

*Oleandridium vittatum* (Brong.), Schimper (?).  
*Pterophyllum princeps*, Oldham & Morris (? *P. Morrisianum*, Oldh.,  
 if these two are distinct species!).  
*Pterophyllum Rajmahalense*, Morris.  
*Palæozamia* cf. *brevifolia*, Braun.  
*Ptilophyllum*, sp.  
*Walchia*, sp.

Finally, I should like to call your attention to the papers of my friend H. von Jhering (now Director of the Museum Paulista in São Paulo, Brazil) bearing upon the old Mesozoic relations of South America with New Zealand and Australia—"Die geographische Verbreitung der Flussmuscheln" (Das Ausland, 1890, Nos. 48 and 49) and "Ueber die alten Beziehungen zwischen Neuseeland und Sudamerika" (*ibid.*, 1891, No. 18)—if you are not already acquainted with them.

TABLE (A) REFERRED TO ABOVE (see p. 448).

Bajo de Velis. Sierra de Los Llanos, Sierra  
 de la Rioja (Vilgo, Amanao).

*Neuropteridium validum*, Fstm.  
*Glossopteris communis*, Fstm. (?).  
 ——— *retifera*, Fstm.

*Gangamopteris cyclopteroides*, Fstm.  
*Phyllothea*.

*Equisetites Morenianus*, Kurtz.  
*Lepidodendron Pedroanum*, Szajn.  
 ——— *Sternbergi*, Brong.

*Nöggerathiopsis Hislopi*, Fstm.  
 ? *Euryphyllum Whittianum*, Fstm. (?).  
*Rhipidopsis ginkgoides*, Schmalh.  
 ——— *densinervis*, Fstm.

*Cyclopitys dichotoma*, Fstm.

Academia Nacional Dr. F. KURTZ.  
 de Ciencias. Cordoba (Rep. Argent.), 5 Aug. 1896.

VI.—THE CHALKY AND OTHER POST-TERTIARY CLAYS OF EASTERN ENGLAND.

By Sir HENRY H. HOWORTH, K.C.I.E., M.P., F.R.S., F.G.S.

AMONG the so-called Glacial beds, none fills a larger place in geological literature than the Chalky Clay of Eastern England. I prefer to call it the Chalky Clay, as Searles Wood named it, rather than the Chalky Boulder-clay, because boulders in the true sense of the word, such as characterize the genuine Boulder-clays of North Britain, are infrequent in it. The term Chalky applied to this clay depends on the fact that it is more or less crowded with chalk rubble and chalk fragments of various sizes, and that it has also incorporated in it a considerable quantity of chalk dust, whence

its colour and superficial appearance. These peculiarities, which mark it over a wide area from Yorkshire to Finchley, and from Southwold to Warwickshire, are, nevertheless, a secondary, and not a primary, feature of the clay, and have disguised and confused the problem of its explanation.

It has been noticed by several writers that, while there is a common appearance to this clay wherever found, due to the fact that it contains much *débris* of chalk strata, yet that in regard to its other contents, and notably its matrix, it varies in accordance with the composition of the beds over which it lies, that is, with the substratum. This fact has been frequently noticed, and was, so far as I know, first observed by the Rev. W. B. Clarke, who, writing as far back as 1837, says:—"The diluvial clay covers a great portion of Suffolk, Norfolk, Cambridgeshire, and Essex, and at Cromer rises to 400 feet; much of it is yellowish, but the greater part blue. In both cases it contains chalk pebbles, sometimes in layers, but generally dispersed. This at once distinguishes it from the London and Plastic Clays." Mr. Clarke then goes on to argue that "the yellow clay was derived from the plastic, and the blue, from its peculiar fossils, from the clay below the Chalk" (*Geol. Transactions*, ser. II, v, p. 365).

These observations of a very good geologist have been amply confirmed by later explorers. Thus Mr. Skertchly says, speaking of the Chalk, the Kimmeridge and Oxford Clays:—"We find that the Boulder-clay lying upon these rocks partakes of their physical character. Thus, upon the Chalk the Boulder-clay is very chalky, and, indeed, in some places, as at Mareham le Fen in Lincolnshire, and Thetford in Norfolk, it is almost entirely made up of that substance; at the former place it is quarried and burnt for lime, and at the latter the presence of seams of clay and ice-scratched flints alone enables us to discriminate between it and the chalk beneath. The Kimmeridge Clay is darker than the Oxford Clay, and we accordingly find the Boulder-clay which reposes upon the former is darker than that which lies upon the latter. Where boulders are rare, it is sometimes very difficult to distinguish the Boulder-clay from the older rocks." ("Great Ice Age," new ed., p. 346.) "The Gault clay again takes the ground in but a small area in the Fens, but the Boulder-clay 'picks it out' as it were, and at Modney Bridge brickyard, near Hilgay, for example, I have known the glacial bed to be mistaken for Gault by persons quite familiar with the latter." "Similar remarks," says Mr. Skertchly, "apply to all other formations upon which I have mapped Boulder-clay. For example, the light-blue Upper Lias Clay of Leicestershire impresses its character upon the Boulder-clay which overlies it, and the other members of the Liassic group, where they are in force, behave in a similar manner. The Great Lincolnshire (Inferior) Oolite Limestone around Melton Mowbray yields so large a quantity of material to the Boulder-clay there, that I have been in doubt as to whether the deposit might not be faulted limestone. These peculiarities are at once and correctly expressed by the statement

that the ingredients of the Boulder-clay are, for the most part, supplied by rocks, upon or near which it reposes. That this is actually the case, and not an accident of colour, is further attested by the included fossils; *Gryphæa dilatata* and *Belemnites Owenii*, for example, are abundant upon the Oxford Clay, and *Ostræa deltoidea* upon the Kimmeridge Clay." (Skertchly, communication to Geikie's "Great Ice Age," new ed., p. 346.)

It is curious that those writers who have been most ready to concede this change in the Chalky Clay, in accordance with its substratum, have not gone a step further, and also seen that the chalky character itself of the clay in certain districts is simply due to its being upon, or in close proximity to, the Chalk *in situ*, and that there is no justification for constituting the Chalky Clay a separate horizon. It is because the Chalk occupies so much of the area, and is itself so easily disintegrated, that the name Chalky Clay, rather than Oolitic Clay or Liassic Clay, has been not improperly given to it.

That this feature of the Chalky Clay is due entirely to its lying upon or close to chalk, is also proved by another feature of its distribution, which is interesting for more than one reason, and which has not been sufficiently noticed. In the first place, the Chalky Clay is, so far as I know, largely confined to Eastern England, and is found nowhere else in the world, pointing to there not being the actual conditions elsewhere which prevail here. But this is not all. Mr. Searles Wood, jun., once published a little map roughly defining the area in which it occurs. A larger and more detailed map is appended to a manuscript memoir of his in the possession of the Geological Society, but it has only been since the detailed plotting and mapping of this area by the Geological Survey that it has been possible to define its frontiers, and it would be very useful to us all if the results thus obtained were set out on a map of moderate dimensions.

It will be seen that the distribution of the Chalky Clay, when thus viewed as a whole, is very remarkable. In the first place, it is entirely an inland deposit with duly circumscribed limits and boundaries. It really occurs in several detached masses—two of them in Lincolnshire, one in Yorkshire of no great importance, and a fourth covering more or less an area of several hundred square miles round the depression of the Fens.

In each case the area occupied by the Clay is an insular area, separated from the sea by other surface beds. At one point only—and this is clearly accidental, and due to the recent cutting back of the coast—does the Chalky Clay look down on the sea. In Lincolnshire it is only found to the west of the Lincolnshire Wolds; while in its great homeland further south it is separated from the sea on all sides by beds of Crag and of so-called contorted beds—Middle Glacial beds, etc. This is the case all round the coasts of Norfolk, Suffolk, and Essex, and in the low-lying northern frontier of the marshes and peat-lands of the Wash. To the south it thins out, and virtually ends with the hills bordering the Thames

on the north. In the west its limits have not been quite defined, but it occurs abundantly in Leicestershire and Rutland, in Bedfordshire and Buckinghamshire, in Nottinghamshire, and parts of Staffordshire and Warwickshire; on all sides it is limited, however, by other beds, and forms a great concentric ribbon or ring round the Fen country.

The lesson I wish to deduce from these facts is, that the chalky nature of this clay in certain places is no criterion of a separate origin and a separate history for the deposit. It means no more than that the same clay, where it lies on or near chalk, is chalky; where it lies on or near Oolitic beds, is largely Oolitic; and where it lies on or near Liassic beds, is Liassic. Where, again, it is remote from chalk, chalk débris is necessarily not present in it, and yet the clays may be, and probably are, of the same age, produced by the same forces, and differentiated from each other only as the sandy deposits of one part of a bay are differentiated from the muddy deposits of another part of it;—the fact is that the Chalky Clay, which, in the eyes of so many geologists, forms a deposit which is treated as *sui generis*, and as marking a particular horizon, is nothing of the kind, but, as I believe, is merely a local form of other clays occurring in Eastern England, which do not contain chalk débris, but which resemble it in other respects, and which are, so far as we know, interlocked with it or mark the same horizon. This very fact, however, involves an issue of importance; for it may well be that where the chalk débris was not available for incorporation in the clay, the clay itself may be of precisely the same age, and be otherwise continuous with the Chalky Clay; and that instead of there being several superficial clays in Eastern England, whose various names, such as Stony Clay, or Hesse Clay, or Purple Clay, etc., suggest a varying origin, there may be only one such clay, marked in different areas by necessarily different characters, pointing, not to a different date, but to different ingredients, and perhaps a different provenance.

Two Boulder-clays have been described from Norfolk—the Upper or Chalky Boulder-clay and the stony loam or Lower Boulder-clay. The difficulty of separating the two may be judged from the following sentence of Mr. H. B. Woodward. He says:—"So little brick-earth is met with that for a long time I could not settle in my mind whether or not the Chalky Boulder-clay was distinct from the stony loam. The absence or rarity of this formation where the Lower Glacial brick-earth was well developed seemed to favour the notion. The apparent passage of stony loam into chalky loam at the brickyard in Long John's Road, also in the railway-cuttings north-west of Hapton; the difficulty in the parishes of Postwick, Brundall, and Plumstead of drawing a line between the Chalky Boulder-clay and the stony loam, where the two seem from their physical relations to merge one into the other, tended to support the supposition that they were but one formation." Mr. Woodward quotes the pits at Upton Hamlington and South Walsham as throwing some light on the subject

("Geol. of Norwich," p. 103). This light, it must be admitted, is a very small one, and he confesses that it illustrates the uncertainty of their development. Both beds contain chalk rubble; in some cases patches of very chalky clay appear in the stony loam; and towards Cromer, and further west, near Weybourn, these marly beds are worked for lime. Sometimes the beds in this stony loam are well stratified and laminated, and often inland, as well as on the coast, exhibit many and remarkable contortions. Hence the term contorted drift applied by Lyell. These contortions include masses or galls of sand and gravel.

One feature, supposed to distinguish the Chalky Clay from the stony loam, is the absence of shell fragments, but, as Mr. Woodward says—"It is by no means improbable that the stronger shells of the Crag period, such as *Cyprina Islandica*, might be caught up and preserved in it, as well as Liassic and other older fossils, or as the shells of the Kimeridge and Oxford Clays. And, indeed, shell fragments have been noticed by Messrs. Bennett, Blake, Skertchly, Reid, and myself, in the Boulder-clay at Flordon, and near Rockland St. Mary" (*id.*, p. 115). Mr. Woodward himself confesses that at Burlingham the Chalky Boulder-clay is much obscured by a loamy soil, so that it is difficult to distinguish it from the Lower Glacial brick-earth (*id.*, p. 119), which is surely an inversion of matters if the distinction is to be maintained.

Let us now turn elsewhere. The Lincolnshire Wolds, as is well known, separate the Chalky Clay of Lincolnshire from what I may call the maritime clays. Here, again, it is difficult to assign a different horizon to the two. It was remarked long ago that the clay in Lincolnshire is often without chalk where remote from the Chalk Wolds (Geol. Mem. N. Linc. and S. Yorkshire). While Mr. Jukes-Browne separates the Boulder-clays of South-west Lincolnshire into an older and younger Boulder-clay, he says some of his colleagues who had worked in that and adjoining areas regard the Boulder-clays as approximately of the same age (Mem. S.W. Linc., p. 74).

"In East Lincolnshire," says Mr. Jukes-Browne, "there are only three localities where the brown Boulder-clay comes in contact with the white Boulder-clay"; and he concludes, after examining them, that the appearances at those places are not against the supposition that the brown clays pass into the Chalky Clay. Mr. Bulman says the separation of the Chalky Clay and the Purple Clays of the Eastern Counties seems to have been made on arbitrary grounds. They do not occur in the same district, being separated by the Wolds. (GEOL. MAG. 1891, p. 345.) Mr. Jukes-Browne similarly shows that the so-called Purple Clay and the Hessele Clay graduate into each other, and that there is no break between them (*id.*). Mr. D. Mackintosh speaks of the Purple Clay of East Yorkshire as horizontally continuous with the Chalky Clay of Lincolnshire (Q.J.G.S., vol. xxxvi, p. 187).

Young and Bird long ago discriminated the three Boulder-clays of Yorkshire, which are superficially marked by certain characters,

but which they admit, as do more recent explorers, pass into each other. Thus they say of the most distinct of the three, the so-called basement clay—a bluish or blackish, tenacious clay, forming the lowest visible portion of the cliffs in Holderness and elsewhere:—“As the brown clay passes into the ash-coloured, so the latter passes into the blue clay, which often occurs in patches rather than a distinct bed. Indeed, all the three kinds of clay are often seen banded together in one mass, but we generally find the brown clay uppermost, the ash-coloured in the middle, and the blue, tenacious clay in the lowest place.” (*Op. cit.*, pp. 17, 18.)

Mr. C. Reid, who is disposed to postulate two Boulder-clays in Holderness, separated by gravel, in some cases by fossiliferous gravel, says: “It is also interesting to find that this Boulder-clay” [underlying the fossiliferous gravel in one pit] “is, in its lithological character, quite indistinguishable from the newer chalky and purple Boulder-clay which overlies the gravel further east.” This is in the valley of Croxton. He also mentions how, south of Laceby, “the gravels suddenly thin out and the two Boulder-clays come together.”

At Grimsby the sections “showed two Boulder-clays, purple and chalky, and exactly alike, separated sometimes by a mere line of division, sometimes by gravelly sand, in which fragments of inter-Glacial shells were found. Though the sections were examined almost daily, not the slightest difference could be detected between the two Boulder-clays, either in their matrix or their included boulders.” (C. Reid, *Linc. and Yorks. Surv. Mem.*, pp. 169, 170.)

This will suffice to show that, essentially, the Boulder-clays of Eastern England are of one age, and graduate into each other. Their peculiarities are local, due to local causes, and mark only superficial *differentiæ*, and do not justify their being assigned to different periods. Their difference of contents depends very largely on their covering a different kind of substratum. The element and factor which unites them is the presence in them all of a certain number of foreign stones and débris, having, apparently, a common origin, and pointing to a common explanation.

Let us now turn to the contents of the clays, and especially of the Chalky Clay. The first ingredient of these clays which is noticeable is the clay itself, and I cannot help remarking that it is a pity the Geological Surveyors, in the various memoirs they have given us on the so-called Glacial beds, have not given us more analyses of the clays. One fact seems certain, namely, that the clayey matrix of these so-called Glacial clays is not an original product, but a derivative one. That is to say, it was in the state of clay before it was mixed with the ingredients which it now contains, and was directly derived from various Secondary and Tertiary clays already formed: the Speeton and other clays of Yorkshire supplied the main part of the Yorkshire so-called Boulder-clays; the Kimmeridge and Oxford Clays, together with the variegated Reading and other Eocene beds of the Fen country, supplying the clays further south. It was because these clays are exposed in Eastern England, and not elsewhere, that we have the

so-called Glacial beds so largely composed of clay there. The clayey matrix referred to was not only derivative, but it was derived from beds close by, and, so far as we know, was home-grown, and not imported from abroad.

As to the other ingredients of the so-called Glacial clays; these consist of two entirely different sets of materials—namely, the indigenous and home-grown on the one hand, and the foreigners or erratics on the other. It has been calculated by more than one observer that over 90 per cent. of the stones found in the Chalky Clay are of home growth; and it is probable that in all the clays of Eastern England generally referred to the so-called Glacial age, the proportion of home-grown boulders or stones is very largely indeed in excess of the strangers and foreigners.

The first and most important fact, therefore, to remember is that, over a very large area in Eastern England, the contents of the so-called Glacial clays, both the matrix and the stones in them, are of local origin and not imported. Most of the writers on these clays have been so impressed by the importance of these strangers which form barely a tithe of the contents of the clays, that they have neglected the more essential and more important lessons to be derived from an examination of the local and home-grown ingredients which they contain. I propose in this paper to entirely neglect the foreigners, and to converge attention upon the natives, reserving the discussion of the former for another occasion.

These natives consist of two entirely different classes. One class comprises more or less angular rubble, with its angles frequently blunted, and with the rude facets on its polygonal blocks often scratched; the other consisting of pebbles rolled perfectly smooth, and of various sizes, resembling sea- and river-shingle, these latter chiefly composed of flints and of quartzites, flints predominating greatly.

There can be no doubt whatever that these latter are the *débris* of marine and fluviatile shingles. It has apparently been argued by some that they were formed as pebbles during the so-called Glacial period. I believe this to be a complete mistake, and, so far as my own observations go—and I have worked pretty hard among them—they all seem to me to be derivative, and to be the *débris* of disintegrated Tertiary gravel and pebble beds. This view has been growing of late years.

Hutton, so far as I know, was the first to suggest that such gravels may have been the *débris* of the disintegration of older shingle beds. Thus he argues that these water-worn materials had their great roundness from the attrition caused by the waves of the sea upon some former coast, and that, after having been thus formed by *agitation on the shores, and transported into the deep*, this gravel contributed to the formation of Secondary strata, such as the pudding-stone he elsewhere described; and, lastly, that it was “from the decay and revolution of these Secondary strata, in the wasting operations of the surface, that have come those round siliceous bodies which could not be thus worn by travelling in the longest river.” (“Theory of the Earth,” vol. ii, p. 144, note.)



This view has been partially urged by Prestwich, and notably by Monckton, Herries, and the other younger geologists who have done so much to unravel the history of the Southern gravels. I would merely press their conclusions further, and affirm that all the rolled and rounded pebbles in the so-called Glacial clays and gravels are derivative, and have been derived from earlier Tertiary beds. I shall have more to say of them in a subsequent paper on the gravels and sands so frequently associated with the clays.

Turning from the polished pebbles to the angular and subangular rubble of home-made rocks, this consists of various kinds of Secondary strata, Lias, Oolite, and Chalk, distributed generally with a preponderance of Lias, Oolite, and Chalk fragments when the underlying beds correspond. These fragments, which have been partially shifted, and rolled and rubbed against each other, are, as I have tried to argue in two recent papers in the GEOLOGICAL MAGAZINE, the result entirely of the violent dislocation of the local Lias, Oolite, and Chalk solid beds, which has broken them up sometimes into great masses, and at others into mere road-metal. This disintegrated rubble was, in my view, ready made when the clay was compounded, and was in a large measure *in situ*; and the only alteration it underwent at the time when it was put into the portentous churn which turned out the chalky and other clays of Eastern England, was to have its angles blunted and its sides scratched and polished by being rolled and rubbed together. This seems as plain as plain can be if we are to explain the facts by inductive methods.

Whatever the forces or the machinery which mixed and distributed the so-called Boulder-clays of Eastern England, they had nothing to do with shaping the home-grown ingredients of the clays. These, with the exception of a little blunting of angles and polishing and some scratching, were already made, and are derivative. The process we have to analyze, therefore, is not complicated by questions as to the *modus operandi* by which the matrix of the clay itself and its contents were formed, but is limited to an explanation of how these ingredients were mixed and mingled together as we find them; and, secondly, how the product, when mixed, was distributed. What is most plain, *in limine*, is that, as the matrix of the clay and nine-tenths of its contents are local, it was fashioned on the spot, and was not imported. This follows from another fact. I have examined the coast of Norfolk and Suffolk with some care, and in those counties, as I have said, the Chalky Clay never reaches the sea, but occupies the projecting bluffs that form the highlands a few miles inland, while the country between them and the sea is occupied by the pebbly beds; the same is the case in Essex. This makes it clear that the Chalky Clay, which occupies the larger part of the interior of those counties, did not move westward from the seaboard, but came from the north or north-west, whence the chalk fragments and the clay itself were derived. This is again shown by the fact that this clay in Suffolk contains so many Liassic fossils. What is



true of the eastern boundary of the Chalky Clay is true also of its southern, western, and northern boundaries. The same conclusion follows from the complete absence of any shells or other marine débris from the Chalky Clay, showing it to have been an inland product of the denudation of local beds; and the evidence seems clear that whatever mixed and distributed the clay, the work itself was done on the spot.

Let us now examine the clay a little more closely.

The local stony rubble in the so-called Glacial clays of Eastern England is dispersed irregularly throughout the matrix. As has been frequently noted, the *prevailing* rock fragments in any district depends upon the substratum, but in every district known to me the rocks of other districts are represented. This means that whatever force or engine mixed the clays as we find them, it must have been one that could take up fragments of rock from the north and east and west, and move them in directions opposite and contrary to each other. The great cauldron in which the clay was mingled must have been occupied by some very powerful mobile machinery, which did not move in direct lines, but could move in various directions, and thus bring together and mix together the débris from the four points of the compass in one common medley, and having done so, could distribute it in the fashion we see it distributed now. What force or machinery was competent to effect this extraordinary work?

A considerable number of geologists unhesitatingly attribute the formation and its distribution to ice, and, in fact, point to this clay and instance it as one of the most remarkable proofs of ice-action in this country. I absolutely traverse this position: not only does it seem to me that the Chalky Clay was not distributed by ice, but I would go further and say that I cannot understand how ice in any shape can have formed and distributed it; and it is a very remarkable fact that those who have chiefly championed the cause of ice in this particular instance, are those who have never seen ice at work at all in Nature, while those who have so seen and studied it are unanimous, or almost unanimously of opinion, that nowhere in Nature is ice-work of the kind postulated to be found now going on anywhere.

The champions of ice have invoked it in several forms. Some of them invoke a foreign ice-sheet coming partly from Durham and partly from Scandinavia. This is supposed to be necessitated as a postulate by the presence in these clays of the foreign stones whose provenance has been deduced from Durham and Scandinavia respectively. We shall have more to say to this when we consider the foreign stones. At present we are dealing with the local ones only, and their distribution. Suppose that we can postulate such a foreign ice-sheet coming down, say, in Lincolnshire and the Fenland and their borders, what is the work which it must have been capable of doing when it reached England in order to explain the Chalky Clay. This vast, almost rigid, mass of ice pressed on from behind, it is presumed, by some tremendous *vis a tergo*, and

moving, if it moved like any ice known to us along definite lines of least resistance, must, when it reached England, have taken to sportively moving in all directions at once, not only towards its outward circumference sporadically, but also from its circumference inwards, in order to move the Oolitic and Lias fragments of Rutland, Northamptonshire, and Leicestershire, to the heights near Southwold, in Suffolk, the Red Chalk, carstone, and the limestones of Lincolnshire, far to the south of Cambridge, and the chalky fragments of the chalk exposures far to the west into middle England; and must have been capable of doing all these things at the same time, drawing in its scattered tribute to a common cauldron, and then distributing it, when mixed, as we see it distributed from Essex to Warwickshire. Have the fantastic attributes of man ever conceived a more preposterous mechanical process, and has science ever been burdened with such absurdities before?

Assuredly these facts make it impossible for those whose science is inductive to explain the mixing of the clays and their subsequent distribution by means of a foreign ice-sheet; and by foreign I mean here an ice-sheet, whencesoever derived, which has invaded Eastern England from the outside.

If we discard a foreign ice-sheet as the explanation of the Chalky Clay, shall we be any better off in making an appeal to a local glacier, or a series of local glaciers, as Searles Wood and others have done? In the first place, it must be remembered that such a local glacier does not in any way explain the crux of the position, namely, the presence of the foreign stones. Not only so, but if the area occupied by the Chalky Clay were occupied by local glaciers, how could it possibly be invaded by the foreigners at all? The presence of the local ice-sheet would form as complete a barrier to the introduction of foreign stones as a stone wall to the passage of the wind. This difficulty seems to have been entirely overlooked.

Let us pass on, however. The next difficulty is to understand how such a *local* ice-sheet or *local* glacier could be formed at all in the area in question when there are no mountains, and only low rolling downs. Glaciers, as we know them, gather on high ground, and descend into the valleys. If it were a local glacier which occupied the wolds of Lincolnshire, and thence distributed the products of its denuding agency, how comes it, again, that the débris of these chalk hills should be so different on the east side of them to what it is on the west? and how are we to account for the absence of chalk fragments in the beds to the east of these ridges? but apart from this, how are we to postulate glaciers as existing on lands so slightly elevated as are these wolds? Where is the gathering-ground for such glaciers to be found here? The same argument applies to the wolds of Norfolk or Yorkshire. If they were covered with local glaciers, how comes it that this ice shed such very different materials from their eastern and western flanks respectively? But suppose we got our local glaciers, each one crowning a different set of wolds, and moving outwards,

how can we possibly explain the collecting of stones from the east and the west, and the north, from areas entirely outside these local glaciers and their influence, and their distributing the mixed products far and wide right over the very areas supposed to have been occupied by the local glaciers?

Again, if the country were more or less blanketed by ice, either by a foreign ice-sheet or local glaciers, whence could the stones have been derived at all? There are no high mountains in Eastern England whose peaks would have projected above the ice, and been broken and weathered off to supply materials in this fashion. If the ice produced the disintegration, it must have been by digging up and excavating its own bed, and not in the fashion in which moraines are formed. Now this process of excavating a bed of rock underneath a moving mass of very heavy ice is not only mechanically incredible, but it is quite unsupported by any facts known to me, and is quite repudiated by Professor Bonney and others whose experience of ice is very much greater and more intimate than mine; and here we have to do, not with a local phenomenon occupying a few square yards or acres, but with a stupendous one involving the digging out and removing of wide stretches of rock, not in the form of mud or powder, but in some cases of great lumps and blocks of chalk and oolitic rock, over a wide area. Whether the ice postulated be foreign ice or native ice, it is equally impossible to understand how it could work in this fashion.

If we turn to the stones themselves, we shall have our view confirmed. True glacier-rubbed stones acquire a very curious contour, that is, so far as I know, never present in these chalk lumps of the Chalky Clay. In the case of all soft stones like chalk, they are rubbed down on two sides into flat cakes, so as to have two parallel faces, which are much scratched and furrowed, having, in fact, been used by the glacier as the "skid" of a coach is used. These are the real products of ice rubbing on soft stones, as known to myself in glacier districts, but such stones are markedly absent here. The stones in the Chalky Clay, etc., are as polygonal as those made by the stone-breakers on the highway, differing from such stones only in the fact that they range in size from dust up to masses many scores of feet long, and also in having their surface smoothed and their angles blunted. These are in no sense glacier stones. It is true that occasionally some are found which are scored and scratched, but those who appeal to these sporadic stones forget that whatever drove the clay along, if the movement were quick and two stones rubbed against each other, scratches or marks of rubbing must have ensued in such soft materials as chalk. Those who have examined the *débris* of such catastrophes as the Holmfirth flood, etc., have noticed how invariably some of the stones are scored and scratched. It has been said that such stones are very scarce in shingles made by seas and rivers. Of course they are, because these shingles are formed of smoothed hard stones, like flint and chert and quartzite, which cannot scratch each other easily, but only rub each other down. Where a number of angular

stones, such as ballast, lie on a beach, and are examined after a gale, scratches and groovings can always be found. Professor Hughes, in an admirable paper published by the Cambridge Philosophical Society, has shown to how many adventitious causes such scratches can be traced; and "it is a long way to Loch Awe" when we invoke an ice-sheet or local icebergs to account for a few scratches on soft chalk stones, which are themselves otherwise absolutely different to true glacier stones, and have been clearly rolled and had their angles blunted by some other cause than ice. If the smaller lumps are difficult to explain by glacier action, *a fortiori*, as I have before argued, are the large masses, such as those in the contorted drift near Cromer, at Ely, in Rutlandshire, and the great masses of oolite in Lincolnshire, not only detached from their matrix but underlain by other so-called glacial deposits, and this, according to the land-ice hypothesis, all done under the tremendous pressure of such a heavy foot as its own gravid mass. It must be remembered also that among these very large transported rocks are, in some cases, great lumps of clay and of stratified sand, which have been moved *en masse*, and if moved under an ice-sheet must have been pounded and kneaded into a mere medley, and not had their lines of stratification intact. In these cases, at all events, the portage of the soft boulders must have been under the heavy foot of the ice, and not on its back.

Let us turn to another argument. In all glaciers known to me, the glacier products are distributed in a certain definite way, which at every point is different to that of the clays of Eastern England. Instead of being deposited in enormously thick masses near the focus of distribution, and gradually thinning out, glaciers deposit their greatest burdens at their furthest point in the form of mounds and ramparts and moraines. To a glacier it is indifferent whether a stone is big or small; big and little travel together, nor do we find the whole country, irrespective of its contour, as we do in this case, mantled and covered with continuous sheets of clay, which differs in texture and in aspect from all moraine matter known to me.

It was apparently the absence of anything like moraines which so impressed the late Professor Carvill Lewis, one of the most aggressive champions of glacial action, that he absolutely repudiated the presence of traces of ice in any form in East Anglia. If the ice here were an ice-sheet, we may well ask where is its great terminal moraine? and, if it were in the form of local glaciers, where are their lateral and terminal moraines?—where are the mounds and heaps of heterogeneous moraine stuff invariably present where glaciers have been at work?

Again, how are we to explain by ice the distribution of this clay in many places over perfectly horizontal layers of finely laminated sand and gravel, with the laminae intact and undisturbed, as if the clay had been simply laid down on the sands by some gentle fingered agency? This is quite inconsistent with a moving mass of hard heavy ice, which would have kneaded and pounded the materials into a mass of what the American farmers call "muck."

Moreover, according to any rational mechanical theory, how can we account for the portage over wide areas of clay, scores of feet thick, under an ice-foot at all? How is it to seize it and move it *en masse* in the way required? It would surely slip over itself at once if the attempt were made to push it by means of a stupendously weighted and heavy ice-foot.

All these difficulties present themselves if we treat the glaciers as ordinary glaciers, such as we know them, moving down an ordinary set of hills, from the highlands to the lowlands. *A fortiori* do the difficulties become intensified when the particular contour of the country is considered. It must be remembered that the clayey matrix of the great mass of these clays only exists in the lowest hollows, where the denudation has been greatest. It is thence that the Kimeridge and Oxford Clays must have come to form the mass of the Chalky Clay, and been thence distributed in various directions. It is in the low grounds of the Fen country where the churning and mixing of the materials must have been carried out, and it is thence the clay must afterwards have been sporadically spread out and scattered. How are we by any stretch of the imagination to realize an ice-sheet, formed in the deep hollow of the Fens, collecting together from the four winds of heaven materials for the clay, working and mixing them up in the deepest part of the area where it occurs, and then distributing it in various directions, *always* moving uphill from the trough on to the plateau? The kind of reasoning involved is assuredly going back to the dark ages of science, and getting away from induction altogether.

It does not seem possible to me that those who have postulated these local glaciers have ever really measured or thought out the conditions under which they would work at all. Mr. Jukes-Browne has stated some of the insurmountable difficulties in an excellent manner. Thus he says, writing of the Lincolnshire beds:—"The Boulder-clay is not disposed in the manner of moraines, but was clearly spread out as a universal mantle over the whole surface of the country. The ice which produced it certainly could not have been generated on the ridge itself, nor on any of the neighbouring hill ridges, and yet the materials of which the clay consists, and nearly all the stones it contains, are essentially local products derived from the rocks in the immediate neighbourhood. It is obvious that the chalk fragments must have been brought from the north-east, the Carboniferous rocks can only have come from the north or north-west, and the marlstone blocks travelled in all probability from west or south-west of the places where they are now found. . . . When we consider the remarkable distribution of the stones and boulders in the clay of this area, the greater proportion of chalk detritus on the eastern slopes, and of Jurassic detritus on the western slopes, the fact that enormous masses of marlstone occur many miles to the eastward of the only place whence they can have been derived, the position of the large boulder of Cornbrash, near Ingoldsby, and the occurrence of Lower

Lias Limestone at Croxton, 300 feet above its level, the steep slopes of the Oolitic escarpment up which the ice must have passed, the difficulties in the way of applying the prevalent land-ice hypothesis become considerable." (Mem. S.W. Leicestershire, Sheet 70, pp. 82, 83.) I agree with every word of this, except the word 'considerable,' for which I should have substituted 'insurmountable.'

Land-ice in any form, therefore, seems quite incompetent to account for the Chalky Clay, nor can we invoke it without shutting our eyes to innumerable difficulties which at once arise. Some geologists have therefore had recourse to floating-ice, in the form of icebergs, or to coast-ice. This seems even a more desperate appeal. It first necessitates our conceding a general submergence of the country where the Boulder-clay is found, that is, as far as the Thames in the south and Warwickshire in the west. Granting this, how are we to solve by this agency any of the critical difficulties of the Chalky Clay; its existence in Lincolnshire to the west only of the Wolds; its existence everywhere in great insular areas separated from the sea; the complete absence of marine shells or débris from every place where it has been examined? How by such means as icebergs or shore-ice can we explain the covering of hundreds of miles of country with continuous blankets of chalky clay, not deposited in local heaps and masses but in sheets irrespective of the contour of the country, and in some cases deposited in very deep beds indeed, and most conspicuously on the higher grounds rather than the valleys? How could such agencies collect together oolitic blocks from Leicestershire and pieces of hard chalk from Norfolk, and mix them with the Oxford or Kimeridge Clays of the Fenland, or of the valley of the Ancholme, and then spread them out, as we find them spread out, from Suffolk in the east, into the Central Midlands?

Mr. Skeretchly has stated the case against icebergs with singular force. "Icebergs," he says, "are the wrecks of land-ice, and the rocky material they carry is derived from the gathering-grounds of the parent ice; hence, if the Boulder-clay be iceberg drift, its components must be those of the *distant gathering-grounds*, and not those of the rocks it falls upon as the berg melts away." He goes on to say that as the chief ingredient in the clay is chalk, as it is found 300 feet above the present sea-level, not only must the gathering-ground have been on chalk but there must have been a submergence of at least 500 feet. This would convert the chalk area into a number of small islands, where it is not possible to understand glaciers gathering at all. Again, all the argillaceous matrix of the Chalky Clay is derived from the Fenland and the valley of the River Ancholme, and all the formations whence it could be derived would be under water. A more powerful argument remains in the fact that, if the clay be of iceberg origin, it can have no relation to the rocks on which it rests, except by accident; but the Chalky Clay does possess such a connection, and the icebergs must have had a selective affinity in shedding their burdens, by virtue of which they preferred to drop Kimeridge



Clay débris upon Kimeridge Clay and Oxford Clay detritus upon Oxford Clay. The clay is dark-blue on Kimeridge Clay, and light upon the light-blue Oxford Clay, besides which the fossils in the clay show a large percentage of Kimeridge Clay species where that rock lies below, and of Oxford Clay fossils where that is the subjacent bed. Not only so, but we find that the Kimeridge Chalky Clay invades the outcrop of the Oxford Chalky Clay, and the latter does not come on until the Oxford Clay has fairly taken the ground. In like manner the Boulder-clay is much more chalky on the Chalk than elsewhere, and this feature it maintains over the narrow Greensand outcrop, on to the Kimeridge Clay, as at Mareham, where chalky Boulder-clay is burned for lime. It is quite impossible, as Skeretchly says, that icebergs should have dropped their burdens so geologically. ("Geology of the Fenland," pp. 215, 216.) The iceberg theory has, so far as I know, no friends left. I have already, in another paper, criticized the shore-ice theory, of which Mr. M. Reade has been the champion. He has invoked it to explain the portage of the vast blocks which so often occur in the Chalky Clay; but he would hardly attribute to coast-ice the collecting of the materials of the Chalky Clay, the mingling of them into the present medley, and the distribution of the mixture far and wide over one-third of England.

Whichever way the problem is approached, the intervention of ice as a *causa causans* seems impossible. It was appealed to in reality to explain phenomena whose explanation is to be sought for in very different causes—(1) the scratching of certain chalk masses, a result which must have followed from any theory of the distribution of the Chalk involving its portage from one place to another, which we all concede; (2) the presence in the eastern drifts of vast continuous masses of chalk, etc., which, as we have seen, is due to an entirely different cause; and, lastly, the presence of the foreign boulders. This last fact I hope to discuss on another occasion, when I should like to correlate with the clays we have been discussing the gravels and so-called Middle Sands of Eastern England, in which these foreign stones also occur. In the meantime the view I would press is, that these clays present no single feature consistent with their having been deposited by ice, nor do I know of any reason which is sound for invoking ice to explain them. The view is held by others besides myself, on other grounds. Thus, Mr. (now Professor) Seeley says:—"I have not found in this locality a vestige of iceberg action. Of glacier action the deposits of the Fenlands offer no traces, unless the fragments of northern rocks be held to prove that one great glacier stretched from the Tweed to the Thames, of which there may be as much likelihood as that the ice of the Caucasus excavated the Black Sea." (GEOL. MAG., 1866, Vol. III. p. 496.) Mr. Jukes-Browne's opinion I have already quoted, but the most unexpected and trenchant view of all is that of the late Professor Carvill Lewis, who was one of the archpriests of Ultra-Glacialism, and who in regard to East Anglia emphatically took the same side.