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ART. XLI.—*On the Relationship of the Pleistocene to the Pre-pleistocene formations of the Mississippi Basin, south of the limit of glaciation;** by T. C. CHAMBERLIN and R. D. SALISBURY.

THE deposits made by the ice and by the waters which originated from it during the glacial period, possess a character so unique, and so markedly unlike that of the underlying formations within the glaciated area of the United States, that there has been little difficulty in discriminating between them. There have been differences of opinion as to the relative importance of the various agencies which are believed to have been operative in the production of the drift, and in some minor measure these differences still exist. But whether the drift of any particular region be believed to be the work of glaciers, or of icebergs or ice-floes, or of glacio-natant lakes or streams, or the joint work of two or more of these agencies, still the drift, as such, is clearly defined from the underlying strata. In many regions, this is true no less of the valley drift which stretches beyond the glaciated area along the avenues of discharge for the melting ice, than of the unmodified drift upon the extra-valley lands farther to the north, where the drift agent is believed to have been land ice.

* The writers have worked in such close association in the study of this and of correlated regions, that it is difficult to define their individual work and their respective responsibilities; nor is it important; but they have reasons for stating that the preliminary determination of the salient features of the correlation, and the direction of the investigation, are largely the work of Mr. Chamberlin, while the detailed investigation, the elaboration of results, and the preparation of this article are chiefly the work of Mr. Salisbury.

But in the central part of the basin of the Mississippi River below the latitude of glaciation, the difference between the deposits made by the waters originating in the melting ice, and the subjacent strata, appears to be much less obvious than in many other regions. In consequence, the recognition of the Pleistocene formations along the course of the Mississippi south of the limit of the general drift sheet, and therefore the correlation of the northern and southern Pleistocene formations, has not been free from difficulties.

The Loess.—The highlands bordering the Mississippi Valley on either side, between the parallels of 37° 30′ (the southern limit of glacial drift), and 35° are overspread by loess. The loess extends much below this latitude, but that is the lower limit of the area especially under consideration. A belt of loess similarly disposed occurs along the course of the Ohio, for a considerable distance above its junction with the Mississippi, though the loess along this stream is less constant in character, and its facies often different from that of the Mississippi River loess. Consonant with the general habit of this formation, the loess is best developed on the highlands immediately adjacent to the rivers. In such situations, the loess possesses the loose, open texture which is one of its most diagnostic characteristics. As the formation is traced eastward or westward from the Mississippi, or northward or southward from the Ohio, these characteristics gradually disappear. The open texture becomes less pronounced, and by almost imperceptible degrees passes from that of a loose, light loam, through that of a clayey loam, to that of a loamy clay. So far does this gradation proceed, that the texture of the loam at some distance from the streams, resembles much more closely that of the residuary earth upon which it rests, than that of the typical loess, on the immediate borders of the valley.

A change in color accompanies the change in texture. The buffish color which everywhere characterizes the river bluff loess in its normal development, becomes deeper with increasing distance from the streams, so that along the borders of the loess, where the texture has come to simulate closely that of the residuary earths, the color has become notably deeper than on the bluffs immediately fronting the river, and the deepening color has been a constant approximation to the color of the underlying residuary earth.

Accompanying the change in texture and color, are changes in the chemical character of the loess. Near the rivers it almost uniformly contains a considerable percentage of carbonates. Here too, it very generally contains shells, and concretions of calcium carbonate, the one a partial cause, and the other at once an index and a result of its calcareous character.

The shells, the concretions (*loess-kindchen*), and the calcareous nature of the loess, are features not less characteristic, though less universal, than the texture itself. As the texture of the loess becomes closer and its color deeper with increasing distance from the rivers, the proportion of carbonates diminishes, and may entirely disappear before the border of the loess is reached. The shells and concretions are limited to the calcareous portions of the loess, or they may be still more restricted in their distribution.

With increasing distance from the streams goes another change in the composition of the loess. The complex silicates (feldspar, mica, hornblende, augite, etc.), which are found to be very significant ingredients of the formation along the river bluffs, become less and less abundant, as the other normal characteristics disappear. They may be found, however, in the loams remote from the streams, after almost every other true loess feature has disappeared.

The thickness of the loess diminishes regularly with increasing distance from the rivers. So far does this thinning proceed, that at a distance of a few miles from the streams, but a thin mantle remains.

The features thus indicated as pertaining to, and defining the loess in the region under consideration, are the features which characterize it throughout its distribution to the north along the Mississippi, and along its tributaries in Illinois, Missouri, Iowa, Wisconsin and Minnesota, and along the tributaries of the lower Ohio, in Illinois and Indiana.

Throughout much of this territory the loess lies upon the glacial drift. In southern Illinois, for example, the drift for many miles north of its southern boundary is overspread with loess, or with clay-like loam which may be traced into direct continuity with the normal, open-textured, calcareous, shell- and concretion-bearing loess, along the immediate valleys of the streams. Here too, in scores and hundreds of places, especially in southeastern Illinois, it may be seen that the surface of the drift upon which the loess rests, is one which gives no evidence of exposure to the atmosphere before the mantling loess was spread upon it. Had such exposure found place, the fact would have left its record in the oxidation of the exposed surface, or in the accumulation upon it of an old soil, traces of which would still be found beneath the loess. But in southeastern Illinois and the adjacent parts of Indiana, no zone of oxidation, and no vegetable layer, or trace of old soil, separates the loess from the till beneath. It would not be necessary to suppose that such a zone as that here referred to would necessarily be preserved at all points, until the present time. But its universal absence over large areas, under conditions which

must have been favorable for its preservation, had it ever been developed, seems to be conclusive against the hypothesis that it ever existed. That the conditions were favorable for its preservation is proved by *its well-nigh universal presence under the loess immediately south of the drift border, in the same region.*

In many places, it may be clearly seen that the superficial loess-mantle and the stony drift beneath, meet each other in a thin zone of gradation. That is, the pebbles of the drift frequently occur in the basal portion of the mantling loess, in and just above the horizon where the imbedding matrix changes from a gritty clay (till) to a gritless loam or loamy clay (loess). In other places, there is a more or less marked accumulation of drift pebbles* immediately below the loess or its clayey equivalent, marking its junction with the till. Both these relationships find ready explanation in the hypothesis that glacial waters covered the till, and spread the mantle of loess upon it immediately after the ice retreated. And no other hypothesis seems to meet the case. In the judgment of the writers, therefore, the relationship between these two deposits, the till and the loess, as seen in innumerable sections, in southeastern Illinois and southwestern Indiana, is such as to admit of no second interpretation as to their sequence. The loess, in the regions where such sections are found, was deposited immediately after the till, so far as not actually contemporaneous with it. We distinguish other sheets of loess, contemporaneous with other stages of glaciation, and some of these are separated from underlying till by old soils, but these do not require special consideration here. The active agent concerned in the production of the loess is believed to have been water, and the material of the loess was in part derived from the till beneath, and in part from the glacial silt carried southward from the melting ice to the north. The evidence that the loess is really a glacier-made silt, re-worked by water, has been elsewhere discussed.†

The age of the loess covering the drift along its southern border, would seem to be clearly fixed relative to the underlying till. The till of the region belongs to the first glacial epoch, as we have been accustomed to distinguish the glacial epochs,‡ and this loess belongs to the closing stages of the same epoch, after the ice had retreated somewhat, but while the region to the south of its edge was still overspread, in part at least, by waters originating from it.

The first glacial epoch embraces at least two episodes of glaciation, separated by an interval when the climate of the

* *Steinsohle* of the German geologists.

† Sixth Annual Report, U. S. G. S., page 278 et seq. ‡ Loc. cit., page 212.

southern part of the drift-covered area was so far ameliorated as to allow the growth of vegetation upon the drift of the first episode. In southeastern Illinois and the adjacent parts of Indiana, the ice advance of the second episode of the first epoch seems to have been equal to, if it did not exceed, that of the first episode. This seems not to have been the case in some portions of southwestern Illinois, but in southeastern Illinois, and indeed in most of the southern part of the state, the till immediately beneath the loess is referred to the second ice incursion of the first glacial epoch. The loess here under discussion is therefore to be referred to the close of the second glacial episode of the first glacial epoch. But it may be traced across the limit of the drift from north to south. The continuity is complete, and the character of the formation is the same on both sides of the line which marks the limit of ice advance. It is a continuous mantle, overspreading alike the drift border on the north, and the residuary earths which the ice did not disturb, on the south. If, therefore, the age of the loess which covers the drift be first glacial (first episode), the age of that which lies south of the drift, in the area under discussion, is likewise first glacial.

Between the relationship of the loess to the till north of the limit of glaciation, and the relationship of the loess to the residuary earths of the Paleozoic rocks immediately outside the drift, there is one important difference to which reference has already been made. The presence of a weathered and highly oxidized zone, immediately subjacent to the loess, south of the drift limit, is as conspicuous as is its absence to the north. This oxidized zone is the upper surface of the residuary earths. There is in places, a slight admixture of residuary material and loess at the junction of the two. But the body of the residuary earth is clearly separated from the body of the loess. The fact of the existence of a long interval between the loess and the residuary earths beneath, is as clearly indicated on the one hand, as is the fact of the absence of an interval between the loess and the underlying till on the other. The phenomena on each side of the drift limit, strengthen the conclusion drawn from the phenomena on the other.

There is in the nature of the case no manifest reason why the formation of loess should not have accompanied and followed the ice action of the first episode of the first glacial epoch, just as it accompanied and followed the second episode. Assuming this to have been the case, there should be a two-fold division of the loess south of the drift, theoretical, if not observable. Such division has been sought for, but without completely satisfactory results, throughout most of the area under consideration. There are a few localities east of the

Mississippi river, as at Memphis, Tenn., where there is some evidence of the division here suggested. The evidence consists in the presence of a thin layer of humus-stained (apparently) loam, between beds of loess, suggesting an old soil. At Forrest City, Ark., there is a similar layer of dark loam, in similar relationships, while at numerous points farther north on Crowley's Ridge, both in Arkansas and Missouri, there is a thin zone of oxidized (red) loam, occupying a corresponding position. The great majority of sections, however, present the aspect of consecutive deposition; at least no positive signs of separate stages of deposition have been observed.*

The Gravels and Sands subjacent to the Loess. ("Orange Sands.").—Beneath the loess, in the southernmost counties of Illinois, in northern and northwestern Kentucky, in western Tennessee, in northeastern Arkansas, and southeastern Missouri, there is a remarkable series of gravels and sands. In portions, at least, of this area, the gravels and sands have been known in geologic literature under the name of Orange Sand. Unfortunately for clearness of understanding, this term has been differently used by different geologists. The Orange Sand or Lagrange formation of Tennessee (Safford), is regarded by Professor Safford as the partial equivalent of Professor Hilgard's Northern Lignitic, and is referred by both geologists to the Tertiary, Safford regarding it as Miocene, though expressing doubt whether it be not older, and Hilgard regarding it as Eocene.† The Bluff Gravels of Safford appear to be the Orange Sand of Hilgard, and are classed by both geologists as Quaternary. Within the area under consideration, both the Lagrange or Orange Sands of Safford, and the Bluff Gravels (Safford), or Orange Sands of Hilgard, occur, and both are covered by loess. With the classification of these formations, and with the question of the relations between the Lagrange Sands and the Bluff Gravels, this article does not deal. It has only to do with their pre-pleistocene age, and with the relation of the loess to them. The Bluff Gravels (Safford) occupy the surface (below the loess) of the river bluffs at various points in Tennessee, while the Lagrange Sands occupy the surface farther east. Farther north, however, sands and gravels which appear to be the equivalent of the Bluff Gravels of Tennessee, have a much greater thickness than in the latter state, and it is not altogether clear that they do not include beds below the Bluff Gravels of Safford. Be that as it may, the gravels have a much greater vertical range in Southern Illinois than has been observed by the writers further to the south. The Bluff Gravel formation "consists

* See further the foot note at the close of the article, p. 377.

† This Journal, vol. xli, page 370, 1864.

generally, of coarse yellow and orange sands, with everywhere more or less coarse gravel, and has usually a layer of white or variegated clay at the base. The gravel is . . . . sometimes cemented by oxyd of iron into great blocks of coarse conglomerate."* Setting aside the question as to subdivisions of the gravels and sands and clays, which the geologists of Illinois have seen no good reason for separating,† it is true, generally speaking, that the body of the gravel overlies the sand. More accurately, the gravel predominates above and the sand below, though the gravel is to be found more or less generally distributed through a considerable vertical range, in the formation in southern Illinois.

Within this series, there are often seams and pockets, or even considerable layers of kaolin-like clay, remarkable alike for its irregularity of development and its brightness and variety of coloring. Oftener than otherwise, the clay is in the lower part of the sand and gravel stratum, but many localities are known to the writers where heavy beds of gravel and sand occur below a considerable thickness of clay. In such cases at least, the clay would seem to be of necessity correlated with the sands and gravels.

At several horizons in various localities, the sand becomes more or less coherent from the presence of a fine sticky matrix of earthy material. The matrix may even predominate over the sand, giving rise to a gritty clay or loam, rather than to a sticky sand. Such gritty clays are wholly unlike the kaolin-like clays above noted. The latter are gritless and variegated in color. The clays here designated as gritty, have always a goodly proportion of coarse sand, and are either of a deep red or a brownish color. In these gritty clays there are frequent laminæ of sand, of variable thickness, and these laminæ are often cemented, forming layers of sandstone of considerable hardness. The same is frequently true of laminæ of sand, and even of layers of considerable thickness, within the body of the sand itself, where there is little admixture of earthy material. In all these cases iron oxide is the chief cement.

Induration is not confined to the sand. Not rarely portions of the gravel are cemented into a firm conglomerate, the cementing material being the same as in the case of the sand. More commonly than otherwise, it is the uppermost portion of the gravel which has been indurated, but there are so many exceptions that this can hardly be said to be the rule. The thickest beds of conglomerate which have been seen by the writers (near Metropolis, Ill.) occur at a low horizon, and (though not shown in vertical section) beneath considerable thicknesses of sand, clay, and loose gravel.

* Safford, this Journal, vol. xxxvii, page 371, 1864.
† Engelman, vol. i, Geol. Surv., iii, page 423.

It is a peculiarity of the distribution of loess, that elevations within the area of its occurrence seem to be no obstacle to its presence. The loess is quite as likely to find its normal development on the higher lands as on the lower. Within the area especially under consideration, the same may be said concerning the gravels. They exist on the highest hills, under the loess, and in fact, speaking generally, find there their best development. The gravels are frequently absent from the slopes of the hills, or but meagerly developed upon them, even when present in quantity upon their crests. These sands and gravels, or at least the portion of them known under the name of Orange Sand (Hilgard), have heretofore generally been regarded as Quaternary, and have even been referred to the Champlain epoch.*

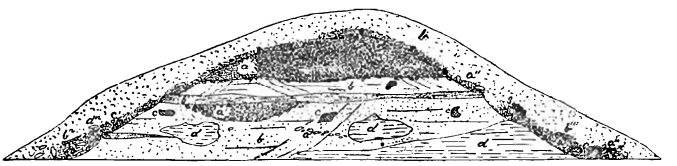
We have already seen, however, that the evidence is conclusive that the loess is to be referred to the melting waters of the first glacial epoch, and the Orange Sand, so far from being referred to a time subsequent to the second glacial epoch, must be referred to a time earlier than the closing stages of the first glacial. How much earlier?

It would not be irrational to suppose that the waters of the melting ice might carry down, along the courses which they followed, great quantities of detritus. Gravel and sand might thus be distributed wherever the currents were strong enough to carry them, conceivably for great distances south of the limit of ice advance, just as gravels are carried far beyond the ends of glaciers to-day by the streams issuing from them. The Mississippi valley must have been an avenue for the discharge of glacio-natant waters, and it would not be strange were glacial gravels found in the same, beyond the extra-valley drift limit, just as glacial gravels, originating from the ice of the second epoch, are found down the valleys far beyond the limit of ice advance at that time. Were the Orange sands and gravels formed in the manner above indicated, and at the time which this origin would necessitate, viz: in the first glacial epoch, we might find evidence of the fact along three several lines, any one of which would be conclusive.

If the gravels be referable to the time of glaciation immediately preceding the deposit of the loess, we should find the loess spread over these gravels conformably, or with only such slight unconformity as might have been developed locally in the interval between the deposition of the gravels, when the

* Hilgard: Agriculture and Geology of Mississippi, 1860. Also this Journal, vol. xli, page 311, 1866. Safford: *Ibid.* vol. xxvii, page 361, 1864. Dana: Manual of Geology, 3d edition, page 548. LeConte's Elements of Geology, page 540. Loughridge: Kentucky Geol. Surv. Jackson Purchase Region, 1888. page 57 *et seq.* By the Geological Survey of Illinois, the formation in question has been regarded as Tertiary. Vol i, page 417, *et seq.*, and page 447, *et seq.*

streams must have been active, and the deposition of the loess, when the streams must have been sluggish. In point of fact such conformity, or so much of conformity as this hypothesis would demand, does not exist. The following diagrammatic section shows the relationship which may be seen to exist between the loess and the gravels and sands, at numerous points in southern Illinois.



Loess (*l*) covers the whole hill. Beneath it, the hill is capped with gravel (*a*). This constitutes a well developed layer, several feet in thickness. The pebbles composing this layer almost uniformly lie upon their surfaces of greatest diameter, and appear to be closely packed. The gravel may be cemented or not. On the slopes of the hill below the gravel layer, there are pebbles (*a*″) few or many, identical in character with those above. Unlike the gravel layer above however, these pebbles have no particular arrangement, and have the appearance of having rolled down the slope to their present position. Along with the loose pebbles there may be masses of conglomerate originating from the gravel above, in case the same is cemented. Beneath the gravel, there is a considerable body of sand (*b*), sometimes distinctly stratified and sometimes not. Seams or pockets of gravel (*a*′) identical in character with that above, may occur in the sand, and occasional pebbles exist where no well defined seam can be traced. Laminæ of the sand at frequent intervals are indurated (*b*′), and bits of ferruginous sandstone derived therefrom, (*b*″) are freely mingled with the pebbles which have come down from higher levels. The pebbles and the sandstone fragments lie upon the eroded edges of the nearly horizontal layers of the sand and gravel stratum. Together with these talus materials there are often large numbers of iron-cemented sand-concretions (*c*′), identical in kind with those (*c*) which may be taken from the undisturbed beds of sand. Like the fragments of the sandstone, they originated close at hand, in the sand layers of the hill itself.

The erosion slopes of the hills, cut out of the horizontally though irregularly stratified sands and gravels, are thus seen to be strewn with gravel, sandstone debris, and ferruginous concretions, originating from the same series higher on the slope. Overspreading the whole, covering the crests of the

hills and the eroded edges of the sand and gravel layers, together with their thin covering of local debris, as above indicated, is the mantle of loess. It is absent only where recent erosion has been sufficient to effect its removal. How far the uniformity of distribution of loess over regions of strongly accentuated relief may be due to the creep of the plastic material down the slopes, is not here discussed; but this is not believed to be an adequate explanation of its uniform slope distribution. The loess and its clayey equivalents, are confidently believed to have been deposited like a mantle over a previously eroded surface. If the body of the hills be Paleozoic rock with only a capping of gravel and sand, the relation of the loess to the latter is not altered.

In view of this marked unconformity, it seems necessary to conclude that the deposition of the gravels and sands must have antedated a long period of pre-loessial erosion, since they themselves suffered erosion, and very extensive erosion, before the close of the first glacial epoch, when the main body of the loess appears to have been deposited. In many places there is evidence that cementation of the gravels and sands of the Orange Sand formation, had been accomplished before erosion had proceeded far. But since cementation may proceed rapidly, it does not seem necessary to allow for any notable interval of time, succeeding the deposition and preceding the erosion of the sands and gravel. Such interval must have been long enough, however, to allow for the shifting of attitude necessary to change the area of Orange Sand, from one of subaqueous deposition, to one of subaërial erosion.

The force of the above argument is not destroyed, although it may seem to be weakened, by the fact that the relationship between loess and Orange Sand here depicted, does not hold throughout the whole area of the development of the latter. Nowhere else, within the range of the writers' observation, is the unconformity so well shown as in southeastern Illinois. But similar facts are less strikingly exhibited at various points in southeastern Missouri, in western Kentucky, in Arkansas and Tennessee. That the degree of unconformity should vary is not strange, since the attitude of the land was such as to expose it to greater erosion on the flanks of the valley and the highlands of southern Illinois, than in the axis of the valley, where the approach to conformity is greatest. In the south the land appears to have remained so low as to allow of little or no erosion beween the Orange Sand and the loess.

From a second line of evidence it may be safely concluded that there was an interval of considerable duration between the deposition of the loess and the deposition and exposure of its substratum.

Although the lapse of time since the closing stages of the first glacial epoch is great, the loess does not appear to have undergone any considerable alteration in chemical character since the time of its deposition. Its surface portion for a depth of 4–6 feet, often shows unmistakable signs of oxidation and weathering. Locally, oxidation has penetrated to greater depths. The particles of the surface portion have been disintegrated by chemical and physical means, so that they have become notably finer than they were at the time of their deposition, and finer than those of the lower portions at the same locality. Were another sheet of loess to be spread over the first to-day, the distinction between the two in later times would be perfectly clear, on account of the chemical and physical changes which the present loess has suffered in its superficial parts. Yet even this distinction would be far less conspicuous than that which now exists between the loess and the surface of the underlying material. This comparison may be in some sense unfair, since it is true that the substratum of the loess and the loess itself are inherently dissimilar; but it is not that difference which is here insisted upon. It is the degree of alteration which the surface of the material below the loess has suffered—an alteration such as surface exposure would effect—which is of significance, and this alteration, which must have taken place before the deposition of the loess, is in general very much greater than that which the surface of the loess has undergone since the close of the first glacial epoch.

In many places there is a thin layer (4–8 feet) of earth above the gravels of the Orange Sand series. This is believed to represent, in many places at least, the last work of the waters which deposited the coarser materials below. It is commonly somewhat gritty, the gritty element (sand) partaking of the nature of the sand below, but it is distinctly clayey in texture. The textural difference between it and the loess is much less than that between the loess and the upper surface of the Orange Sands as commonly developed, but quite as great as that between the loess and the till. But it is in just such situations that the line marking the junction of the loess and the underlying earth is most conspicuous and significant. The latter shows the texture and deep coloration which denote the oxidation and surface alteration that result from long exposure to atmospheric action. In many places the junction of the loess with this layer, is the most obtrusive line in the section. In more than one place, it may be noted in passing, does this super-gravel earth show an eroded surface, upon which the loess rests unconformably, though the degree of unconformity in such cases is often slight.

The chemical changes in the sands and gravels are not confined to their surfaces. Beneath the surface, and so far beneath as to be below the zone of active surface weathering, there is evidence that great changes have taken place, denoting the lapse of long intervals of time. The most obvious of these changes is the extent to which the leaching and concentration of coloring matter has been carried. Besides this there are various other changes less clearly defined, but which in the aggregate give to the whole series below the loess an appearance of age which is unmistakable. The changes which the Orange Sands have undergone since their deposition, certainly appear to be several times as great as those which the loess has suffered since its deposition. And while this might not be a safe standard for chronological measurements, taken by itself, it has a strong corroborative significance, since it falls into correspondence with conclusions drawn from other lines of evidence.

Outside the drift region, the material underlying the loess is often residuary earth derived from Paleozoic rock, instead of from Orange Sand. So far as oxidation and the changes induced by exposure are concerned, the residuary earths of the Paleozoic rocks do not seem notably more affected than those of the Orange Sands. This is but an eye estimate, and may be erroneous quantitatively considered, though it is based on the observation of hundreds and thousands of sections. But in any case the fact of very profound affection of the pre-loessial surface by atmospheric agencies in pre-loessial times, is believed to be beyond dispute. And this is no isolated phenomenon. Generally speaking, it holds throughout the length and breadth of the extra-drift loess territory, within the limits of the writers' observation, and by report much beyond. On this point Professor Hilgard writes:* "The Orange Sand . . . . . as a rule contains nothing that is capable of further oxidation or solution by atmospheric agencies, unless it be silex. Such complete peroxidation and lixiviation, the effects of which have been largely extended into underlying formations, unquestionably indicates a long subaërial exposure, from which the northwestern stratified drift was in a great measure exempt." Dr. Loughridge† likewise recognizes the presence of "a bed more clayey and darker (than the loess) in color," between the loess and Orange Sand at Hickman, Ky., and "4 feet of the stiff darker loam" below the loess and above the gravel at Columbus, Kentucky. These "darker loams" represent the oxidized and

* This Journal, vol. iv, page 266, 1872. The same point is repeatedly insisted upon by Professor Hilgard in other articles in this Journal, and in his report on the Agriculture and Geology of Mississippi.

† Kentucky Geol. Surv., Jackson Purchase Region, F., 1888, page 78.

humus-stained material of the pre-loessial surface, as we interpret the phenomena, and are to be sharply discriminated from the loess, with which, except in the matter of position, they have nothing to do We fully concur with Professor Hilgard in his conclusion that this material "unquestionably indicates a long subaërial exposure," before the deposition of the loess. In a few localities where the pre-loessial surface does not appear to have suffered erosion, and where the loess therefore appears to be conformable with the substratum, the junction is marked by a humus-stained layer indicating an old soil. This occupies the same position, relatively, as the oxidized and weathered upper surface of the Orange Sands described above, and points to the same conclusion as to the sequence of events.

From the relative position of loess and Orange Sand, it is evident that the latter is the older. From the stratigraphic relations of the two formations, it is equally evident that the deposition of the former followed that of the latter, only after a considerable interval of time. The chemical changes which the older formation has suffered, strengthen the conclusion drawn from the unconformity, that the interval was long.

The main deposition of the loess seems to have taken place during the second episode of the first glacial epoch. The only evidence that we have thus far developed of a similar deposition that could be referred to the earlier episode of the first glacial epoch, is found in the lower stratum of loess, separated from the higher by the humus-marked and oxidized horizon, referred to above, as occurring at Memphis, Forrest City, and several other points on Crowley's Ridge. This lower subdivision of the loess, although fairly differentiated at these points, is not distinguishable at a sufficient number of points to make it certain that it is the fluvial representative of the first episode of the first glacial epoch.* If the force of the correlation of this lower division of the loess with the earliest drift be set aside, it might be supposed that the Orange Sands were synchronous with the first episode of this epoch. Were this their age, there would have been an interval between their deposition and the deposition of the loess. While this interval is not believed to have been long enough, or nearly long enough, to bring about the changes which the Orange Sand suffered before the loess epoch, our means of estimating time may be supposed to have led to erroneous conclusions, we therefore may seek the answer to the present question along another line.

* The observations recorded in the footnote on page 377, seem to make it reasonably certain that the lower subdivision of the loess here referred to, is the fluvial representative of the first episode of the first glacial epoch. This however does not weaken the argument here adduced, although it may seem to make it unnecessary.

Were the gravels and sands of the Orange Sand series to be referred to the first episode of the first glacial epoch, their origin should be revealed by their constitution, if glacial waters were the depositing agent. In this case we should confidently expect to find pebbles of northern origin among these gravels. It would not be necessary to suppose that all the gravel deposited by a stream springing from the glacier would necessarily be northern, since tributaries might bring in material from other directions, in the ordinary process of river degradation. But emphasize the importance of this latter consideration as we may, it yet remains an indisputable fact, that, were the conditions of drainage such that tributaries could bring gravel to their main in great quantities, the main itself, if springing from the ice, would inevitably bring something of glacial debris, which would be found mixed with the material of more local origin, brought in by the tributaries. And this would be true, even if the accumulation took place at an earlier stage of the glaciation of the first episode, long before the ice approached the latitudes under consideration; for the drainage basin of the Mississippi reaches several hundred miles to the northward, and probably extended still farther in that direction at an early stage of the ice invasion, when the ice had so far spread itself over the British possessions as to prevent drainage into Hudson's Bay.

If then, the Orange sands and gravels were accumulated during the first glaciation of the first glacial epoch, as valley or estuary deposits, we should of necessity have northern material represented in this formation, if not in the form of sands and gravels, *at least in the form of silt.* Such, however, is not the fact. In the hundreds of exposures of gravel which the writers have seen, large numbers of which, in various localities in six states, have been examined in detail for this especial purpose, not a single pebble of demonstrably northern or glacial origin has ever been found. Northern pebbles have been found associated with pebbles *derived from the gravels* under consideration, but only in such situations that the secondary character of the deposits containing such pebbles, was certain or altogether probable, from considerations entirely independent of those here adduced. And the freedom from glacial gravel and sand and silt does not characterize the Orange sands simply in their most southern distribution, where the local material might naturally be more abundant than to the north, but even up to the northern limit of the Orange Sand region, scarcely more than a score of miles from the southern border of the glacial drift, the northern or glacial materials are likewise altogether absent.

Even in the silts and loams that overlie the gravels and underlie the weathered and humus-marked horizon which divides the gravels, sands and silts below, from the loess above, microscopic examination fails to reveal the particles of the various complex silicates and dolomite which characterize the loess above, and which characterize all glacial silts with which we have any familiarity. It is to us wholly incredible that these sands and silts could have been deposited by a river originating in a glaciated tract, without including these characteristic products of the glacial grinding.

If it be suggested that the gravels date from the interval between the two glaciations of the first glacial epoch, and so from a time when the streams did not carry glacial waters, the case is no better. For on this hypothesis, even if the main stream did not carry glacial waters at the time of the deposition of the sands and gravels, it was still coursing through a basin covered with drift, and this drift must certainly have yielded its contributions to the river gravels, for by hypothesis the conditions of drainage were such as to allow the rivers to transport gravel and sand. The only escape from this conclusion would be to suppose that neither the Mississippi nor its tributaries north of the limit of drift, had power to transport sand and gravel, or even silt, and that both the Mississippi and its tributaries south of the drift limits, had such power. But it is incredible that there could have been drainage conditions up to within 25 miles of the edge of the ice, or up to within 25 miles of the drift sheet if the ice had retreated, such that enormous quantities of gravel could have been brought in by tributaries from right and left, and carried down by the Mississippi well toward the Gulf of Mexico, while the Mississippi just above the point where current velocities necessary to the above work existed, should be so sluggish as to bring down nothing whatever of glacial gravel or sand or silt from the north. If the main were strong enough to carry down the gravel of its extra-drift tributaries (and it certainly was, if the Orange gravel be river gravel at all, or if it ever were transported through the Mississippi valley), it would in all likelihood be strong enough to erode above these tributaries, and the material which it brought down from its intra-drift course, would be admixed when deposited, with that contributed by the extra-drift tributaries. If then the Orange gravels be river gravels, and if drift existed in the Mississippi basin when they were deposited, even if the ice had wholly retreated from the same so that no glacial waters coursed through the valley, such drift must certainly have yielded a contribution of gravel and sand to the Mississippi, both directly and through tributaries, at the same time that the tributaries south of the drift

limit were making their contribution of sand and gravel. In this case as in the other, there would necessarily be northern material in the gravel. The freedom of the Orange sands from all northern material, therefore, seems altogether conclusive against the reference of its gravels to the time of the first glaciation, or to any time subsequent to the first glaciation.

We are not oblivious of statements concerning the constitution of the Orange sand and gravel, which are quite at variance with our own. By implication at least, all geologists who have referred them to the Champlain epoch, assign them a northern origin. Professor Hilgard thinks the difference between the Orange sand formation and the northern drift, "quantitative rather than qualitative," and that the materials of the two "are essentially correspondent,"* but we have been unable to find any basis in the regions we have studied, for such conclusions.

If the position of the Orange sands under first-glacial loess be fatal to their reference to the Champlain epoch, and if their unconformity with the loess, and their "perfect peroxidation" antecedent to the deposition of the loess, be fatal to their reference to an epoch immediately preceding that of the loess, no less does the complete absence of glacial material from the Orange sands and gravels, seem to us to preclude their reference to the ice period, or to any period subsequent to the first ice invasion. We are therefore shut up to the conclusion that the Orange sands are Pre-pleistocene. And even if an occasional northern Archæan pebble should hereafter be found in the Orange sand, we should not, on the strength of this evidence alone, regard our present conclusion invalidated; for the drainage basin of the Mississippi reaches well back into the area of Archæan rocks, and it would not be at all surprising if Archæan pebbles from this source should have found their way into the lower Mississippi Valley before the glacial period.†

It may be an open question whether the formation below the loess in the region under consideration, immediately preceded the Pleistocene, but it is not the purpose of this article to discuss that question. It is pertinent to the subject here discussed, however, to remark that the conditions of drainage during the first glacial epoch were such as to produce only exceedingly sluggish currents, so far as now known. But the Orange sands, whether of fluvial or estuarian deposition, date

* This Journal, vol. xli, pp. 313 and 315, 1866.

† Hilgard says (this Journal, xli, p. 318), that there have been found "rare and well worn pebbles of greenstone, porphyry, trappean rock, and even mica schist, ... among the shingle of the Mississippi band." and raises the question whether they may not have originated from Arkansas. Considering the absence of such material in the gravels of the Orange sand formation farther north, this hypothesis seems plausible.

from a time when drainage conditions were such as to allow the rivers to bring in large quantities of gravel, and often of very coarse gravel, from widely different sources. It is therefore manifest that the attitude of the country must have been very different in the Orange Sand and the glacial epochs, and the shifting of attitudes to match the drainage conditions of these two epochs, may have involved a considerable lapse of time.

In the light of the foregoing evidence, we find but one conclusion possible, respecting the age of the Orange Sand. In six states at least, it is true that beneath the loess and above the Orange Sand there is an old surface so deeply weathered and oxidized, as to indicate a long period of exposure before the deposition of the loess. Occasionally this old surface is humus-stained, indicating the growth of vegetation upon it, before the subsequent formation was made. Between this weathered and oxidized or humus-stained surface and the loess, there is wide-spread and often striking stratigraphic unconformity. Everywhere below this horizon, which is clearly recognizable in nearly every one of the thousands of exposures seen by the writers, there is an absence of material which can be referred to a glacial origin, while above this horizon, the loess and other fluvial deposits contain material of glacial derivation.* *This old surface, this horizon of oxidation, weathering and erosion; this horizon below which glacially derived materials do not occur, and above which they are present, we hold to be the dividing plane between the Pleistocene and the Pre-pleistocene formations.*

Thus far no mention has been made of certain beds of gravel which have given rise to more or less of misinterpretation. So soon as the gravels of the Orange Sand series were elevated above the waters which deposited them, their degradation began. From these Pre-pleistocene gravels, materials have been eroded and re-deposited throughout the course of Pleistocene time, and these processes of erosion and re-deposition are still in progress. That there are, therefore, beds of gravel derived from the Pre-pleistocene formation in Pleistocene times, goes with saying. Such of these beds as were formed in Pleistocene time previous to the deposition of the loess, might well contain glacial pebbles. Such of these beds as were formed during the epoch of the loess, and in the region where the loess was accumulating, necessarily contain something of the later material. In post-loessial times too,

* Microscopic study of these silts and earths cannot be said to have been carried to an exhaustive extent. But the statements here made seem to be fully warranted by the work already done.

loess and gravel have been carried down slopes and deposited together at their bases. But none of the gravel beds of this category belong to the Orange Sand formation, or to the formation of bluff gravels of Safford, and their existence has no bearing upon the conclusion cited above.

It remains to indicate briefly the relationship of the second glacial deposits to those of the first, in the region under consideration. Starting from the points where the edge of the ice sheet crossed them, trains of gravels stretch down the valleys which served as avenues of discharge for the glacial waters. From the terminal moraines of the second epoch in which they head, these gravel trains, in the form of valley plains, extend down the valleys for great distances. Into these plains, post-glacial streams have sunk themselves, and such portions of the plains as have escaped removal constitute the gravel terraces which are so generally found in the valleys heading within the area of second glacial drift, from the Atlantic to Dakota. From the position of these terraces in relation to the terminal moraines, there can be no doubt as to their second glacial age. Their constitution too, in comparison with that of the material of the same grade of coarseness in the adjacent second glacial till, confirms the conclusion to which their position leads. Traced down stream, these terraces decline, somewhat rapidly at first, but soon more slowly. There is also a change in their physical constitution as followed down the valleys. The coarse gravel issuing from the moraines soon gives place to finer, and this ultimately to sand. Often there is but a single terrace, representing the level of the glacial flood plain, but often also, there are terraces at lower levels, representing subsequent stages of post-glacial river degradation.

These terraces of the Mississippi Valley are of especial significance in this connection, since this valley traverses the region under consideration. Not only does the altitude of the main terrace above the sea decline southward from the moraine, but its elevation above the stream likewise diminishes in the same direction, until it disappears altogether below the present flood plain of the Mississippi.* We have not seen the terrace south of the limit of glacial drift in Illinois, though terrace remnants near the mouths of tributaries occur at about that latitude, and may exist still further down the valley.

In the Ohio Valley at Louisville, there is a corresponding terrace, built up of material brought down by tributary streams heading within the area covered by second glacial ice. This

* Below the point where second glacial terraces have been identified, there are, in places, low plains slightly above the present flood plain of the Mississippi, which possibly are to be correlated with these terraces.

terrace, if we correlate rightly, may be traced nearly to the junction of this valley with that of the Mississippi. The streams tributary to the Ohio from the north, have their systems of terraces corresponding to those of their main, and the streams tributary to the Mississippi—so far as they head within the area of second glacial drift—are likewise terrace-bordered. At various points in many of these valleys, the terraces have been removed by late erosion, so that the modern flood plain extends from bluff to bluff.

The Mississippi Valley south of the latitude where the terraces occur, is known to have a filling of considerable depth and of geologically recent age. This filling, as we interpret, is in large part of second glacial origin, is in fact the southward extension of the northern terraces, and constitutes the only southern representative of the second glacial epoch. We have never seen the material brought up by the borings in the Mississippi flat, but borings in the Ohio flat, not far from the Mississippi (Mound City, Ill.), show sand of unmistakably glacial origin. Here the filling is certainly second glacial. The inference that the corresponding filling of the Mississippi is of the same age, lies close at hand, quite apart from the argument drawn from the southward decline of the Mississippi terraces, and their disappearance beneath the flood plain.*

* Since this article was written, the junior author has revisited some of the localities referred to in the first paragraph of p. 364, and at a season especially favorable for observations bearing on the question here raised. The lack of homogeneity in the loess is much more conspicuously shown when the face of the section is wet, than when it is dry, and it was mostly in the latter condition that the loess sections of this region had been seen heretofore. The new observations seem to leave little doubt that the loess, outside the drift limit, is to be referred to two episodes of deposition. The loess sections just east of Forrest City, Ark., seem most conclusive. Here there are two loesses, separated by a thin belt of humus-stained soil. This soil constitutes a sharply marked horizon throughout considerable parts of the extensive railway cuts near the station. It is not everywhere equally conspicuous, apparently containing varying amounts of organic material: but well-defined or ill-defined, it is a very persistent feature of the Forrest City cuts. The loams above and below this soil are identified as loess by their mineralogical constitution, by their fossils and by their *kindchen*. The upper surface of the lower loess sometimes shows unmistakable signs of oxidation and weathering, just below the soil. Laboratory tests for organic matter sustain the determination made in the field, that the coloring matter of the old soil is of vegetable origin. At scores of points in Illinois, Kentucky, Tennessee, Arkansas and Missouri, a similar division of the loess occurs, as distinctly marked as in some parts of the Forrest City section, where the less clearly marked soil is traceable into direct continuity with that which is unmistakable.

The lower division of the extra-drift loess we refer to the first episode of the first glacial epoch.