in New York and in Ohio, where rock ridges are prominent, in which the Wisconsin glaciation has served to produce what has been termed by Salisbury superimposed youth.* In these areas the drainage lines are often as poorly developed as in areas of the Wisconsin drift, where the rock irregularities are completely buried, and they indicate to the physiographer a similar youthfulness. Such areas, however, are not so satisfactory as the smooth areas of heavy drift for determining the relative age of the different drift sheets.

The character of the glacial drainage of the Earlier Wisconsin appears to have been different from that of the Later Wisconsin, there being no extensive outwash gravel plains associated with the Earlier Wisconsin moraines such as charac-

* *Journal of Geology*, vol. xii, pp. 711-713, 1904.

terize portions of the Later Wisconsin moraines of the same general region. This fact, and the fact that the outer portion of the Earlier Wisconsin drift in Illinois carries a thin coating of loess, is thought to indicate that a certain degree of aridity prevailed during the culmination and the withdrawal of the ice of this early part of the Wisconsin stage of glaciation. The relatively arid conditions may account to some degree for the poor development of drainage lines, which otherwise seem rather inconsistent with the amount of toning down of knolls and filling of basins which took place on the Earlier Wisconsin moraines. The filling of basins would be accomplished rapidly under conditions of aridity, as is exemplified in our arid western region. It is well, therefore, to keep this climatic factor in mind when making a comparison of the amount of erosion of the Earlier Wisconsin drift with the somewhat younger Later Wisconsin drift.

As may be seen from the above table (p. 351), the Wisconsin drift is the only one of the series named in the Labrador and Keewatin fields which is correlated with certainty. There is a continuous belt of moraines connecting the Labrador and Keewatin fields, but these moraines are of Later Wisconsin age, and it yet remains to be determined whether the Earlier Wisconsin drift is exposed outside the Later Wisconsin in the Keewatin field.

Probable European Correlatives of the Wisconsin Drift.

In the European fields, Skandinavian and Alpine, and also in Great Britain, there is a drift sheet which corresponds closely in the amount of weathering with our Later Wisconsin drift, while certain of the outer moraines of the north German lowland and of Great Britain seem to correspond with our Earlier Wisconsin. The complexity of the last stage of glaciation seems, therefore, about as great in northwestern Europe as in North America. In the Alps the Würm drift has a freshness of contour very similar to that of the Later Wisconsin moraines, while the "Verwaschene Würm," which lies outside the Würm proper at a few points in northern Switzerland, and also at a few points on the southern side of the Alps, has a similar toning down to that displayed by our Earlier Wisconsin moraines, of which it may prove to be the correlative.

The Upper Diluvium of the North German Lowland is much more extensive than the limits assigned by Geikie to the fourth or Mecklenburgian drift. The great Baltic ridge seems, as has been interpreted by several German geologists, to lie well within the limits of the last glaciation, though it certainly

marks a very important position of the ice border, whether a mere halt or a readvance is not yet clear. The results of my own studies are in full accord with those of the German students in placing the limits of the last glaciation far enough south to embrace the prominent moraines along the south border of the region characterized by lakes.

Illinoian Drift.

The Illinoian drift of the Labrador icefield is exposed outside the limits of the Wisconsin drift in Illinois, Indiana, and Ohio, and at its farthest extent reached slightly into Iowa.* The entire outlying portion of this drift is covered by loess except a small district in northwestern Illinois and southern Wisconsin, where the loess is of rather patchy distribution. Beneath the loess there are widespread occurrences of a black soil and muck known as the Sangamon soil, which rests upon the leached surface of the Illinoian drift. It thus appears that the Post-Illinoian history is somewhat complex. The occurrence of the black soil and muck is suggestive of cool, damp conditions, while the overlying loess suggests conditions of aridity. The loess is found to pass beneath the outermost moraines of the Earlier Wisconsin drift and hence antedates the Wisconsin ice invasion.†

The leaching which the Illinoian drift has experienced appears to have been largely accomplished prior to the deposition of the loess, for the loess is sufficiently thick over much of the Illinoian area to preserve an unleached basal portion. Yet in spite of this cessation of the leaching at the time of the loess deposition it had reached a depth, and weathering had gone to a degree, far in advance of the leaching and weathering thus far experienced by the Wisconsin drift. The removal of calcareous constituents, pebbles as well as fine material, was nearly complete to a depth of 4 to 6 feet, while weathering often extended to two or three times these depths. Indeed pipes and weathered seams extend far down into the unleached portion, as is not found to be the case in the Wisconsin drift. One cannot well escape the conclusion that the time involved in this leaching was at least two or three times as great as that of the Wisconsin, and it may considerably exceed this amount. In addition to the weathering and leaching there is a general induration of the entire deposit, produced probably by a partial cementation, a feature which is very sparingly exhibited by the Wisconsin drift.

Turning now to the amount of erosion which the Illinoian

* See *The Illinois Glacial Lobe*, Monograph xxxviii, U. S. Geological Survey, 1899, pp. 24-130. Also Monograph xli, 1902, pp. 253-294.

† See Monograph xxxviii, pp. 128-129 and plate xi.

drift displays, we find that where drainage gradients are good it far exceeds that displayed by the Wisconsin drift. An excellent topographic sheet for comparing the erosion of the Illinoian with the Earlier Wisconsin is that of the Peoria, Illinois, quadrangle, the western portion of which shows Post-Illinoian erosion, while the eastern portion shows Post-Wisconsin erosion. In studying this sheet, however, it should be borne in mind that the Wisconsin drift area is morainic and more elevated than the Illinoian, and thus has a great advantage in the rapidity of shedding its water; but in spite of this advantage the extent of the erosion is far less than in the Illinoian drift.

Topographic sheets that lie entirely within the Illinoian drift area are the Springfield, Eldorado and Belleville, Illinois, sheets. The Belleville topographic sheet is of especial interest since it exhibits the contrast in the work of streams under different gradients. The western portion, a section of which is here reproduced in fig. 3, illustrates the appearance of the drainage when under a good gradient, while fig. 4, taken from the southeast part of the same quadrangle, illustrates drainage under a low gradient. It will be observed that Silver Creek (in fig. 4) has a broad valley in which abandoned courses of the stream testify to the sluggishness of the drainage and suggest that aggradation rather than channeling is now in progress. The entire Eldorado topographic sheet is in a region of low drainage gradient, while the Springfield sheet represents a region of more rapid drainage gradient. The series is, therefore, very instructive in setting forth the amount of variation that may be found on a drift formation of a given age.

To properly compare the Illinoian erosion with the Wisconsin one must select areas in which drainage conditions are similar, and also where no inequalities of drift surface, such as moraines, etc., come in to give complexity. Figs. 2 and 3 represent fairly well the development of drainage under similar conditions of slope. The conditions are perhaps more favorable in the area represented by fig. 2 for the rapid development of drainage than in fig. 3, yet the stage of drainage development in fig. 3 is advanced far beyond that in fig. 2. The writer has estimated that in the portion of the Illinoian drift in western Illinois and southeastern Iowa, where the conditions for development of drainage are the best, that approximately one-half the surface has been reduced below the original level as a result of the drainage, while in the Wisconsin drift, as already indicated, scarcely one-tenth of the surface has been thus reduced. It is evident that the time required for developing the drainage found on the Illinoian is much greater than that on the Wisconsin on the assumption that the climatic

conditions have been uniform and similar to the present conditions. It is probable, however, that a period of aridity came in at the time of the loess deposition, and this would lengthen materially the time required for the development of the drainage lines in the Illinoian drift.

The presence of a drift sheet of Illinoian age in the Keewatin field is still open to question. The only deposits sus-

FIG. 3.

FIG. 3. Part of the Belleville, Illinois, quadrangle, showing Post-Illinoian drainage under a fair stream gradient. Scale, 1 : 93700. Contour interval, 20 feet.

pected to be of Illinoian age, so far as yet noted, are found in southeastern Minnesota and neighboring parts of Wisconsin, just outside the limits of the Wisconsin drift, and these have not as yet been given sufficiently close study to clear up their relations to the broad sheet of Illinoian drift of the Labrador field.

European Correlatives? of the Illinoian Drift.

From their position in the series one would naturally expect to find correlatives of the Illinoian drift in the Middle Diluvium of north German lowland and the Riss drift of the Alpine region. But neither the Riss nor the Middle Diluvium was found to bear a close resemblance to our Illinoian drift. These European drifts are commonly weathered to a depth of

FIG. 4.

FIG. 4. Part of the Belleville, Illinois, quadrangle, showing Post-Illinoian drainage under a very low stream gradient. Compare the small amount of dissection of the drift plain with that in fig. 3. Scale, 1:93700. Contour interval, 20 feet.

only 3 or 4 feet and there is a very abrupt change to fresh-looking drift at the base of the weathered portion. Were the upper part to the depth of a meter stripped off from these drifts one would find difficulty in distinguishing the Riss from the Würm, or the Middle Diluvium from the Upper Diluvium. The induration of the deeper portion, so generally found in

the Illinoian, is not seen in the Riss and the Middle Diluvium, nor is there the deep penetration of weathered pipes and seams into the unweathered portion. The Riss moraines have not the sharp hummocks that characterize the Würm moraines, but the contrast is not much more striking than is found between our Earlier and Later Wisconsin moraines. The impression one obtains is that the Riss and the Middle Diluvium have reached a condition of weathering intermediate between our Earlier Wisconsin and our Illinoian drifts. Further study into climatic conditions in the several fields and into the constitution of the drift deposits may serve to remove some of the difficulties of correlation. Portions of the area of the Middle Diluvium lying east of the Harz Mountains have at present a very light rainfall, which seems to produce less leaching than is accomplished in more humid districts to the west. Possibly long continued aridity will account for the lack of deep penetration of weathered pipes and seams. At present waters charged with calcareous constituents rise into the soil by capillary action and tend to keep it well supplied with calcareous material. Prof. Keilhack reports that the calcareous material is in the form of a coating on the grains of silica, feldspar, etc., and not in the form of grains or coarse particles of limestone. In other words, the present calcareous content is secondary.

So far as inferences can be drawn from relative amounts of erosion these European drifts differ but little from the Illinoian in the places where erosion conditions are similar as to gradient and texture of deposit. The erosion of the high terraces (Hochterrassen), which connect with the Riss moraines of the Alpine region, seems to be about as great as the ordinary erosion of the Illinoian drift under good stream gradients. The erosion of the Middle Diluvium has been sufficient to remove nearly all traces of the deposit along the borders of the main drainage lines, which compares favorably with the amount of erosion in our Illinoian drift.

Kansan Drift.

The Kansan drift, which is the most extensive sheet of the Keewatin field, is widely exposed in northern Missouri, southern and western Iowa, and neighboring parts of Kansas and Nebraska. Its northern portion is concealed by the Wisconsin drift. The greater part of this drift, like the Illinoian, is covered by loess. Some of this deposit may be older than the Illinoian drift, at least loess has been found between the Kansan and the Illinoian in the district along the Mississippi where the Illinoian overlaps the Kansan drift. A large part of the loess, however, seems to be of the same age as that which

covers the Illinoian drift, and seems to have been deposited after the Kansan drift had been very greatly eroded, for it covers the valley terraces and valley slopes as well as the uplands, and appears deep down in the valleys in positions that can scarcely have been reached by a secondary deposition or by a creep of the deposit. Beneath the loess on the remnants of the old drift plain, preserved between the valleys, one finds a black soil and muck similar to that at the junction of the loess and the Illinoian drift. The region seems, therefore, to have had alternations of wet and dry climates which will complicate to some extent the estimates of erosion. So far as the time element is concerned the periods of aridity will render the length of the Post-Kansan time greater than that required for the mere cutting of the valleys under present conditions of precipitation. The presence of two sheets of loess would seem to call for two periods of aridity.

The topographic maps of northeastern Missouri, from which figs. 5 and 6 are taken, represent a region where the erosion is almost entirely in glacial deposits, the rock surface being deeply buried. It will be observed that a large part of the original Kansan drift plain has been destroyed, the plain being preserved only in narrow tabular divides, such as that on which the towns of Atlanta and Memphis stand. The valley slopes as well as valley bottoms are very broad. The slopes are so toned down as to be generally below an angle of 5° and not uncommonly are reduced to 3° or even less. By reference to figs. 5 and 6 it will be seen that the 20-foot contours are generally broadly spaced, so that four contours, or 80 feet elevation, occupy a breadth of one-fourth to one-half mile on a valley slope. On streams of comparatively small drainage area the valley bottoms frequently exceed a mile in breadth. In the region covered by these maps and in much of northern Missouri and southern Iowa narrow tabular remnants of the original drift surface are preserved. But as one passes from the tributaries of the Mississippi westward to the tributaries of the Missouri these tabular remnants gradually dwindle and in the vicinity of the Missouri valley entirely disappear. The tributaries of the Missouri have some advantage in directness of drainage, which probably partially accounts for the more advanced state of drainage erosion. There may also have been a flatter surface in the vicinity of the Mississippi, since the underlying limestone there was left with broad tabular surfaces at the oncoming of glaciation, while the sandstone areas to the west were broken up into ridges and hills. The tabular divides in the drift surface, however, do not coincide with preglacial divides in the limestone surface, nor are they restricted to the limestone area, but extend westward some distance into the

sandstone area. The average amount of removal of drift in Post-Kansan time is estimated to be somewhat more than 50 feet, at least it would take more than that amount to bring the valleys up to a level with the tabular divides. This is apparent from the sections of maps here presented, and was carefully worked out in the field in a neighboring county of Iowa by Dr. C. H. Gordon, while connected with the Iowa

FIG. 5.

FIG. 5. Part of the Atlanta, Missouri, topographic sheet showing Post-Kansan drainage. Scale, 1:86500. Contour interval, 20 feet.

Geological Survey. To the question whether the streams may have begun their work in depressions somewhat below the level of the tabular divides, it is remarked that the lack of correspondence between the tabular drift divides and the preglacial rock divides, together with the consistent fitting in of each tabular divide with its neighbors to form a plain sloping in the direction of drainage, as well as the evidence to be gathered from the lateral drainage, gives a strong presumption that the surface was brought up very nearly to a plain of the kind preserved in the tabular remnants.

The Kansan drift, in places where erosion has been at a minimum, as on the tabular divides, has a weathering to a depth of several meters. There is more or less complete removal of limestone pebbles as well as of finer calcareous material to an average depth of $1\frac{1}{2}$ to 2 meters. Apparently the deposit originally was as calcareous at its surface as in its unleached portion. It lies in a region where limestone formations have extensive outcrops and there are numerous calcareous

FIG. 6.

FIG. 6. Part of Edina, Missouri, topographic sheet showing Post-Kansan erosion. Scale, 1:173000. Contour interval, 20 feet. The map on this scale is introduced for purposes of comparison with that of the so-called Iowan, fig. 7, which has the same scale.

nodules at the base of the leached part testifying to a contribution of lime from it. The uppermost half meter of the leached portion is often of a decidedly red tinge, below which is a transition through brown to yellow and finally to gray or blue in a space of 4 to 6 meters or more. The statements just made represent conditions in the humid Mississippi valley where there is an average rainfall of about 40 inches. But as one passes westward into the semi-arid districts along and west of the Missouri River, the amount of leaching in this drift sheet is found to become markedly less, and that too where erosion has been fully as great as in the Mississippi valley.

The best sheets to illustrate the Post-Kansan erosion are the Atlanta, Edina, and Kahoka, Missouri, quadrangles, not only because the drift there is sufficiently thick to dominate the topography but also because the maps are better executed than older contour maps of eastern Iowa and eastern Nebraska. The Des Moines, Iowa, and Waukee, Iowa, topographic sheets are, however, recent and of a high standard, and they serve to exhibit the contrast between the erosion of the Kansan and the Wisconsin, the southern edges of the maps being within the limits of the Kansan drift, while the remaining, much less eroded portion is in the Wisconsin drift.

As to the length of the Post-Kansan period of weathering and erosion compared with that of the Post-Wisconsin, only a rough approximation is likely to be reached by measurements of the changes effected in the two drifts. Dr. H. F. Bain has made a computation of the relative size of valleys in the Kansan and in the Wisconsin drift in the vicinity of Des Moines, Iowa, and ascertained the capacity of the Post-Kansan valleys to be about seventeen times that of the Post-Wisconsin.* While a considerable time must necessarily be allowed for a drainage system to get well started and thus correspondingly lengthen the Post-Wisconsin time and reduce the difference in the age of the Wisconsin and the Kansan drift, the periods of aridity through which the Kansan drift has passed prior to the Wisconsin stage of glaciation may fully offset this lengthening of the Post-Wisconsin time.

The question of a correlative of the Kansan drift in the Labrador field is considered below in connection with the discussion of the Pre-Kansan drift.

European Equivalents of the Kansas Drift.

In each of the glaciated districts of Europe a drift sheet is found in which the weathering is strikingly similar to that of the Kansan drift. In the Alpine region the apparent correlative is the Mindel drift; in north Germany it is the Lower Diluvium, the drift formed at the maximum extent of the Skandinavian ice field, when it reached the recesses of the mountainous districts of Silesia and Saxony; in Great Britain it is the chalky boulder clay of the southeastern counties. Not only is there a similar depth of leaching but also a similar degree of oxidation, and a deep penetration of weathered pipes and seams. In the Cromer sections on the east coast of England the weathered seams are conspicuous to depths of 10 to 15 meters, and the leaching of the chalky boulder clay is generally thorough to a depth of about 2 meters. The reddish tinge of the upper part of the weathered drift in these supposed Euro-

* Geology of Polk County, Iowa Geological Survey, vol. vi.

pean correlatives is also as conspicuous as in our Kansan. If we consider that since the time when the Kansan drift and its correlatives were deposited there have been repeated climatic changes from cold to warm and probably also from humid to arid, it may seem remarkable that weathering should have been so similar in amount in these widely separated glaciated districts. It is at least suggestive of worldwide influences in the control of the climatic conditions that produced glaciation.

Pre-Kansan Drift.

The Pre-Kansan drift of the Keewatin field, so far as yet known, lies entirely within the limits of the Kansan drift and has exposures only beneath the Kansan. It is from these exposures alone that one may learn the degree of weathering, and they are inadequate to throw much light upon its erosion. Recent studies in western Iowa, under the Iowa Geological Survey, indicate that herbivorous animals had taken possession of that region in the interval of ice recession between the Pre-Kansan and the Kansan, so it is inferred that there was plant growth such as comes only with a genial climate. Data bearing directly upon the amount of leaching of the gravelly surface portion of this drift were obtained by my assistant, R. T. Chamberlin, in 1907, at exposures near Afton Junction, Iowa, the type locality of the interglacial Aftonian exposures. Four classifications of pebbles from near the surface of the deposit show percentages of limestone pebbles ranging from 14 to 20 per cent, while two classifications of pebbles from underlying till, not affected by leaching, show 38 and 52 per cent of limestone pebbles. In other respects the pebbles of the gravel and of the underlying till are strikingly similar. It thus appears probable that the limestone content of the gravel was originally about the same as that of the till, and that nearly two-thirds of the limestone had been removed from the surface portion of the Pre-Kansan drift before it was buried under the Kansan. The limestone pebbles remaining in this surface portion are in an etched and deeply weathered condition, so that had there been but a moderate extension of the interglacial stage the limestone might have been completely removed. In places gravelly portions of the Pre-Kansan drift had become firmly cemented in this interglacial stage, so that masses were gathered up by the ice of the Kansan stage and incorporated as boulders in the Kansan till. The change which the Pre-Kansan drift experienced probably approaches if it does not equal that which the Illinoian has experienced, and appears to be greater than that which has affected the Wisconsin drift. It may therefore properly be referred to a distinct glacial stage.

Equivalents of Kansan or Pre-Kansan in the Labrador Field.

The writer has never had opportunity to study, or even to travel across, the area in New Jersey and northeastern Pennsylvania occupied by the sheet of old drift of the Labrador field to which Chamberlin and Salisbury have applied the term Jerseyan. The patchy distribution and weathered appearance

FIG. 7.

FIG. 7. Part of Oelwein, Iowa, topographic sheet showing topography of a so-called Iowan drift plain. The amount of erosion here displayed should be compared with that in the Illinoian, figs. 3 and 4, and Kansan drift, figs. 5 and 6. Scale, 1:173000. Contour interval, 20 feet.

reported by those who have studied it, seem to indicate an age as great as that of any drift sheet in the Keewatin field. It is, therefore, considered by these students a probable correlative of the Pre-Kansan or Sub-Aftonian drift of the Keewatin field. The old drift of northwestern Pennsylvania, which has been examined by the present writer, is thought from the weather-

ing and erosion to be at least as old as the Kansan drift, and possibly the correlative of the Pre-Kansan drift. Its aspect is decidedly older than the Illinoian drift exposed in the western part of the field covered by the Labrador ice sheet. The topography of the quadrangles within the limits of the Jerseyan drift and of the old drift of northwestern Pennsylvania is controlled to so slight an extent by glacial deposits that the topographic sheets are not likely to have much value in setting forth the amount of Post-Jerseyan erosion, and hence are not drawn upon for illustrations.

European Equivalents of the Pre-Kansan.

Upon turning to the European fields conditions somewhat similar to that of the Kansan and Pre-Kansan have been brought to notice. Thus in the Alpine region the oldest drift, known as the Gunz, is almost completely overridden by another old drift, the Mindel. In that region, as in the American, just discussed, it is difficult to determine the difference in age because of the meager exposure of the Gunz drift. The studies of Penck and Brückner, however, have shown that there was an advanced state of weathering of the surface of the Gunz drift before the Mindel glaciation buried it. The Mindel and Gunz drifts are thought by Penck to be separated by a shorter interval than that between the Riss and Mindel.* In the Skandinavian field observations by Nathorst and others indicate that in southern Sweden a set of striæ out of harmony with the ice movement which carried the lower boulder clay of Germany is likely to have preceded that movement. While the earlier movement may not have been sufficiently distinct from the later to constitute a separate stage of glaciation, Geikie has suggested applying to it a distinct name, Scanian, from the district in Sweden where it was brought to light.

Iowan drift?

Since it is through a study of weathering and erosion that the presence of the so-called Iowan drift has come to be questioned, it seems fitting that this discussion should include a brief statement concerning the leading features in the region that drift has been supposed to cover. The region lies in northeastern Iowa immediately east of the area covered by the Des Moines lobe of Wisconsin drift. The topographic maps which lie wholly or partly within its limits are the Decorah, Oelwein, Elkader, Winthrop, Farley, Stanwood and Rock Island. Fig. 7, which represents part of the Oelwein quad-

* Die Alpen im Eiszeitalter, p. 1168.

range, illustrates well the topography of the part of this region where the valleys are excavated entirely in the drift. Farther east the drift becomes so thin that rock ridges dominate the topography. It will be observed that the surface presents broad slopes, as in the Kansan drift, but the valley bottoms are less well defined, the slopes on either side extending nearly to the streams. Tabular divides are also wanting and considerable inequality is found along the lines of water parting. This region differs also from neighboring parts of the Kansan in being nearly free from loess.

The inspection of such a map as that given in fig. 7 naturally raises the question whether the departures which it exhibits from the typical Post-Kansan erosion, shown in figs. 5 and 6, may be interpreted as a superimposed youth, such as might result from a fresh invasion of the ice into a much eroded region of older drift. A study in the field would naturally be directed to the solution of the question of the existence of a drift sheet too fresh to be consistent with the interpretation that the valleys were entirely formed after its deposition, and a special search should be made to discover whether a fresh drift is so situated in the valleys as to indicate clearly that it was deposited after the valleys were excavated. Upon visiting the field in 1906 and again in 1907, and spending about two months in careful examination of the exposures on uplands, slopes, and valley bottoms, the writer was unable to discover any trace of fresh drift. The valleys were found to be filled with a concentrate of the more resistant constituents of the drift, the soluble constituents having apparently been removed just as in the weathered portion of the Kansan drift. The valleys are shallower than in the Kansan drift of southern Iowa and northeastern Missouri, and run out at their heads in so-called sloughs. But so far as discovered this shallowness is not occasioned by the deposition of a fresh sheet of drift, but rather seems due to a filling by slope wash. The ramification of the valleys into the uplands is not strikingly different from that found in the Kansan drift and seems to call for a maturity of stream work of a similar rank. In view of the fact that my own studies have not been exhaustive and that the Iowan invasion is still held by the Director of the Iowa Geological Survey, who has had a longer acquaintance with the region, I still consider the question of an Iowan invasion an open one.

Ann Arbor, Michigan, February 22, 1909.