CHAPTER V.

CAMBRIDGESHIRE, BEDFORDSHIRE, AND WEST NORFOLK.

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INTRODUCTION.

THE area treated of in the following memoir includes the counties of Cambridge and Bedford, together with so much of the southern part of Huntingdonshire as is necessary to give continuity to the description. As a matter of convenience also, West Norfolk is included, especially that part around Hunstanton, since although this district is geographically part of Norfolk, in its physical and geological features it is more closely related to Cambridgeshire.

The Geologists' Association has conducted a considerable number of excursions to interesting localities in this area at dates ranging from 1862 to the present time. Eleven visits have been paid to Bedfordshire between 1881 and 1905, while the county of Cambridge has been visited six times since 1862. Of all these excursions accounts are preserved in the PROCEEDINGS or in the "Record of Excursions," with the exception of one to Cambridge in 1866, at which time no PROCEEDINGS were issued. South Huntingdonshire has apparently never been visited, but Hunstanton was the scene of excursions in 1867, 1869, and 1883.

The object of this chapter is to give within a small compass a general sketch of the solid and superficial geology of the district, with reference to general principles rather than to details, together with an account of the physical causes which have given rise to the local peculiarities of the stratified rocks here met with, and their distribution at the present time. When any particular division is normal in its development little will be said about it, and consequently it may appear that undue prominence has been given to certain features of only local importance. However, such developments are as a rule of more than local interest, and their study often casts light on problems of wider application. No attempt will be made to give a complete list of exposures, and as a rule even the important ones will be dealt with only in general terms. Again, lists of fossils will be avoided owing to considerations of space. All such details can be found in abundance in the memoirs of the Geological Survey, and in many other monographs and papers.

The literature of the subject is a very large one, as may be

gathered from a glance at the extensive and very complete bibliography given by Mr. Cowper Reed in his "Geology of Cambridgeshire." This was originally compiled by Mr. Whitaker and brought down to 1897 by Mr. Reed. Since that date not much has been written, and some points which have arisen as the result of more recent work are here dealt with somewhat fully. In the following pages references are as a rule only given in the case of work published since the date of the bibliography just referred to. The most important general accounts of recent date are, for Cambridgeshire, the one by Dr. Marr and Mr. Fearnside in the *Handbook* published by the British Association for the Cambridge Meeting of 1904, and for Bedfordshire, that by Messrs. Hopkinson and Saunders in the *Victoria History*. My thanks are due to Mr. H. Woods, of St. John's College, for suggestions and criticism, and for his kindness in reading the manuscript.

PHYSIOGRAPHY.*

So far as concerns its surface features, the district here to be described may be divided more or less clearly into three regions of differing relief. In the western part we have the rolling country of Bedford and South Huntingdon, comprising land of moderate elevation above sea-level, with generally rounded contours and flowing curves, and showing no very distinctive features. This consists of the Jurassic strata, ranging from the Bathonian limestones of the extreme south-west to the Corallian clays of Huntingdonshire. To the north-east of this comes the great expanse of the Fen country, a dreary dead-level carved out of the soft clays of the upper Jurassic—Oxford Clay, Ampthill Clay, Kimeridge Clay, with the Gault along the south-eastern margin. Over the greater part of this area no solid geology is seen, as the whole is covered by a thick alluvial deposit, the origin of which will be discussed in due course. However, it is clear that the Fen country is underlain by soft clays, which have undergone denudation with great readiness. To the south and east of the two regions above mentioned comes the escarpment of the Cretaceous rocks, which forms such a conspicuous feature right across England from south-west to north-east. Nowhere is the distinction between the physiographic features of the Jurassic and Cretaceous series seen in greater perfection than along the line of country from Aylesbury to the Wash. The Chalk escarpment is almost unbroken, but there are one or two small outliers of Chalk forming isolated hilly tracts in the neighbourhood of Cambridge.

In addition to the three broad divisions just indicated there are to be seen local features formed by the Lower Greensand, as, for example, the conspicuous winding scarp near Sandy and

* The topography of the district is illustrated by the map, Plate III, p. 108.

Potton, and at Woburn, and some of the "islands" in the Fens. In West Norfolk also, from King's Lynn to Hunstanton, Lower Cretaceous strata form the principal features of the landscape and give rise to a sandy type of country something like the heathy commons of Surrey.

Thus it is seen that this district affords an excellent example of the intimate connection between physical features and geological structure; the relatively harder beds stand up as rising ground, while the relatively softer strata are excavated into the broad plains which are such a conspicuous feature of this part of England. However, this generalisation is not of invariable application, as differences in lithological character of the underlying rocks are not always effective in producing variations of contour. For example, running westward from Cambridge towards St. Neots is an elevated plateau, including the outcrops of Cretaceous and Jurassic strata of varying hardness, but preserving an almost unbroken level surface for fifteen miles or more. Evidently some other factor has here operated to modify the influence of the law of structures. But such deviations are of minor importance; on the whole this law is dominant.

In close connection with geological structure is in almost all cases the arrangement of the drainage system, which is the primary factor in determining the present relief of the ground. It so happens that the district, as defined in the opening paragraph, corresponds very closely with the basin of the Great Ouse, which is one of the most important of the rivers of east-central England. The course of this river has been determined by the underlying geological structure, since it is one of the great subsequent or strike streams which form the dominant feature of the drainage of this part of the country. Hence, the course of the Great Ouse is on the whole a simple one: it lies in a valley eroded from the softer Upper Jurassic strata, and bounded on the north-west by the dip-slopes of the Middle Jurassic, and on the south-east by the escarpment of the Cretaceous. However, when examined more closely, there are complications in detail. Although the general direction of the Great Ouse follows the strike of the Jurassic strata very closely, it displays a tendency to transgress on to higher and higher beds of the series. Now, these transgressions are performed not by a diagonal course, but by abrupt turns at right angles, followed by reversion to the original direction; that is to say, for a short distance the river becomes a dip-stream, and then again turns parallel to the strike. A very good instance of this is to be seen in the neighbourhood of Bedford. The river enters the county near Olney, and flows in a meandering, generally north-east, course to Sharnbrook. Here it turns abruptly to the south-east, and flows in that direction as far as Bedford, where it again turns to the north-east. By this process the river has trans-

gressed from the Bathonian to the Oxfordian or Corallian. Between Huntingdon and Ely a series of similar transgressions occur, so that the original course of the Great Ouse at the latter place lies in the Kimeridge Clay. This is an expression of a general principle enunciated by Prof. Gilbert as *monoclinical shifting*.

In connection with the development of the Great Ouse basin a very interesting and suggestive theory has lately been put forward by Mr. F. W. Harmer.* He supposes that the whole of the Oxford region before the Glacial period drained to the north-east by way of Buckingham towards the Wash. As a result of the advance of the North Sea ice this drainage was ponded back, forming a great lake, which ultimately found an outlet over the Chalk escarpment at Goring, thus diverting a great amount of drainage into the synclinal valley of the original Thames. Hence the subsequent Great Ouse is older than the present course of the Thames below Oxford, a view which is diametrically opposed to that of Prof. W. M. Davis. This subject is outside our present purpose, and cannot here be pursued farther; but it is of interest on account of its bearing on the size of the Great Ouse basin, and the deep excavation of the Fenland area. This, if we accept the theory, we may attribute to the great volume of water carried down by the river before it lost the drainage of the upper part of its basin by diversion into the Thames.

The Great Ouse receives numerous tributaries from both sides; as would naturally be expected, those on the left bank were originally consequents of the second order, flowing down the dip-slope of the Jurassic rocks, while those on the right bank are obsequent streams flowing against the dip, down the face of the Cretaceous escarpment. The courses of these tributaries have undergone many important modifications, owing to diversion by meandering and capture. The most important tributary is the Cam, which is worthy of a somewhat detailed description. There is unfortunately a good deal of confusion as to the nomenclature of the Cam and its tributaries. If we take the source of the Rhee, near Ashwell, as the true head of the Cam, the river is then purely a strike stream, which must be regarded as independent of and parallel to the Great Ouse, till it joins the latter at one of its right-angled turns near Ely: that is to say, the Great Ouse has undergone monoclinical shifting until it has transgressed into the strike valley of the Cam, which from this point of view may be considered as captured by the Great Ouse. The Cam receives tributaries of considerable size from both sides; of these, the Bourn brook on the left bank is a dip-stream. Those on the right bank are naturally obsequent streams, such as the Granta from Saffron Walden and the Lin from Bartlow. The drainage of the Fen country is of a highly complex order on

* *Quart. Journ. Geol. Soc.*, vol. lxiii (1907), p. 470.

account of much meandering, and now the actual watercourses are for the most part artificial. There is no doubt that the drainage system has undergone considerable changes as a result of the Glacial period, and an interesting feature is the existence of long narrow ridges of gravel near Cambridge, which are supposed to be relics of rivers older than the existing ones, and running in quite different directions. These, which will be described later, may, however, be of Glacial origin.

Concerning the topographical features other than those which are immediately connected with the rivers there is little to be said. They are on the whole of great simplicity, and present few special features of interest. The scenery of the Chalk tract is much like the Down country of the south of England, and the few differences to be observed may be accounted for by the presence in most places of a covering of glacial drift of greater or less thickness, which frequently masks the Chalk beneath and produces a soil much heavier and of greater depth than is commonly to be seen in the Chalk country; the consequence of this is a greater abundance of trees and herbage and more widespread cultivation of the land. In some places, however, unenclosed spaces occur, as near Royston and on Newmarket Heath. Just beyond the limits of our district, in Suffolk and Norfolk, around Brandon and Thetford, there occur great open heaths and other areas, which can only be described as sandy deserts, consisting of Glacial sands lying on Chalk. This type of country does not extend into Cambridgeshire, but must be mentioned as characteristic of drift-covered land lying on the Chalk. Another feature worthy of passing notice is the common occurrence here, as in the rest of the Down country, of dry valleys; these valleys have evidently been excavated by stream erosion, but no streams now run in them. It has been suggested that they were formed at a period when the subsoil was frozen and did not permit the rain or snow which fell to soak into the rock and circulate underground, as it now does.

GEOLOGY.

The general succession of the strata in Cambridgeshire and Bedfordshire is very simple, and may be summarised in a few words. The lowest division seen is probably the Bathonian, to the west of Bedford; from this horizon there is a more or less complete succession of the major divisions of the Jurassic up to and including the Kimeridge Clay, and possibly higher in the extreme west of Bedfordshire. However, the Purbeck and Wealden are nowhere seen, and the Cretaceous series begins with the Lower Greensand. Above the Chalk, moreover, there is a very considerable gap. Tertiary strata seem to be practically

absent within the limits of the two counties, and the next deposits to be met with are of Pleistocene age. Hence it will be convenient to treat the geology of the district in three parts, viz., Jurassic, Cretaceous, and Pleistocene and Recent. It must be noted, however, that the connection between Jurassic and Cretaceous is much closer than that between the latter system and the Pleistocene. In fact, the relations of the Jurassic and Cretaceous rocks form perhaps the most interesting feature of the solid geology of the district, and to this point comparatively little attention has hitherto been paid. Each of the great divisions here sketched out presents local features of exceptional interest, and it may be truly said that although exposures, at any rate in Cambridgeshire, are few and poor, nearly all of them raise some problem worthy of investigation, and often difficult to elucidate. Most of these are touched on in the succeeding pages.

THE JURASSIC ROCKS.

INTRODUCTION.

The Jurassic rocks occupy about one-half of the county of Bedford, the whole of Huntingdonshire, and, so far as can be judged on account of the thick covering of alluvium, something between one-half and two-thirds of Cambridgeshire. Since they form an integral part of the great band which stretches across England from Dorset to Yorkshire, they possess a general dip to the south-east, which must become more nearly due east in the north of Cambridgeshire. The dips are in all cases very slight, so that the outcrops of comparatively thin beds are very wide, and in particular, as before pointed out, the Upper Jurassic strata occupy a very large area in the northern part of the Fen country.

The oldest rocks actually exposed at the surface in the county of Bedford belong to the Bathonian series; they form the lowest part of the valley of the Great Ouse just below Olney. With regard to the upper limit of the Jurassic series in Bedfordshire, we find exposed at the surface nothing higher than Corallian, although Portland and probably Purbeck beds are shown within a very few miles of the western boundary of the county west of Leighton Buzzard. It is possible that these higher Jurassic strata extend farther east below the Cretaceous, although direct evidence is wanting on this point. The Kimeridge Clay also disappears under the Cretaceous before entering Bedfordshire, but emerges again in strong force in Cambridgeshire, and underlies much of the Fen country. No representatives of the Portland and Purbeck beds are again seen to the south of the Wash. The reason for this peculiar distribution of the upper divisions of the Jurassic will be discussed in detail in a later section.

The general classification of the Jurassic system, which will be here adopted, is that given in the Geological Survey Memoir.* In its most general form for the part of the system here represented this is in descending order as follows :

Kimeridgian	Kimeridge Clay.
Corallian	Amphill Clay and Upware Limestone.
Oxfordian	Oxford Clay.
Bathonian	{ Cornbrash. Great Oolite Clay. Great Oolite Limestone.

Speaking generally, the succession is a continuous one, but there are interruptions in places due to slight local unconformities, and in one or two cases important variations of lithological character break the monotony of the series. The Upper Jurassic in the Midlands is, in the main, a succession of thick clays, but here and there a calcareous facies is found, which presents features of interest.

With respect to the conditions under which the Jurassic strata were deposited, it is unnecessary to say much. The Liassic sea apparently terminated in this direction against an old land of Palæozoic rocks, of which the remains now underlie the London basin, and the successive members of the Jurassic overlapped one another against the shores of this land. At the end of Lias times a fairly rapid emergence seems to have taken place, producing shallow water and even terrestrial conditions over the Midland counties, leading to the formation of small local unconformities and the deposition of fresh-water and estuarine beds of peculiar character. After a time the sea again became deeper, so that the majority of the Upper Jurassic strata are marine. This sea appears to have been, on the whole, a muddy one with occasional clear areas, where reef-building corals could flourish, as at Upware. The large amount of mud in the sea of this period was probably derived from the rapid destruction of shaly rocks of Lower Palæozoic age in the land to the south, including Silurian and possibly Ordovician strata, together with Devonian and Carboniferous. In some Jurassic rocks small fragments of coal have been observed, but they may have been derived from older Jurassic strata, subsequently destroyed, and need not necessarily be of Carboniferous origin.

BATHONIAN.

Some difficulty has arisen in the correlation of the lowest divisions of the Oolitic strata in the valley of the Great Ouse above Bedford, so that it is somewhat uncertain what is the

* H. B. WOODWARD.—“The Jurassic Rocks of Britain,” vols. iv and v.

exact horizon of the lowest beds exposed within the limits of the county. In this area the lower limit of the Bathonian is ill-defined, and the Bajocian has not been identified with certainty. It seems probable that here the latter division is absent, the Bathonian resting discordantly on the Upper Lias. The absence of representatives of the Northampton Sands and Lincolnshire Limestone in this direction may be due either to failure of deposition, owing to unfavourable physical conditions, or to removal after deposition by pene-contemporaneous erosion, such as has undoubtedly occurred in Yorkshire. Beyond the boundary of Bedfordshire to the west certain clays at Stoke Goldington and Weston Underwood were originally mapped as Upper Lias; in the Geological Survey Memoir they are referred to the Upper Estuarine series, but Mr. Beeby Thompson has recently maintained the correctness of the original ascription, hence it is clear that the Lias must underlie western Bedfordshire at a small depth; how far it extends to the east is unknown.

It is certain, at any rate, that some beds seen below the Great Oolite Limestone series in quarries and borings in the neighbourhood of Bedford must be referred to the Upper Estuarine series, and these probably come to the surface near Harrold and Sharnbrook. They consist of sands and sandy clays of various colours, having a total thickness of from 15 to 30 ft. They are not persistent, and frequently occur in pipes or pockets, resting on a surface of erosion. The precise character and age of the beds on which they rest is not clear. The clays appear to be of estuarine or shallow-water marine origin and contain some badly-preserved remains of land-plants.

The deposition of these strata appears to have been followed by slight submergence, ushering in the more purely marine conditions of the Upper Jurassic. The remaining members of the Bathonian series are usually subdivided in ascending order as follows: Great Oolite Limestone, Great Oolite Clay, and Cornbrash. All of these are represented around Bedford.

The Great Oolite Limestone has a total thickness of about 30 ft., but it is often difficult to fix a limit between this and the beds above and below. The so-called limestone division consists of a succession of bands of limestone, each usually about 10 ft. thick, or less, with thin clay partings. The limestone is sometimes soft and marly, but more often hard and frequently blue-hearted in the middle of the larger blocks. It is occasionally more or less oolitic, and the characteristic fossil is *Ostrea sowerbyi*. Above the limestone comes in most places a bed of clay of variable thickness and character, which is separated as the Great Oolite Clay. Near Bedford it is rarely more than 4 ft. thick and is sometimes absent altogether, as, for example, at Stevington, where the Cornbrash rests directly on limestone without the intervention of any clay.

The Cornbrash appears to be very thin in this neighbourhood, not exceeding 10 ft. in total thickness. It consists of rubbly and shelly limestones and marls with a good many of the characteristic fossils. On the one-inch maps of the Geological Survey it is indicated as thinning out near Bedford, but Mr. Woodward states on the authority of Mr. Cameron that it covers a more extensive tract of country than was supposed near Harrold and Sharnbrook. Owing to the prevailing south-easterly dip of the strata it is not seen to the east of the town of Bedford, in the Ouse Valley. Along the valley of the Nene there is a nearly continuous outcrop on both sides as far as Peterborough, but this is just outside our area.

OXFORDIAN.

The Oxfordian series covers a greater superficial area than any other in the district under review. Its north-western or lower limit follows approximately the course of the River Nene from Wellingborough to Peterborough and then disappears under the alluvium of the Fens. The upper boundary is less well-defined, partly owing to paucity of exposures and partly on account of the lithological similarity between the Oxford Clay and the overlying Ampthill Clay; the two series are not separated on the maps of the Geological Survey.

The Oxfordian series may be divided generally into three zones, in descending order, viz.: *Cardioceras cordatum*, *Cosmoceras ornatum*, *Kepplerites callovienensis*.

In the South of England and in Yorkshire the lowest zone is usually ranked as a separate division, the Kellaways Rock. It is, however, merely a sandy facies of the lowest part of the Oxfordian, and passes laterally into the basement beds of the Oxford Clay of Huntingdonshire. The lithological differences are owing to varying conditions of deposit, the Kellaways Rock being formed in shallower water than the normal Oxford Clay. This sandy Kellaways facies extends into Bedfordshire, and good exposures can be, or have been, seen in several quarries around Bedford. It is separated from the Cornbrash by some 10 ft. of dark clay with selenite, the so-called Lower Oxford Clay, more properly called the Kellaways Clay. The Kellaways Rock proper consists of brown or greenish sands, with pyrites and concretions or doggers of calcareous sandstone. The total thickness of the sandy beds is here very small, and within a very few miles to the north-east they pass laterally into the ordinary argillaceous facies of the Oxford Clay.

The Oxford Clay of Huntingdonshire has been, and still is, largely worked for brick-making. At the present time the most important brick-pits are those near Peterborough and Whittlesea, in the *Ornatus*-zone. These are described in Chapter XX,

p. 483, of this volume. At Eynesbury, near St. Neots, there are also large pits in the *Ornatulus*-zone, but at a higher horizon. In the clay here are seen various bands of earthy limestone, and one of these was dignified by Professor Seeley with the name of St. Neots Rock. It seems to be of no importance for purposes of correlation.

A fine section of the upper beds of the Oxford Clay is to be seen at Sandy, close to the station. It consists of a stiff grey clay, with pyrites and selenite, and abundant fossils, which indicate the *Cordatus*-zone, or more precisely the *Lamberti*-sub-zone. There are two limestone bands which appear to be of no importance. The whole is overlain with a strongly marked unconformity by the Lower Greensand. An exposure of the Oxford Clay at about the same horizon can be seen in a brick-pit one mile from St. Ives, on the Ely Road, but the most important section in this neighbourhood was the one formerly to be seen in a now deserted pit near the river. Here are exposed the uppermost beds of the Oxford Clay, and the whole is capped by the so-called St. Ives Rock, which is usually regarded as the basement bed of the Corallian series in this neighbourhood.

The total thickness of the Oxfordian series is difficult to ascertain, and very various estimates have been made, ranging from 300 to 700 ft. The latter estimate included the Corallian Clays as well. Mr. Woodward is inclined to place the probable thickness at about 500 ft. So far as its lithological characters are concerned, the Oxford Clay indicates deposition in an area of increasing depth, deep over Cambridgeshire and South Lincolnshire, with shallower water to the north and south, at any rate at the beginning of the period, as shown by the wedging out of the Kellaways facies in both directions. At a later stage fairly deep water extended throughout.

CORALLIAN.

The Corallian rocks of the district, and especially those of Cambridgeshire, present features of special interest, in that they display two totally distinct lithological facies. In the north of England and in the south-west the Corallian series consists mainly of an alternation of calcareous sandstones and shelly or oolitic limestones, often with abundant corals. This facies appears to be of somewhat shallow-water character, having been deposited not far from land on the northern and southern margins of a marine area. Over the range of country from South Yorkshire to Oxfordshire, however, the water seems to have been deeper and more muddy, so that here the deposit of this age consists of a rather small thickness of clay, very similar lithologically to the underlying Oxford Clay. Only in one limited locality in Cambridgeshire has any representative of the cal-

careous facies yet been discovered. It will be seen that the character and distribution of the different types of Corallian sediment offer for solution some interesting problems of a general character, and in the case of the limestone development there are also special difficulties which need explanation.

I. *Argillaceous Facies: Ampthill Clay*.—In the early days of geological mapping the existence of Corallian strata in Cambridgeshire was not recognised, except at Upware, and even now in the published one-inch maps of the Geological Survey the Corallian strata are assigned partly to the Oxfordian and partly to the Kimeridgian. The only division definitely indicated as Corallian is the thin calcareous bed known as the Elsworth Rock; this is indicated as Lower Calcareous Grit, and is placed sometimes in the middle of the Oxfordian and sometimes at the base of the Kimeridgian. Professor Seeley was apparently the first to recognise that part of the clays were of Corallian age. He first proposed for this division the name of Tetworth Clay, later he substituted Bluntisham Clay, but the name finally adopted was Ampthill Clay, from the name of the locality where the best exposures were seen at that time.

The dividing line between the Oxford and Ampthill Clays is now drawn at the base of the Elsworth and St. Ives Rock. As before mentioned, this has long been known in isolated patches, but the outcrop for a long distance has been mapped by Mr. Wedd, and the identity of the limestone bands of Elsworth and St. Ives fully established. The Elsworth Rock was originally described by Professor Seeley as a dark-blue homogeneous limestone with iron-shot oolitic grains and iron pyrites, varying in thickness from 3 to 7 ft., overlain by 5 ft. of brown-black clay with *Ostrea flabelloides*; this is capped by another rock bed like that below, making a total thickness of 14 ft.; above this comes normal Ampthill Clay. The correctness of this general description is confirmed by Mr. Wedd. A similar rock is noted by the latter author as forming the floor of the pit at Gamlingay, to be hereafter described, and its occurrence at Upware will also be noticed subsequently. Besides this there appear to be other less important rock-beds at different horizons in the Ampthill Clay, but these do not contain oolitic grains.

A very typical section of the Ampthill Clay is to be seen at Gamlingay. The upper part of the pit here consists of Lower Greensand of the usual character, which lies on the clay with a very sharp junction, showing practically no mixing. This is a very fine example of an unconformity. The upper surface of the clay is usually smooth and level, but here and there it is thrown up into curious little sharp ridges or anticlines, 2 or 3 ft. high. The cause of these is obscure, but it may be connected with surface-creep. The clay itself is mostly of a dull grey colour and quite soft, but two or three bands of whitish argillaceous

limestone occur at different horizons, usually about 10 ft. apart. Recent excavations in the floor of the pit have exposed beds which are supposed to belong to the Oxford Clay, and if that is so the Ampthill Clay must here be very thin. Fossils are fairly abundant in the Ampthill Clay and well preserved; they are all calcareous, instead of being preserved in iron-pyrites, as in the Oxford Clay. One of the most characteristic forms is *Ostrea discoidea*, and this appears to be the only form which is peculiar to this division.

II. *Calcareous Facies: The Upware Limestones.*—The calcareous facies of the Corallian series has a very limited extension in Cambridgeshire, being only known at one locality, forming a long narrow ridge with a maximum visible length of three miles and possibly less than half a mile broad. It was stated by Dr. Fitton in 1836, on the authority of Professor Sedgwick, that similar beds existed near Haddenham, on the road to Chatteris. This statement is referred to by T. Roberts, who says that, although he worked the Haddenham district, he had not been able to identify them. Probably Professor Sedgwick was misled by a poor exposure of the white limestones which occur at various horizons in the Kimeridge Clay, and are seen in strong force in the brick pits at Haddenham and elsewhere.

The identity of the limestones at Upware with the well-known Corallian limestones of other parts of the country, both north and south, was early recognised, and they were assigned to their proper horizon long before the existence of argillaceous beds of the same age was known in Cambridgeshire. Owing to the lithological character the general correlation was a simple task, even without the conclusive fossil evidence which exists, but in matters of detail there was room for much argument, and it is only of late years that a complete solution of certain questions has been arrived at. Besides the Corallian rocks the Upware "island" presents other features of interest, especially in connection with the Lower Greensand, and the section will be referred to again at a later stage.

There is no doubt that the limestones of Upware must be regarded as a coral-reef of Corallian age, formed in a region of exceptionally clear water in the midst of the muddy sea in which the Ampthill Clay was laid down. As will be hereafter explained in detail, the reef-limestones are underlain by the Elsworth Rock and overlain by Kimeridge Clay, so that their general equivalence to the Corallian Clays of the rest of Cambridgeshire and Bedfordshire does not admit of doubt.

The so-called "island" or ridge of Upware lies on the east side of the Cam about twelve miles below Cambridge. It is, unfortunately, very inaccessible by land owing to the badness of the roads. It can, however, easily be approached by water. The

general succession of strata here recognised can be summarised as follows:

Gault.
Lower Greensand.
Unconformity.
Kimeridge Clay.
Coral Rag.
Coralline Oolite.
Elsworth Rock,
Oxford Clay.

The Cretaceous strata rest on the Jurassic with a strong unconformity, and according to W. Keeping an unconformity could once be seen between the base of the Kimeridgian and the limestone; this section is no longer exposed, and the break is probably very slight. There are two principal pits about a mile and a half apart. Most of the floor of the South Pit is occupied by Coralline Oolite, but in the northern wall Coral Rag is seen; both series dip north at 4° or 5° . In the North Pit, owing to variations of dip and rolling of the strata in the intermediate area, only Coralline Oolite is seen, dipping in the same direction, but it is now much overgrown.

The relations of the beds seen in the South Pit and in the smaller excavations between this and the inn have been variously interpreted. For the following account of the most recent views I am indebted to Mr. Fearnside, who investigated the question and summarised his results in the official handbook for the Cambridge Meeting of the British Association.

The Oolite is exposed over about three-quarters of the length of the pit and passes gradually up into the Rag. Owing to the northerly dip the lowest beds occur at the south end of the pit, and in 1901 a further excavation was made at this end. At a depth of 4 ft. a hard bed very like the Rag was met with; below this the rock was variable in character, partly coral rock and partly marl; at a depth of 9 ft. there was found a hard oolitic rock stained with iron, which is undoubtedly the Elsworth Rock. It is clear from the evidence of this boring that the Coralline Oolite sometimes takes on very closely the appearance of the Coral Rag, and that the differences are in the main due to variations in the conditions of deposit. This Rag facies of the Oolite has misled some of the earlier observers, and in particular it caused the belief that in a well near the inn the Coral Rag rested directly on the Elsworth Rock, which was, therefore, looked upon as passing laterally into the Coralline Oolite.

The Elsworth Rock comes to the surface near the inn, and has thence been traced some distance towards the south-east. This suggests that the actual extension of the limestone series beneath Cretaceous and drift may be greater than is indicated by the actual exposures.

From the foregoing account it is clear that the actual suc-

FIG. 26.—DIAGRAMMATIC SECTION OF THE STRATA NEAR THE SOUTH PIT, UPWARE.—*P. Rigby.*

cession of the Corallian rocks of Upware in descending order is as follows:

Coral Rag—a reef limestone, consisting of masses of coral;
20 ft.

Coralline Oolite in two facies—one oolitic or pisolitic, the other a coral limestone resembling the Rag; 30 ft.

Elsworth Rock—ferruginous oolitic limestone.

From the diagrams of former exposures given by W. Keeping and others it is clear that the Upware reef is overlain by Kimeridge Clay and Cretaceous rocks, which are, in part, banked up against it in the form of catenary curves, and, as before mentioned, at one point an unconformity was observed at the base of the Kimeridge Clay. This break is in all probability of no importance, being the natural consequence of the oncoming of conditions which resulted in the deposition of muddy sediment round the shores of an elevated coral-reef which had ceased to grow in size and was undergoing a natural process of degradation by wave and current action. It has been customary to speak of the Upware Island as an anticline; the actual structure of the district does not lend much support to this view, and the necessity for the assumption is doubtful; the super-elevation of the Corallian rocks as compared with the Kimeridgian can be accounted for by the greater thickness of the fast-growing reef-rock compared with the slowly accumulating muddy sediments of the rest of the district.

In Fig. 26 is given in diagrammatic form the latest interpretation of the phenomena seen at and near the South Pit. It was drawn by Mr. P. Rigby, of Christ's College, from a rough sketch supplied by Mr. Fearnside.

KIMERIDGIAN.

The Kimeridge Clay covers a large area in Oxfordshire and Buckinghamshire, but when traced towards the north-east it is lost to view before entering Bedfordshire, being overstepped by the Cretaceous just to the west of Leighton Buzzard. It reappears at the base of the Cretaceous at Waresley and Great Gransden, and forms a narrow strip by Papworth and Oakington to the borders of the Fens at Cottenham. Most of the so-called "islands" of the Fens also consist of Kimeridge Clay, with or without a cap of Lower Greensand, which in most cases has been removed by denudation. The outcrop of the Kimeridge Clay appears to be very wide in North Cambridgeshire; judging from the distribution of the islands, it exists as far west as Chatteris and March, and extends to the foot of the Cretaceous escarpment in West Norfolk. It is mapped as a narrow band below the

Lower Greensand to within a mile of King's Lynn, and therefore probably underlies the marshland between the latter place and Wisbech. How much farther west it extends is unknown.

In the Kimeridge Clay of Cambridgeshire the following subdivisions or zones were recognised by T. Roberts :

UPPER . . .	{ <i>Discina latissima.</i>
	{ <i>Exogyra virgula.</i>
LOWER . . .	{ <i>Cardioceras alternans.</i>
	{ <i>Astarte supracorallina.</i>
	{ <i>Ostrea delloidea.</i>

He estimated the total thickness at 142 ft., but this is probably excessive, and the whole apparently does not much, if at all, exceed 100 ft. The upper division, with *Exogyra virgula*, is only 15 ft. thick, and although this characteristic fossil is abundant, it is doubtful whether any part of the true Virgulian is here represented. The causes of this truncation of the Kimeridge Clay and the absence of all higher Jurassic beds in Cambridgeshire will be discussed in full in the next section.

The junction between the Ampthill and Kimeridge Clays is not well defined; it is usually said to be indicated by a line of phosphatic nodules, which is to be seen in pits at Haddenham and elsewhere. The clay above the nodule band is much darker than that below, and seems to indicate a slight change of physical conditions. The Kimeridge Clay is generally more bituminous than the Ampthill or Oxford Clays, and partakes more distinctly of a shaly character. Bands of impure limestone are not uncommon, and a characteristic feature is the occurrence of immense calcareous concretions or septaria sometimes 3 ft. in diameter. They often contain abundant scalenohedral or dog-tooth crystals of calcite.

The best exposure of Kimeridge Clay in the district is the well-known pit at Roswell or Roslyn Hill, about one mile north-east of Ely. This has been visited by the Geologists' Association and by innumerable other geological parties. As the greater part of the pit has been excavated below the level of the river it is full of water, and the lower beds cannot be well seen. Occasionally, however, fresh excavations are made to a greater depth, some 6 or 7 ft. below water-level, and the lowest beds thus exposed contain *Astarte supracorallina* in great abundance. On the north wall of the pit a good and clear succession can be seen. In the lower part of this wall aptychi of ammonites are very abundant. The greater part of the clay is crowded with fossils, and the zone of *Exogyra virgula* is well marked by a band of very large septaria. In the north-west corner of the pit can be seen 7 ft. of shale with *Discina latissima*, and no higher Jurassic beds are known anywhere in the district. This pit will be referred to again in connection with the very remarkable erratic of Cretaceous rocks which it exposes.

THE RELATIONS BETWEEN THE JURASSIC AND CRETACEOUS SYSTEMS.

We now come to consider one of the most interesting features of the solid geology of the district, from the stratigraphical and structural point of view. It has been shown that the Jurassic system is incomplete, the highest beds seen in Cambridgeshire being the lower part of the upper division of the Kimeridgian. In studying the Cretaceous system it will be found that this also is incomplete, since the Wealden is unrepresented, and the lower part of the Lower Greensand is also absent. In places the latter division is overlapped by the Gault, which thus comes to rest directly on Jurassic rocks, but for the purposes of the present argument this is immaterial; it will suffice to speak generally of the base of the Cretaceous, regardless of whether at the point in question it happens to be Lower Greensand or Gault. It has also been pointed out in the preceding sections that as the outcrops of the different divisions of the Upper Jurassic are followed from south-west to north-east from the neighbourhood of Oxford towards the Wash, each in succession disappears under the unconformable Cretaceous, and reappears again farther to the north-east. In the south and south-west of England there is little or no break in the succession, the Portland and Purbeck divisions being succeeded in due order by the Wealden and Lower Greensand. Farther north, however, the Cretaceous begins to overlap, the Wealden disappears, and the Lower Greensand comes to rest on denuded surfaces of the Upper Jurassic. Portland beds certainly extend as far as Oxford and Aylesbury, while the Purbeck is somewhat doubtfully represented in Buckinghamshire. From Aylesbury to Leighton Buzzard the Cretaceous rests on Kimeridge Clay, from Leighton Buzzard and Feuny Stratford to Ampthill on Ampthill Clay, and at Sandy on Oxford Clay, which is the lowest division exposed along this line. Here the order of succession changes, since at Gamlingay we find the Lower Greensand again resting on Ampthill Clay; to the north-west of Cambridge, and at Upware and Ely, it rests on Kimeridge Clay, and this state of affairs appears to extend to the Wash.

The map (Fig. 27) is an attempt to show in a graphic form the relations above outlined. On the published maps of the Geological Survey the Ampthill and Oxford Clays are not separated, and the boundary line here shown between the Corallian and Oxfordian series is merely approximate, and founded on the best information available, which is scanty. This map and other new figures here given were drawn by Mr. P. Rigby, of Christ's College, to whom I am much indebted for the time and care expended in their preparation.

Even after the detailed researches of Mr. Lamplugh it still remains uncertain whether the transition from Jurassic to Cretaceous is complete in Lincolnshire; but at any rate, most of the

FIG. 27.—MAP SHOWING THE RELATION OF THE JURASSIC AND CRETACEOUS STRATA IN THE CAMBRIDGE DISTRICT.—*P. Rigby.*

1. Tertiary.	6. Corallian.
2. Chalk.	7. Oxfordian.
3. Gault.	8. Bathonian and Bajocian.
4. Lower Greensand.	9. Lias.
5. Kimmeridgian.	10. Trias.

beds missing in Cambridgeshire are there represented. There seems to have been disturbance along the Willoughby axis of Professor Kendall*; but at all events the gap is much smaller

* *Rep. Coal Commission*, 1905, Part ix, p. 30.

in Lincolnshire, and the successive strata seem to overlap towards the south, which is all that is required for our present purpose.

All this may be conveniently summarised in the following table:

Dorset	Series complete.
Wilts	Base of Cretaceous resting on Purbeckian.
Oxford	Portlandian.
Aylesbury	Kimeridgian.
Amphill	Corallian.
Sandy	Oxfordian.
Gamlingay	Corallian.
Ely	Kimeridgian.
Interruption at the Wash.	
Lincolnshire and Yorkshire	Series complete.

From a consideration of these facts it is evident that the base of the Cretaceous rests on a denuded surface of Jurassic strata of varying ages, the oldest being near the centre of the region, on the borders of Bedford and Cambridge, with an ascending succession away from this point in either direction. It follows from this that the general structure of the Jurassic Rocks must be an anticline, with its axis in the neighbourhood of Sandy. This uplift diminishes in importance on either side, and its influence is not felt to the north of the Wash. Towards the south-west disturbance seems to have extended over a greater area, but at the extreme end of the visible exposure, in the Isle of Purbeck, we again find a complete succession.

The next question that arises is as to the age of this uplift. The highest Jurassic beds seen in Cambridgeshire, at the top of the Roswell Pit at Ely, are bituminous shales with *Discina latissima* of the ordinary marine type, and affording no particular indications of any marked shallowing of the water, so it is a fair inference that higher beds of the Kimeridge Clay once existed. However, the phosphate bed at the base suggests that this was not a very deep-water deposit, so that premonitory signs of the uplift may even then have been apparent. Whether the Portlandian and Purbeckian series were ever deposited here is uncertain, but the probability is that they were not, since among the abundant derived fossils of the basement beds of the Lower Greensand at Upware and Potton, as described by Walter Keeping, no undoubted species belonging to these two series seem to have been recognised, whereas fossils from the Kimeridge Clay are abundant. A very few Portlandian species are doubtfully mentioned, and Purbeck forms seem to be wholly absent. This evidence is not absolutely conclusive, but it affords a very strong presumption that the uplift began in late Kimeridgian times, or at latest at the beginning of the Portlandian. From the facts at our disposal it is impossible to estimate the total thickness of strata removed; but at the centre of the arch it must have been considerable, including at least the whole of the

Kimeridgian and Corallian, together with part of the Oxford Clay. As we have seen, the thickness of the remaining Kimeridge Clay is about 100 ft., or rather more, while the Ampthill Clay was estimated by Roberts at 200 ft. It is improbable that the Kimeridge Clay of Cambridgeshire was ever much more than 200 ft. thick, and it may have been less; if we allow 100 ft. for the sum of the vanished Kimeridge Clay at the top and the vanished upper part of the Oxford Clay at the bottom, we shall obtain a total denudation of 400 ft. from the centre of the anticlinal arch, which is probably not far from the mark.

With these facts before us, let us now see whether any explanation of the phenomenon can be found. It is well known that many small unconformities exist in the Jurassic rocks of the Midland Counties. These are in part discordances induced by mere failure of deposition, and in part true unconformities due to pene-contemporaneous erosion and removal of material recently laid down. These breaks in the succession are specially noticeable in the Lias and Inferior Oolite, whereas the Great Oolite and Upper Jurassic seem to have been periods of continuous deposition, until a sudden interruption occurred at the top of the series, as just described. These repeated small movements along similar axes of disturbance are undoubted instances of "posthumous movement," and Professor Kendall in his luminous exposition of the whole subject of post-Carboniferous earth-movements in the final report of the Coal Commission, has referred them to repeated movements of the Charnian axis. Referring to these local disturbances, he says: "These signs mark the Charnian axis as perhaps the most unstable and persistently accentuating fold that has yet been recognised in Britain." The strike of the visible volcanic rocks of Charnwood Forest is approximately north-west and south-east; they have been directly proved to underlie the very thin representative of the Trias at Orton, near Northampton, and in a boring at Bletchley some igneous rock resembling the Charnian series was found under the Oxford Clay at a depth of less than 400 ft. It is suggested that these are boulders in the Kellaways Rock, and not *in situ*; even if this is so, they cannot have come far, and there must at any rate be volcanic rock *in situ* near at hand. We may conclude, therefore, that the existence of a ridge of ancient rocks, running south-east from Charnwood, is proved. The direct evidence, perhaps, leaves something to be desired, but the indirect evidence is overwhelming. On the assumption, therefore, of an ancient ridge running south-east from Charnwood through Bedfordshire, the repeated uplifts which have affected the Jurassic rocks of this district are easily explicable. As we shall see later, a similar type of uplift persisted, at any rate, till the beginning of the Upper Cretaceous. The chief difficulty from a tectonic point

of view with regard to this Charnian axis is to conceive how it terminates to the south against the London plateau; but, at any rate, the idea is quite in harmony with what we know of the disposition of the Palæozoic rocks in the London district, and in particular it helps to explain in a satisfactory manner the known occurrence of Silurian rocks within 800 ft. of the surface at Ware, which lies very nearly on the continuation of the same line of direction. The elevation of the Charnian axis in pre-Cretaceous and early Cretaceous times may well have given this part of the Palæozoic plateau a small extra elevation, which would account satisfactorily for its unusually small depth under Hertfordshire.

The peculiar relations between the Jurassic and later rocks of Cambridgeshire and Bedfordshire are thus to be accounted for on the supposition that in late Jurassic times there commenced a marked elevation of the Charnian axis, which continued until the central part of the resultant anticline of Jurassic rocks had been raised some 400 ft. By the ordinary processes of denudation this ridge was eventually levelled down, till late in Lower Greensand times the sea again overflowed the diminishing barrier, re-uniting the marine basins of the north-east and south-west. The shallow water conditions of the Lower Greensand were succeeded by the deeper water of the Gault, leading up, with one local interruption, to be described later, to the widely extending sea of the great Cenomanian transgression.

THE CRETACEOUS ROCKS.

As explained at length in the preceding section, there is everywhere within the limits of our district an important discordance between the Jurassic and Cretaceous rocks. At the end of Jurassic times an anticlinal uplift occurred, by which a considerable tract was raised above sea-level and underwent denudation. Against the flanks of this ridge the Lower Cretaceous strata were deposited, probably during a period of gradual submergence, so that the successive zones overlap each other; southwards in the north-east, northwards in the south-west. It is not clear, however, how much of this overlap was due to submergence and how much to destruction and removal of the old land-surface. The northern area, in Yorkshire and Lincolnshire, remained marine throughout, but the Purbeck and Wealden beds of the south are estuarine and fresh-water. It is certain, at any rate, that towards the end of the Lower Greensand period the two areas of water, both of which were then marine, became confluent over the Bedfordshire anticline, and there were then laid down the shallow-water strata which here characterise this division. These were, in their turn, succeeded by the deeper

water sediments of the Upper Cretaceous, which overlap the lower division, so far as we know, in all directions. At this time the ancient London plateau was buried from sight and has remained so ever since. The local episodes of the Cretaceous period will be dealt with, each in its proper place, and it is unnecessary to refer here more in detail to the general history of the period, which in this district differs little from that of the whole south-eastern part of England.

THE LOWER GREENSAND.

Owing to the unfossiliferous character of a great part of the Lower Cretaceous strata of this district it is difficult, if not impossible, to ascertain what is the lowest horizon represented. It is true that fossils are, or were, abundant in places, but their distribution is very local, and their state of preservation often poor, since most of them have been obtained from the beds of phosphatic nodules which occur in several localities. At Upware and Brickhill, however, very fine specimens were obtained. Unfortunately these nodule-beds are usually underlain by a considerable thickness of barren sands, so that they do not fix the age of the lowest part of the deposit where they occur. It is clear from the detailed researches of Mr. Lamplugh in Yorkshire, Lincolnshire and Norfolk, that the break in the succession in the north is unimportant, if any exists, and that, on the whole, each successive zone of the Lower Cretaceous, when followed southwards, overlaps the zone below. Consequently it follows that the Lower Greensand of West Norfolk includes beds at a lower horizon than anything seen around Cambridge or in Bedfordshire, both of which were near the top of the anticlinal arch; the beds of the latter region probably represent only the highest part of the Lower Greensand of the Isle of Wight, the Aptian of the Continent. In following the series westwards it is probable that lower and lower beds successively come in, but this is not yet established in detail. This view of the general relations of the Lower Greensand is confirmed by the variations in the actual thickness of the beds which can be observed in Bedfordshire and Cambridgeshire; speaking generally, the series is much thinner on the top of the arch, and in one district it is lost to view altogether, being overlapped by the Gault. In the west of Bedfordshire it attains a thickness of 250 ft.; this gradually decreases eastwards, till at Upware there is only some 12 ft. of sand. In Norfolk this is again found to have increased to something like 170 ft., and some beds of clay are intercalated, indicating somewhat deeper water conditions. Towards the south-east and south also the Lower Greensand is known to thin out against the London plateau.

As would naturally be expected under such conditions, the

beds of this age give the clearest evidence of having been deposited in shallow water. Their general character in Bedfordshire and Cambridgeshire is that of loose, incoherent sands of a yellow or brown colour, with well-rounded and polished grains, consisting for the most part of quartz, with occasional pebbles of a peculiar black or dark-greenish substance known as Lydian-stone. In a fresh, unweathered sample from deep borings there are to be seen numerous green-coated grains and rounded grains of glauconite, which are supposed to be casts of foraminifera. Such is the Greensand as observed at Sandy or Gamlingay. In other localities, however, it is coarser in texture and harder. Some beds are conglomeratic in character, and there are also to be seen layers of phosphatic nodules, which are of great interest and will be described later. The hard stony facies is frequently spoken of as *Carstone*; it is usually a dark-coloured ferruginous rock, cemented by deposition of iron oxide. It is believed, however, that the hardening and cementing is a purely superficial process of quite recent origin and actually in progress, being due to percolation of water holding iron salts in solution. Sometimes the iron compounds are deposited in very peculiar forms, even giving rise to hollow structures known as *box-stones*, which, when broken open, are found to contain only a little bleached sand.

The normal Lower Greensand is unfossiliferous, and it is only in certain spots that fossils are found. These, when they do occur, are extremely abundant and their manner of occurrence is peculiar and interesting. At several localities there have been found deposits of a conglomeratic character, consisting very largely of pebbles or nodules of phosphate of lime; some years ago these were extensively worked as a source of phosphate, and were then commercially spoken of as *coprolites*. The nodules are for the most part casts of fossils, and they are of two kinds. One type represents the indigenous fauna, living at the time the bed was formed, while the other type, which is generally more numerous, consists of rolled fossils derived from older beds, chiefly Jurassic. The most important deposits of this nature were those at Upware and Potton, and at Brickhill, near Leighton Buzzard. These are no longer worked, except at Potton, and the sections are obscure, but they have been described in detail by Dr. Teall and Walter Keeping. One of the most remarkable features of the derived fauna is the occurrence of fossils belonging to the lower stages of the Lower Greensand, which were evidently once deposited in this neighbourhood and removed, unless, as is possible, the fossils have been carried for some distance by current action. There have also been found a good many boulders of far-travelled rocks, such as gneiss, granite, mica-schist, etc., and at Potton Professor Hughes found a Carboniferous trilobite. It has been suggested

that the presence of these boulders indicates floating ice, but they may have been carried to their present position entangled in the roots of floating trees.

The most interesting recent development in connection with the Lower Greensand is the discovery by Mr. Lamplugh and the late J. F. Walker* of an indigenous fauna at Leighton Buzzard. This occurs embedded in lenticular masses of a gritty limestone in some large sand pits at Shenley Hill, a mile and a-half north-east of Leighton Buzzard. It is quite clear that the beds in question are below the Gault, but, curiously enough, the fauna shows a greater affinity to that of the Upper Greensand than to any known Lower Cretaceous horizon. The reason for this anomalous state of affairs is possibly connected with the general absence of fossils in the upper part of the Lower Greensand; that is to say that the actual incoming of the so-called Upper Cretaceous fauna occurred earlier than was formerly supposed, and did not coincide with the change of lithological character from Greensand to Gault, as has been hitherto assumed.

The best exposure of the Lower Greensand in the district is that at Sandy, which has been visited by the Geologists' Association; it presents no very remarkable features. At Potton Heath also there is an interesting exposure which is still worked for "coprolites," but it is very strictly guarded and trespassers receive short shrift. Again, at Gamlingay in a large brick-pit, there is a very fine exposure of Lower Greensand resting on Ampthill Clay. The line of junction is everywhere absolutely sharp, and in some places the surface of the clay is crumpled up into curious little anticlinal ridges 2 or 3 ft. high. These are probably due to surface creep. At Great Gransden there is to be seen a very fine example of false bedding in somewhat hardened sands, with boulder clay above resting on a smooth surface of Greensand. Beyond this point exposures are poor or wanting, but the Greensand caps some of the islands in the Fens, and can be seen at the west end of the Roswell pit at Ely.

The development of the Lower Cretaceous series in West Norfolk is of considerable interest. These strata crop out along the stretch of rising ground on the eastern border of the Fens, and are particularly well seen between King's Lynn and Hunstanton. Exposures are fairly numerous, and the area has been worked out in considerable detail by the officers of the Geological Survey, especially by Mr. Lamplugh.

The division of the Aptian strata here is a three-fold one, since a considerable thickness of argillaceous beds is intercalated between two sandy series, and the whole has a total thickness of about 170 ft. For these sub-divisions the following local names are adopted by Mr. Lamplugh.

* *Quart. Journ. Geol. Soc.*, vol. lix (1903), p. 234.

		ft.
CARSTONE.	{ A deep, bright brown ferruginous sandstone	
	{ or grit, often in massive beds. About	40
SNETTISHAM	{ Clays and loams, with casts and impressions	
CLAY.	{ of marine fossils and land plants	30
SANDRINGHAM	{ Light coloured or silvery sand, with occa-	
SANDS.	{ sional flaggy brown stone	100

This is the succession as seen in the neighbourhood of Appleton and Sandringham, where the outcrop of the series is some four miles broad. When followed southwards the lower part of the Snettisham Clay passes into a flaggy sandstone, but towards the north it thickens. Owing to its northerly dip it occurs at a very low level at Hunstanton, but it has been described on the beach and in excavations for the foundations of the pier. This clay was at one time mistaken for Kimeridge Clay.

The lower part of the cliff and the foreshore at Hunstanton are formed of Carstone, which is for the most part a rather hard brown ferruginous sandstone, generally containing a good many small pebbles, especially in certain layers. Some way down in the series there is a very well-marked pebbly band, which can only be described as a conglomerate. The pebbles of which this bed is composed are well rounded and their surfaces are conspicuously well polished. This probably indicates long-continued drifting to and fro in shallow water. The appearance of this conglomeratic Carstone, with its shiny pebbles and dark ferruginous cement, is very characteristic and unmistakable. Some bands are distinctly harder than others and stand out in strong relief, especially one near the pier and another on the shore at the eastern end of the cliff; this latter is divided by joints into large blocks, and the whole forms a very conspicuous pavement on the beach. This particular bed is the dark conglomerate, above referred to, and it forms a very striking feature. Fossils, especially ammonites, can often be found *in situ* in the hard rock on the beach. They belong chiefly to the *Deshayesi* and *Martini* types. Large specimens of *Perna* are also seen, but the fauna is not a rich one.

With regard to the correlation of the divisions of the Lower Greensand of Norfolk some difficulty has arisen, chiefly owing to our imperfect knowledge of the Lower Cretaceous faunas of England. From an examination of the fairly abundant fossils Mr. Lamplugh is inclined to consider the Snettisham Clay as the equivalent of the Tealby Limestone of Lincolnshire, while the Carstone is equivalent to the upper part of the Speeton Clay. It is wholly uncertain how much of the succession in the south of England is represented by the Sandringham Sands, but it is at any rate clear that they include strata lower than anything found in Cambridgeshire or Bedfordshire; that is to say, the successive

FIG. 28.—GEOLOGICAL MAP (WITHOUT DRIFT) OF THE NEIGHBOURHOOD OF HUNSTANTON.

(Reproduced, by permission, from the Map of the Geological Survey.)

zones, if worked out in detail, will be found to overlap towards the south against the flanks of the Jurassic anticline, as previously explained.

THE GAULT.

At the end of Lower Greensand times a movement of submergence set in and the strata of the Upper Cretaceous were laid down in deeper water and over a larger area than those of the lower division. The depression appears also to have been greater towards the north, so that, when followed along its strike, the Gault of Cambridgeshire passes into the peculiar red rocks of Norfolk, Lincolnshire and Yorkshire, which are very much thinner.

The Gault of the district under review belongs almost entirely to the argillaceous facies, and the so-called Upper Greensand is hardly represented. It can, however, be followed from the west within the limits of our district in the neighbourhood of Totternhoe, and possibly as far as Charlton. The sandy facies could not be expected to occur to the eastward of this point, for, as will be seen later, there has been in East Bedfordshire and Cambridgeshire extensive erosion of the Gault before the deposition of the Chalk Marl. It is commonly stated that no Upper Gault occurs in Cambridgeshire, and that possibly even some of the lower division is missing. This view, however, will probably undergo revision, at any rate in part.

So far as can be ascertained in the poor exposures of the junction now available the Gault rests conformably on the Lower Greensand, wherever the latter is present, as is usually the case; in the west of Bedfordshire, however, the Gault overlaps considerably and rests directly on the Jurassic. The reason for this state of affairs will be obvious from what has already been said as to the relations of the Charnian axis to the Jurassic and Cretaceous strata. The Gault is thick in Bedfordshire, amounting to about 230 ft. at Totternhoe, but it thins eastwards, and this thinning is not entirely due to subsequent erosion, but must be ascribed to deepening of the water in this direction. The denuded area is believed to come to an end a few miles south of Stoke Ferry, but where the whole of the Gault is again seen near this place the total thickness is only 60 ft. North of this point it gets thinner still, and is eventually represented only by 4 ft. or so of the Hunstanton Red Rock.

The Gault of Cambridgeshire is a soft, sticky clay of a pale bluish-grey or occasionally brownish-grey colour. It is fairly fossiliferous and contains abundant phosphatic nodules scattered through it, or sometimes in layers; in one or two places, as, for example, at Barnwell, in the suburbs of Cambridge, there are calcareous bands which seem to be very largely composed of

broken prisms of the shells of *Inoceramus*. A similar band probably occurs in a well at Arlesey.

Exposures of Gault are fairly numerous, since it is much used for brick-making, but most of them are not very interesting and no good purpose would be served by a detailed description of them. The point of greatest interest which has recently arisen is the question of the Upper Gault at Cambridge, which has been investigated by Mr. Fearnside. A large brick-pit at Barnwell, which has been visited more than once by the Geologists' Association, shows a very fine section some 60 ft. in height. At the top is 15 ft. of re-arranged material, soil and Chalk Marl, which was disturbed during the working of the Cambridge Greensand. Below this comes some 40 ft. of normal Gault, and then the hard shelly bed before referred to. This and the few feet of clay which have been exposed below it contain a fairly abundant fauna, which corresponds most closely with that of the upper part of the zone of *Schloenbachia varicosa* at Folkestone. *Schloenbachia rostrata* is also recorded, but with some doubt, owing to bad preservation of the specimens. The occurrence of this species has long been known in the district, but little importance was attached to it; it was regarded as merely an instance of the occurrence of a zone-fossil out of its proper zone. Taking this fauna as a whole, however, there can be little or no doubt of the correctness of the view put forward by Mr. Fearnside, that at least 40 ft., and perhaps more, of true Upper Gault are here present. If this fact is established a difficulty is raised in accounting for the presence in abundance of Lower Gault fossils in the Cambridge Greensand around Cambridge; it is difficult to believe that such comparatively heavy objects could be carried for a great distance, and this suggests that the presence of Upper Gault is probably quite local, and that in the immediate neighbourhood erosion must have reached the lower zone.

THE HUNSTANTON RED ROCK.

The development of the beds representing the Gault in West Norfolk, and especially in the well-known cliff-section at Hunstanton, is so interesting that it is worthy of description in detail. The exposure is of exceptional clearness, being free from the landslips which disfigure so many of our cliff-sections, and the strongly-marked differences of colour bring out the stratigraphical divisions very plainly. As seen in the cliff which runs eastwards from the pier we have at the base the dark brown Carstone, then the conspicuous bright red band of the Hunstanton Red Rock, which is surmounted in its turn by a considerable thickness of white Chalk.

The Red Rock occurs all along the base of the Chalk hills from a point west of Shernborne by Heacham to Hunstanton, but it has never been worked commercially, so that exposures are few. It is here very thin, but probably thickens eastwards, since a deep boring at Holkham showed 8 ft. of Red Rock underlain by 10 ft. of grey Gault.

Near the pier at Hunstanton the Red Rock is at the top of the low cliff, but it dips to the north, and at Old Hunstanton it comes down to the beach. It rests regularly and evenly on the Carstone, and there is no sign of erosion or unconformity between them. The thickness is about 4 ft., and three slightly different bands can be recognised. The lowest part is softer and more calcareous, and contains a good many quartz grains like those in the sandstone below. The central part is a dark red rough nodular limestone with many fossils, while the highest band, about 1 ft. thick, is a hard light red or pink limestone, mottled with white and more calcareous than the rest. There is at the top a seam of ferruginous earth separating it from the Chalk. The fauna is fairly abundant, comprising about 90 species, excluding Foraminifera, which are numerous, and this fauna clearly includes forms characteristic of both the Lower and Upper Gault, so that the whole thickness of this formation, as seen farther south, is represented here by 4 ft. only of this peculiar rock.

As regards its chemical and lithological characters, the rock is certainly calcareous; in fact, a sandy limestone with occasional pebbles. The colour is undoubtedly due to ferric oxide, but its origin is unknown. It does not appear to be due to infiltration from above, and it can scarcely be derived from the ferruginous sands below. The absolute sharpness of the limits of the red colouration is almost conclusive evidence that it is an original and not a secondary character.

As to the conditions of deposition of the Red Rock, nothing is really known. It seems probable that it was laid down in clearer water than the normal Gault, or at any rate in an area where less argillaceous sediment was being deposited. On account of the abundance of fossils, however, it cannot have been formed very far from land, as the fauna is not a wholly pelagic one. Its extreme thinness may be ascribed to a failure of sedimentation, perhaps consequent on the final submergence or disappearance of the land area from which the sandy material of the Carstone was derived. In this regard it is significant that the London plateau was for the first time completely covered by sedimentary deposits during the Gault period. This fact, taken in connection with the thinning of the last named series towards the north, and the absence in the same direction of the sandy Upper Greensand facies, suggests that the origin of the material is to be sought in the south and west, where an ancient shore-line

existed, formed by the folded and uplifted area of the American or Hercynian zone.

THE CHALK.

We now come to the highest and most conspicuous division of the Cretaceous system, viz., the Chalk. Succeeding the varying conditions of the Lower Cretaceous and the lower part of the Upper Cretaceous there occurred a period of greater uniformity, owing to a widespread movement of submergence. This submergence naturally led to an overlap, and this overlap of the Chalk over the beds of the Lower Cretaceous was a phenomenon of almost universal occurrence. It is one of the most conspicuous features of the stratigraphy of the Mesozoic period, and is spoken of by Suess as the *Cenomanian Transgression*. Over north-western Europe there were laid down a thick series of white or pale-coloured limestones and marls of peculiar and characteristic composition, which are known collectively as the Chalk. This is not the place to discuss the origin of the Chalk generally, but it is clear that it was laid down in a partly enclosed sea on a large scale, perhaps something like the Gulf of Mexico, and probably in water of moderate depth, as shown by its lithological character. Consequently it must be regarded as a local facies and not the typical deposit of the period. The Chalk constitutes perhaps the most strongly-marked feature of the geology of south-eastern England, and it reaches a large development within the area here treated of.

With regard to the nomenclature of the sub-divisions of the Chalk, the attempts which have been made to apply the foreign classification of Cenomanian, Turonian and Senonian to this country have not been found altogether satisfactory, and the old division into Lower, Middle and Upper Chalk, which still prevails in the Memoirs of the Geological Survey, is here adopted.

In the west of Bedfordshire and in Norfolk there is an uninterrupted passage from the Gault into the Chalk, but over a large part of Bedfordshire and Cambridgeshire there is a break between the two series, and the lowest bed of the Chalk is here of a peculiar character. This is the well-known Cambridge Greensand, and although in reality only the base of the Chalk, it is of sufficient interest and importance to be treated of in a separate section. It will be more convenient, therefore, to postpone our consideration of the Chalk in general until after the description of this deposit.

The Cambridge Greensand.—At the end of the Gault period there occurred a farther movement of the Charnian axis, a movement of small amplitude, but sufficient to raise the upper portion of the Gault within the range of active denudation and

to produce a clear discordance between the Gault and the lowest beds of the Chalk over a considerable stretch of country. The limits of this denuded area have already been referred to; it extends approximately from Harlington in Bedfordshire to a point somewhere between Soham and Stoke Ferry, a distance of at least 50 miles. Over the whole of this area the upper surface of the Gault is an irregular one, having been worn into ridges and furrows probably by the action of strong currents. By this means the finer material was removed, while the heavier residue remained behind and to a great extent settled down into the hollows, forming a discontinuous bed of varying thickness and peculiar character. To this bed the name of the Cambridge Greensand has been given. Although of but small thickness, generally not much exceeding 1 ft., it is a deposit of very great interest, especially from the palæontological point of view, owing to the variety of its fauna. Besides this, it is or was of great commercial importance, owing to its richness in phosphate of lime, so much so that by far the greater part of it has now been removed and employed in the manufacture of artificial manure. In fact, in its present condition the Cambridge Greensand is little but a memory. Fortunately, however, its scientific value was fully realised at the time of the greatest commercial activity, and the Sedgwick Museum at Cambridge contains a magnificent collection of fossils obtained from it. The diggings were in full swing during some of the earlier visits of the Geologists' Association to Cambridge, and in 1871 and 1884 the members had excellent opportunities of inspecting the workings in the neighbourhood of Cambridge. At the time of the earlier visits this bed was referred to the Upper Greensand, the importance of the break at its base not being fully appreciated. Later, however, it was seen that it must be considered merely as the lowest bed of the Chalk Marl.

Lithologically the Cambridge Greensand is a greenish, sandy marl with abundant grains of glauconite, to which it owes its colour and texture. This is its usual character, but in places it seems to consist of worked-up clay from the Gault, and here it has more of a grey colour. Upwards the bed graduates without a break into the true Chalk Marl. The most remarkable feature of the bed is the occurrence of vast numbers of phosphate nodules, and these are most thickly crowded in the lowest layers, becoming scarcer upwards. The usual thickness of the rich nodule-band is about 8 ins., but it is sometimes thicker in the deeper hollows. The great majority of the nodules, perhaps 95 per cent., are very dark or black in colour; the remaining 5 per cent. are of a dull buff colour. Besides these, there were often found pebbles or large boulders of far-travelled rocks. These will be referred to again.

The greater part of the nodules of both kinds are obvious

fossils, and palæontological investigation has shown that the fossils preserved in dark phosphate are all derived from the Gault, whereas the pale specimens are forms of a higher horizon, and represent the indigenous fauna of the bed—that is, they are Chalk Marl forms. The total number of species recorded is very large, and the complete list of the fauna, including both derived and indigenous forms, occupies no less than twelve pages of Mr. Cowper Reed's *Geology of Cambridgeshire*. Owing to considerations of space, it is impossible to discuss here the affinities of this derived fauna. It must suffice to say that the most abundant forms are those which characterise the middle and upper portions of the Gault in adjoining areas, e.g., *Schloenbachia rostrata*, *Hoplites auritus*, and *Hoplites splendens*. The derived nodules are much water-worn, and to many of them are attached small valves of *Dimyodon nilssoni* (*Plicatula sigillina*) and oysters, showing that they have remained uncovered on the sea-floor for a considerable time, and consequently the formation of the Cambridge Greensand must have been a slow process.

As already noted, there also occur a considerable number of pebbles and boulders of extraneous rocks, many of which must obviously have come from long distances, since nothing in the least resembling them is now exposed in the district. They vary in size from large blocks measuring nearly a cubic foot down to small pebbles of an inch or two in diameter, and attached to all of them, with very few exceptions, are phosphate nodules and *Dimyodon*. It is noteworthy, however, that the igneous rocks show fewer of these attachments than the sediments, probably owing to the differing texture of their surfaces.

A very large collection of these boulders, numbering some hundreds of specimens, is preserved in the Sedgwick Museum. From a somewhat casual examination of them it appears that the most abundant types are greenish and greyish grits and grey-wackes of no very distinctive character. These might be derived from almost any source. There are also a good many red and purple sandstones, whose general appearance suggests that they may be derived from the Old Red Sandstone, or possibly Lower Carboniferous. Some very fine-textured red quartzites are noteworthy, and there are also many fine-grained rocks which for want of a better name may be summed up as hornstones. A coarse-grained conglomerate of white quartz pebbles also occurs in large blocks, and one small pebble of agglomerate shows a strong suggestion of the felsitic agglomerates of Charnwood. It is, however, probably of aqueous origin. Turning now to the rocks of igneous origin, we find that granites and gneisses are fairly common. They are mostly very rich in muscovite, and often of coarse texture. Their general facies does not suggest a Scotch or Norwegian origin, and it may be definitely stated that most of them are not derived from the south

of Norway, since they show no resemblance to the soda-rocks of that petrographical province. Various porphyries and rhyolites with good flow-structures also occur. One of the most interesting boulders is a specimen which has been frequently referred to in the literature of the subject as Labradorite, Norite, Hyperite, etc. This alone is certainly of Norwegian origin, and has been recently identified as the Essexite of Christiania. Some doubt has been cast on the authenticity of this specimen, and it is suggested that it was derived from the glacial drift, and accidentally included with the boulders of the Greensand. A careful inspection shows, however, that it possesses the usual attached shells, and a chemical examination has confirmed the existence of adhering phosphate nodules. Its derivation from the Greensand is therefore beyond doubt.

This collection is very briefly referred to by Professor Kendall in the Coal Commission Report. He says: "I think the majority of these stones were certainly not derived from the Charnian series; some may have come from Scotland, and one or two granites were rather of a Cornish type, but there are at Cambridge several specimens of a purple felspathic grit which bears rather marked resemblances to a Carboniferous rock encountered at Kettering Road, Northampton." It is therefore possible that these boulders were derived in part, at any rate, from the Charnian anticline.

As to the manner in which these boulders reached their present situation, various suggestions have been made. It is clear that they were by some means floated along and dropped where they now lie. They are much too large to have been rolled for any distance by current action, and the only probable agencies are floating trees and floating ice. Against the first supposition, that of entanglement in the roots of floating trees, is the great variety of rock-types here found. It is hardly likely that trees would carry along stones which must have come from widely-separated areas and drop them in such abundance in one limited locality. The other supposition, that of floating ice, is much more probable, and Messrs. Sollas and Jukes-Browne have described on some specimens striations which they refer to ice-scratches. It is to be noted that an accumulation of ice-borne boulders does not necessarily imply glaciation of the region in question, since icebergs may melt and deposit their load far from their point of origin, as on the Banks of Newfoundland. It seems most likely, therefore, that the area covered by the Cambridge Greensand represents a shallow or shoal on which icebergs stranded and deposited the solid material which they had brought from a distant source.

The Chalk of Bedfordshire and Cambridgeshire.—The general succession of the beds composing the Chalk in these two counties is on the whole a very uniform one, with slight variations

in the thickness of the different divisions when followed along the outcrop. The Chalk varies to a certain extent in hardness and lithological character from bed to bed, so that it has been found possible to separate certain horizons by means of their lithological character, and these are found to be on the whole persistent—at any rate, within our limited district. It must be understood, however, that these lithological sub-divisions do not hold good in other areas, and the description here given must be taken as of only local application. More satisfactory, however, is the separation into zones by means of fossils; this has been thoroughly carried out in the case of the Chalk, and by this means it has been found possible to correlate the beds of widely-separated areas. Unfortunately, Dr. Rowe's remarkably detailed researches have as yet only extended to the coast sections and the Isle of Wight, so that some points with regard to inland ex-

posures are still somewhat obscure. The classification here adopted is in some sense a compromise, and does not agree in all points with that given in the Memoirs of the Geological Survey. The chief variation from the latter is with respect to the dividing line between the Middle and Upper Chalk, which is here drawn above the Chalk Rock, so that the whole of the zone of *Holaster planus* is referred to the Middle Chalk. Other slight discrepancies will be referred to later.

Exposures of Chalk are numerous along almost the whole line of outcrop, so that it is impossible to deal with them all, and no good purpose would be served by doing so, since in all districts the succession is very similar. The method here adopted will be to take as types one or two districts which have been visited by the Geologists' Association, while for other sections reference must be made to the extensive literature or to the Survey Memoirs.

The districts selected for this purpose are the Dunstable Downs in Bedfordshire, and the neighbourhood of Cambridge, since both have frequently been the scene of the excursions of the Association. Beginning with the latter, the old Roman road known as the Via Devana runs in a south-easterly direction from Cambridge, and consequently passes successively over all the divisions of the Chalk seen in this neighbourhood. This line corresponds almost exactly with the horizontal Section 126 of the Geological Survey, and so forms a convenient basis for description. The succession of the strata along this line, with their lithological and palæontological nomenclature, and approximate thicknesses are summarised in the following table. The same is also shown, with a greatly exaggerated vertical scale, in Fig. 29.

ZONE.	LITHOLOGICAL DIVISION.	MAXIMUM THICKNESS.
UPPER CHALK.	Upper zones absent in Cambridgeshire.	ft.
	<i>Microaster cor-testudinarius</i>	450
	<i>Holaster planus</i>	14
MIDDLE CHALK.	Chalk	50
	<i>Terebratulina lata</i>	100
	<i>Rhynchonella cuvieri</i>	70
	Chalk	10
	Melbourn Rock	6
LOWER CHALK.	<i>Actinocamax plenus</i>	80
	Belemnite marls	20
	<i>Holaster subglobosus</i>	60
	Grey Chalk	—
	Totternhoe Stone	
	Chalk marl	
	<i>Schloenbachia varians</i>	
	Cambridge Greensand	

As will be seen from the foregoing table, the Upper Chalk is only seen in part in Cambridgeshire; but higher zones are exposed in the neighbourhood of Dunstable, so that consideration of this division may be conveniently deferred for the present.

The *Lower Chalk* is generally divided into three zones, and these correspond to fairly well-marked lithological divisions. The zone of *Schloenbachia varians* includes the Cambridge Greensand, which has already been fully described, and the Chalk Marl. The lower part of the latter division is a soft greyish marl, while the higher part is harder and more chalky. The total thickness is about 60 ft., and the lower part in particular is well adapted for cement making, so that exposures are numerous.

The Totternhoe Stone, which in Cambridgeshire is often called the Burwell Rock, is a sandy chalk considerably harder than the Chalk Marl; at its base is a layer of phosphatic nodules with a green coating. The harder beds above have been used to a considerable extent as a building stone; they are extensively quarried at Burwell, where the total thickness is about 20 ft. They also form the floor of the large pit at Cherryhinton. As will be explained later, this bed gets considerably thinner towards the north-east, and at Hunstanton it is reduced to 2 ft. The fauna of the bed is a large one, and fossils are much more abundant than in the beds above and below.

Above the Totternhoe Stone and below the zone of *Actinocamax plenus* there is a thickness of about 80 ft. of grey and white Chalk, in which fossils are scarce, only about eight species being recorded. This division corresponds to the Grey Chalk of Bedfordshire, etc., but near Cambridge only the lowest 30 ft. is grey, the rest being rather conspicuously white. This division is remarkable from the peculiar curved divisional planes which are such a conspicuous feature of it; these appear to be joints, not bedding planes, and are perhaps due to contraction on drying.

The highest division of the Lower Chalk is here formed by a few feet of yellowish marl without fossils, the equivalent of the zone of *Actinocamax plenus* of other districts.

With regard to the zonal divisions of the Lower Chalk, a modification has lately been suggested by Mr. T. O. Bosworth.* He considers that the fauna of the Totternhoe Stone is more closely allied to that of the *variens*-zone than to the *Holaster*-zone; he also states that *Holaster subglobosus* is rare in the upper part of the Grey Chalk, while another species, *Holaster trecensis*, is common. Mr. Bosworth therefore proposes to re-arrange the zones as follows:

Zone of *Actinocamax plenus*.

Zone of two <i>Holasters</i> . . .	{	Sub-zone of <i>H. trecensis</i> .
		" " <i>H. subglobosus</i> .
Zone of <i>S. varians</i> . . .	{	Burwell Rock (Totternhoe Stone).
		Chalk Marl.

* *Geol. Mag.*, dec. 5, vol. iii (1906), p. 412.

The *Middle Chalk* as here defined possesses well-marked boundaries both above and below, since the Melbourn Rock and the Chalk Rock are conspicuous hard bands, which are easily traced across country. Some difficulty has arisen in the delimitation of the zones of *Terebratulina lata* and *Holaster planus*, which are not clearly separated. In fact, Mr. Jukes-Browne, in the Survey Memoir,* proposes to abolish the latter and to include all the beds between the zone of *Rhynchonella cuvieri* and the base of the Chalk Rock as the zone of *Terebratulina lata*. However, for purposes of local description, it is more convenient to retain *Holaster planus* as a zone-fossil. In the memoir above quoted, Mr. Jukes-Browne includes the Chalk Rock in the Upper Chalk, but its fauna certainly has more affinity to that of the Middle Chalk, and it is here retained in that stage. Considerable difficulty has arisen as to the nomenclature of the fossil which is adopted as the index to the middle zone; it was originally identified erroneously as *Terebratulina gracilis*, which is a well-known fossil of the Trimmingham Chalk; at the present time it is commonly called *Terebratulina lata*.

The Melbourn Rock of Cambridgeshire is a hard, whitish or yellowish chalk, varying from 6 to 10 ft. in thickness. Its beds are generally found capping the escarpment of the Lower Chalk; it is not well seen at Cherryhinton, as it occurs just in the line of the road above the large pit. Fossils are very scarce, and only four species are recorded.

The upper part of the zone of *Rhynchonella cuvieri*, above the Melbourn Rock, is much more fossiliferous, although even here individuals, not species, are abundant, only about a dozen forms having been recorded. In a small pit to the south of the road, just above the large pit at Cherryhinton, *Rhynchonella cuvieri* and *Inoceramus labiatus* exist in profusion. The greater part of this division consists of white chalk with occasional thin marly layers and a few flints. This zone forms the greater part of the north-western slope of the Gog-Magog Hills, including most of the golf links, and a fairly good exposure is seen in a pit on the latter, by the side of the Hills Road.

The Vandlebury beds or zone of *Terebratulina lata* form the upper part of the first ridge of the Gog-Magog Hills, taking their name from the ancient earthworks of Vandlebury. Almost the only exposure is to be seen in a cutting on the abandoned railway at Worsted Lodge, where flints are abundant. Fossils are rare, and belong to but few species.

The lower part of the *Holaster planus*-zone, to which no local name is applied, consists of soft white chalk with some flints. There are very few exposures, since rock of this soft type has no special value for any purpose. The fauna is not very large, only nineteen species being recorded in the Survey Memoir.

* "The Cretaceous Rocks of Britain," vol. II, p. 362.

The Chalk Rock, which is here regarded as the upper part of the zone of *Holaster planus*, consists of one band or more of hard crystalline chalk with layers of green phosphatic nodules. The upper surface is generally quite sharply defined, and is here taken as the dividing line between Middle and Upper Chalk, although Mr. Jukes-Browne places the Chalk Rock in the Upper Chalk, chiefly for palæontological reasons. The total thickness of this bed varies from 2 to 14 ft.; it usually forms a somewhat conspicuous feature, and exposures are fairly numerous. The fauna is a rich one in comparison with most of the Middle Chalk, and it has been exhaustively investigated by Mr. Woods,* who pointed out its relationship to the fauna in the zone of *Heteroceras Reussianum* in N.W. Germany.

The *Upper Chalk* is hardly represented in Cambridgeshire, since it is for the most part covered by the Tertiary deposits of the London basin. However, the lowest division, the zone of *Micraster cor-testudinarium*, is exposed in the south-east of the county. It is much masked by drift, and very little is really known about it. The Upper Chalk covers more ground, and higher zones are exposed in the neighbourhood of Dunstable, so that further details will be given in dealing with that area.

As will be seen from the above description and sections, the lie of the Chalk in the Cambridge district is a very simple one, with a uniform and very gentle dip to the south-east. In the neighbourhood of Royston the outcrop of the Chalk Rock reveals the existence of a noticeable departure from this general uniformity. In this neighbourhood pits are numerous in this bed, and they show the existence of a remarkable line of flexure probably accompanied by a fault. The following description is taken from the Survey Memoir.†

"This flexure is exposed in a series of quarries; it appears to commence near Therfield, crosses the North Road (Ermine Street) about two miles south of Royston, and curves round by Newsells Bury, Smyth's End (Barley), Great Chishall, and Heydon. At all these places the beds are bent into an anticline, the northern limb of which plunges down the slope of the escarpment. Whether they are cut off by a fault, or whether the curvature is continued by a corresponding syncline, we do not know, but there must be either a fault or a syncline along the lower slopes of the escarpment, as the Chalk near Royston has normal southerly dips. If there is no fault there would be a second outcrop of the Chalk Rock to the north of this series of exposures, but no such outcrop was found."

In one at least of these pits patches of Boulder Clay can be seen plastered up against overhanging surfaces of Chalk—that is to say, there is actual inversion, and Mr. H. B. Woodward‡

* *Quart. Journ. Geol. Soc.*, vol. lii (1896), p. 68, and vol. liii (1897), p. 377.

† "The Cretaceous Rocks of Britain," vol. ii, p. 469.

‡ *Quart. Journ. Geol. Soc.*, vol. lix (1903), p. 362.

attributes the whole disturbance to the pressure of an ice sheet against the edge of the Chalk escarpment. This view is not, however, accepted by Dr. Bonney.*

Coming now to our second selected district, we find that there is on the western borders of the county, in the neighbourhood of Dunstable, a perfectly gradual upward passage from the Gault to the Chalk Marl. At Eaton Bray and around Totternhoe the upper beds of the former division consist of soft glauconite sands; this is the most northerly point at which the Upper Greensand (Selbornian) facies of the Gault has been observed. The local unconformity which gives rise to the Cambridge Greensand sets in near Harlington, and in the intervening stretch of country neither Upper Greensand nor Cambridge Greensand occur, but the clay of the Gault passes up by imperceptible gradations into the marls of the zone of *Schloenbachia varians*.

So far as the rest of the succession is concerned it is very similar to that already described near Cambridge, so that detailed description of each bed is unnecessary. All, or nearly all, the minor sub-divisions of the Cambridge section can here be recognised; the total thickness of the Lower and Middle Chalk is here somewhat greater, viz., about 425 ft., as against 400 ft. at Cambridge, a trifling difference only. The extra thickness appears to be in the Lower Chalk.

The locality which has been most frequently visited by the Geologists' Association is the neighbourhood of Totternhoe, where the physical features due to the various bands of the Chalk are well displayed. The Dunstable Downs form the highest ground in the Cretaceous escarpment north of London, reaching a height of 800 ft. above sea-level at Kensworth Hill, while Totternhoe Knoll, a conspicuous outlying mass, is 524 ft. high. The Chalk here forms two distinct escarpments, the lower one consisting of the beds of the Lower Chalk capped by the Melbourn Rock, while the upper one is crowned by the Chalk Rock. At Kensworth Hill this is again covered by some 80 ft. of Upper Chalk.

The most interesting and important sections in this district are afforded by the well-known quarries at Totternhoe. This is the type-locality for the Totternhoe Stone, which, as has been said above, is called the Burwell Rock in Cambridgeshire. The section given for the Totternhoe quarries in the Survey Memoir is as follows:

	ft.
Firm grey sandy stone in thick beds	9
Hard brownish stone in two massive beds	8
Similar stone in three courses, with many phosphatic nodules at the base	5
Soft marl said to lie below,	

* *Quart. Journ. Geol. Soc.*, vol. lxiii (1906), p. 491.

The middle beds are those usually quarried, and they are traversed by wide vertical joints, which break up the mass into blocks weighing from two to three tons. This stone has been quarried for building from very early times, and it is also a source of water supply, since many strong springs occur along the line of its outcrop and give rise to small permanent streams, an unusual feature in the scenery of Chalk districts. (The substance of the foregoing paragraph is taken from the Geological Survey Memoir: The Cretaceous Rocks of Britain, Vol. II, pp. 187-8.) The quarries at Totternhoe are of an unusual character for the Chalk, since they are very largely underground galleries and not open pits, as is usual in this formation.

Above the Totternhoe Stone comes the Grey Chalk, which is only grey in the lower part and white above. It is extensively quarried for lime.

The Melbourn Rock forms a conspicuous and continuous feature in Bedfordshire, and usually forms the capping of the lower escarpment. Near Ivinghoe it is about 9 ft. thick and consists of very hard nodular, yellowish chalk. The remaining part of the zone of *Rhynchonella cuvieri* is much the same as in Cambridgeshire, the zone fossil and *Inoceramus mytiloides* being very common, especially in the lower part. The zones of *Terebratulina lata* and *Holaster planus* here possess a total thickness of about 220 ft., and consist of rather soft white chalk, with few flints and in no way remarkable. As before observed, the Chalk Rock forms the crown

of the higher escarpment, and this completes the Middle Chalk of our present classification.

The Upper Chalk occurs in places, forming the highest points of the escarpment, and the dip slope down towards the London basin is largely composed of it. However, only a small part of its outcrop comes within the county of Bedford. The dip of the strata coincides very nearly with the slope of the ground in this district, so that the outcrop of the upper beds of the Middle Chalk is here very wide, and in particular Middle Chalk runs a long way down some of the valleys draining to the south-east, which trench the dip-slope in this district.

The Lower and Middle Chalk in West Norfolk.—It appears from the preceding descriptions that the general succession and the thicknesses of the several divisions of the Chalk are very similar in Bedfordshire and Cambridgeshire. Not very much is known of the Lower and Middle Chalk in Suffolk and the southern part of Norfolk, but when exposures to the north of the latitude of King's Lynn are considered it is at once apparent that the total thickness of these two divisions is very small as compared with Cambridgeshire. On the other hand, the Upper Chalk is very thick in Norfolk, amounting to nearly 1,100 ft. at Norwich. The Upper division, however, does not occur within our area, and the account here given will be confined to the Lower and Middle Chalk.

When followed from Cambridge towards the north-east, the thinning of the Lower Chalk appears to be quite gradual; at Stoke Ferry the thickness is about 125 ft., but at Hunstanton this is reduced to 56 ft. The thickness of the Middle Chalk in this area is very uncertain; it is about 200 ft. in Suffolk, but in the northern part of Norfolk it is probably less than 100 ft.

The most important section for our present purpose is that seen in the neighbourhood of Hunstanton, and this shows some interesting, though slight, variations from the development in Cambridgeshire and elsewhere. The unconformity of the Cambridge Greensand dies out somewhere to the south of Stoke Ferry, and everywhere north of this there is a gradual and uninterrupted upward transition from the Gault. The Chalk Marl at Hunstanton is a hard, white, chalky limestone, only 18 ft. thick; the lower division consists of a hard, whitish rock, containing peculiar branching and anastomosing structures, which were once supposed to be organic, and from these this stratum took the name of *Sponge-bed*. Professor Hughes has shown* that these so-called sponges are undoubtedly inorganic. Above this comes a grey shelly band, the *Inoceramus* bed. The base of the next higher zone consists of a somewhat diminutive representative of the Totternhoe Stone, only 2 ft. thick, consisting of

* "On the so-called *Spongia paradoxica*," *Quart. Journ. Geol. Soc.*, vol. xl (1884), p. 273.

tough, gritty, grey chalk, with a layer of green nodules at its base. Next comes the rest of the *Holaster subglobosus* zone, to a thickness of 36 ft., and, as usual, grey below and white above. It is noticeable that, although so much thinner, this shows the same grey and white divisions as in the much thicker zone in Cambridgeshire and Bedfordshire. The *Belemnitella* Marls are not here seen, and their representatives have not been separated.

Passing on to the Middle Chalk, there is to be seen at Heacham 6 or 7 ft. of hard, nodular, yellowish chalk, which is undoubtedly equivalent to the Melbourn Rock. Above this the succession is very uncertain; according to the Survey Memoir the thickness of the Middle Chalk is probably less than 100 ft. With respect to the further sub-divisions, it is very doubtfully suggested in the Memoir that the whole zone of *Rhynchonella cuvieri* is about 30 ft., including the Melbourn Rock, and this leaves a somewhat problematical 70 ft. or less for the *Terebratulina lata* and *Holaster planus* zones. The Chalk Rock has not been recognised with certainty in Norfolk, but may be represented in a railway cutting near Swaffham station.

It will be seen from the foregoing account that not only are the Lower and Middle Chalk of Norfolk thinner than the corresponding beds farther south, but on the whole they are also harder; the soft marls of the *varians*-zone are here replaced by hard chalk, and the *Belemnitella* marls are not distinguishable by special softness. This change of lithological character is probably to be explained by differences in the conditions of deposit, and by analogy with the similar variations in the Gault and Red Rock we may suppose that the beds in Norfolk were laid down in deeper water than those farther south.

In conclusion, it may be interesting to give a comparison in tabular form of the thicknesses of the different divisions of the Cretaceous system in the three areas here described, omitting the Upper Chalk, which is not seen in our district to any appreciable extent. Figs. 31 and 32 also show vertical sections drawn to true scale of the Cretaceous series in the three areas described, Fig. 31 the Lower Greensand and Gault, and Fig. 32 the Lower and Middle Chalk. In Fig. 31 it must be noted that the lines uniting the base of the Lower Greensand refer solely to thickness, and do not imply correlation. In the table on page 168 no attempt is made to separate the Lower Greensand and Gault into zones, owing to insufficiency of data. The thickness of Lower Greensand given for Cambridgeshire is the lowest known, viz., at Upware; this is selected to show the thinning of this division over the anticline.

FIG. 31.—DIAGRAM TO ILLUSTRATE THE RELATIVE THICKNESS OF THE CRETACEOUS ROCKS IN BEDFORDSHIRE, CAMBRIDGESHIRE, AND NORFOLK: LOWER GREENSAND AND GAULT.—*R. H. Rastall.*

(Scale, 100 ft. = 1 in.)

BEDFORDSHIRE.

CAMBRIDGESHIRE.

NORFOLK.

a. Lower Greensand.

b. Gault.

a1. Sandringham Sands.

a2. Snettisham Clay.

a3. Carstone.

b1. Hunstanton Red Rock.

FIG. 32.—DIAGRAM TO ILLUSTRATE THE RELATIVE THICKNESS OF THE CRETACEOUS ROCKS IN BEDFORDSHIRE, CAMBRIDGESHIRE, AND NORFOLK: LOWER AND MIDDLE CHALK.—*R. H. Rastall.*

(Scale, 100 ft. = 1 in.)

- a.* Chalk Marl.
- b.* Totternhoe Stone.
- c.* Grey Chalk.
- d.* Belemnite Marls.
- e.* Melbourn Rock.

- e., f.* Zone of *Rhynchonella cuvieri*.
- g.* Zone of *Terebratulina latr.*
- h.* Zone of *Holaster planus*.
- k.* Chalk Rock.

TABLE SHOWING COMPARATIVE THICKNESSES OF
THE CRETACEOUS ROCKS.

ZONES.		THICKNESSES.		
		Bedford- shire.	Cambridge- shire.	Norfolk.
		ft.	ft.	ft.
MIDDLE CHALK.	<i>Heteroceras reussianum</i> . . .	4	14	?
	<i>Holaster planus</i> . . .	220	50	30
	<i>Terebratulina lata</i> . . .		100	70
	<i>Rhynchonella cuvieri</i> . . .	60	80	37
LOWER CHALK.	<i>Actinocamax plenus</i> . . .	4	6	?
	<i>Holaster subglobosus</i> . . .	120	100	38
	<i>Schloenbachia varians</i> . . .	80	60	18
Gault		230	170	4
Lower Greensand				
	Carstone . . .	250	12	40
	Snettisham Clay . . .			30
	Sandringham Sands . . .			100

PLEISTOCENE AND RECENT.

The marine conditions of the Upper Cretaceous in the south and east of England were followed by a period of earth-movement and emergence of land, causing a considerable break in the succession. From physical evidence alone it is clear that the break is an important one, since the Eocene beds of the London basin rest in different localities on all the different zones of the Chalk. Palæontologically the difference is still more marked, since only one species is said to pass up from the Cretaceous to the Eocene. It happens, however, that in the district now under review the gap is still greater, since Tertiary deposits are entirely absent in Cambridgeshire and West Norfolk, so far as is at present known, while in the south of the county of Bedford they are represented by a few scanty patches of gravel, etc., which are generally correlated with the Reading Beds. Consequently we pass directly from the Upper Cretaceous to the Pleistocene. In the absence of all deposits of Tertiary age it is difficult, if not impossible, to draw any certain conclusions as to the state of affairs which prevailed in the interval, but, judging by analogy, we may assume that it was a period of uplift and denudation. At any rate it is certain that the relative distribution of land and sea underwent a considerable change, and that the face of the land then assumed something approximating to its present condition. It is certain also that during Pleistocene times considerable modifications of detail took place. How far to the north the Lower Tertiary deposits originally extended

is not known; if they ever covered Cambridgeshire all traces were at any rate removed during the great denudation of Miocene and later times, while the Pliocene deposits of Norfolk and Suffolk do not extend into our district, and probably never did so. In connection with the Tertiary age, the chief fact which is of interest here is the gradual refrigeration of climate which eventually culminated in the Arctic conditions of the Glacial Period.

The post-Tertiary deposits of East Anglia may be most conveniently divided into two groups, viz., (1) Glacial, (2) Post-glacial and Recent. This division is naturally an arbitrary one, since the glacial climate must have gradually given place to a milder type, so that no line can be drawn with any degree of certainty between the latest Glacial deposits and those which are here classified as Post-glacial. Still the distinction is a convenient one in practice.

THE GLACIAL DEPOSITS.

The general succession of the Glacial deposits of East Anglia may be summarised as follows:

Plateau Gravels.
Great Chalky Boulder Clay.
Contorted Drift.
Cromer Till.

This classification in its entirety only applies to East Norfolk and Suffolk; in our area the two lower divisions are absent, whereas the upper ones are largely developed. This is not the place to discuss the origin and manner of formation of the Boulder-clay and gravels. Their general character differs considerably from place to place, so that it is only possible in the space available to give a general description of their distribution and manner of occurrence. In its excursions to this district the Geologists' Association does not appear to have paid much attention to the Glacial deposits, as references to them in the records of excursions are few and scanty. The subject is a difficult one, and much still remains to be done in the way of detailed investigation. (See *ante*, chapter iv.)

The Great Chalky Boulder Clay.—The lower division of the Glacial deposits of Bedfordshire and Cambridgeshire forms part of the sheet of Boulder-clay, of very variable character, which covers such a great area in eastern and central England. Since this clay is, for the most part, derived from the strata immediately underlying it, or close at hand, it naturally consists of more or less ground-up fragments of these rocks, Jurassic and Cretaceous, and in this area at any rate one of its most conspicuous constituents is Chalk. Material derived from the Jurassic clays is also abundant in places, and the larger frag-

ments are for the most part derived from the same formations. By far the most abundant are flints, but angular and sub-angular fragments of sandstone, limestone, etc., are not rare. Besides these boulders of local origin there are also to be found many rock-types which must have come from distant sources; these include sedimentary, igneous and metamorphic rocks which have been derived from the north of England, Scotland and Scandinavia.

The number of rocks of distant origin which have been recognised in the drifts of Cambridgeshire is now very large, and a detailed account of them has recently been communicated to the Geological Society.* Norwegian rocks, including nordmarkite, laurvikite, and rhomb-porphry, are common over the whole area as far west as Fenny Stratford. Rocks from the Cheviots and Central Scotland are more abundant than was formerly believed, and specimens have also been identified from the Old Red Sandstone conglomerates of Forfarshire, and from Buchan Ness, Aberdeen. Lake district material probably occurs in small quantity. It is concluded by the authors that an older boulder clay, the equivalent of the Cromer Till and Contorted Drift once extended over the whole district, but was subsequently ploughed up by ice of British origin and incorporated with the Great Chalky Boulder Clay. This ice of British origin came from the north or north-west, and probably to a certain extent displaced the Scandinavian ice towards the east.

The boulders such as are described in the preceding paragraph are almost always of small size, rarely exceeding 2 ft. in their greatest measurement. But occasionally there are to be found in the Boulder-clay inclusions of much greater size, so large, in fact; that their dimensions can be stated in hundreds of yards. Such huge transported masses, which are best designated *erratics*, are a characteristic feature of the glaciation of East Anglia, and at least two very fine samples exist, or formerly existed, within our district near Ely and at Biggleswade. Others are known in Lincolnshire, Huntingdonshire and Norfolk. The existence of abnormal relations between Jurassic and Cretaceous strata at Roswell Pit, Ely, have long been known, and in the days before the immense transporting power of ice was fully recognised they were ascribed to faulting. The possibility of the erratic character of the Cretaceous strata here was first pointed out by the Rev. O. Fisher, and Professor Bonney showed conclusively that any explanation involving faulting was impossible, demanding an incredible complexity of structure. Since then it has been universally recognised that the Cretaceous strata, including Lower Greensand, Gault, Cambridge Greensand and Chalk, form a huge erratic some 300 yds. long by 100 yds. broad, which has been transported by ice and

* R. H. Rastall and J. Romanes, *Quart. Journ. Geol. Soc.*, vol. lxx (1909), p. 246.

deposited in a valley ploughed out of the Kimeridge Clay. At the present time nearly the whole of this erratic has been quarried away, and only fragments remain round the margin of the pit to attest its former extent. A full description of the erratic as it formerly existed will be found in Professor Bonney's *Cambridgeshire Geology*, Appendix II., to which reference may be made for further details.

Another interesting case of the same kind, of more recent discovery, is that described by Mr. H. Home, near Biggleswade.* In sinking a well the following beds were met with:

	ft.
Boulder clay	8½
Dark blue clay with septaria and fossils	67
Chalky Boulder clay	16½
Gault.	

The above section is slightly condensed from that given by Mr. Home. Fossils are abundant in the bed of dark-blue clay, and the fauna shows indisputably that it is a mass of Amphill or Lower Kimeridge Clay. Moreover, in its lithological character, it resembles very strongly the Lower Kimeridge of Market Rasen, and it is believed to have been transported from that district.

As would naturally be expected, the thickness of the Boulder-clay is very variable, owing to its deposition on a diversified land-surface. At times it is spread out as a thin sheet, while in other places it attains a great depth in hollows and inequalities of the underlying rocks. Especially noteworthy is the fact that some of these hollows filled with drift extend far below present sea-level, and they undoubtedly represent pre-Glacial valleys, which were excavated by sub-aerial denudation while the land stood higher relatively to the sea than it does now, and were afterwards submerged. The most striking examples of such deep channels are outside of our area, but may be very briefly referred to here. At Newport, in the upper part of the valley of the Cam, and not far from the borders of Cambridgeshire, the bottom of the drift was not reached at a depth of 340 ft., nearly 140 ft. below sea-level, while in the valley of the Stour, near Glemsford, no less than 477 ft. of drift was passed through before reaching the Chalk. Other instances of great thicknesses of drift are known in Essex and Suffolk, and a deep, drift-filled channel near Hitchin has very recently been described by Mr. W. Hill.† At Impington, north-north-west of Cambridge, drift extends 60 ft. below sea-level, while to the west, near Caxton and Old North Road station, it is as much as 180 ft. thick.

From these facts it is evident that the drift of this district must have originally comprised an enormous amount of material, though much of it has undoubtedly been removed by subsequent

* *Quart. Journ. Geol. Soc.*, vol. lix (1903), p. 375.

† *Quart. Journ. Geol. Soc.*, vol. lxiv (1908), p. 8.

denudation. As a glance at the drift map will show, the Boulder-clay is now, for the most part, confined to the higher ground, having been removed by denudation from the valleys. Its larger constituents have undoubtedly gone to a great extent to form the accumulations of Post-glacial and Recent gravels, which are so characteristic of the low-lying land adjoining the rivers.

The Plateau Gravels.—What has just been said with regard to the distribution of the Boulder-clay applies with still greater force to the so-called Plateau or High-level Gravels. These are only found on some of the higher elevations of the Chalk hills, and their distribution is very sporadic. Sometimes the gravels rest on Boulder-clay, sometimes directly on the Chalk. With regard to their manner of formation, there has been a good deal of discussion, but it is now generally conceded that they are of glacial origin, and in all probability represent the heavy residue left during washing and re-sorting of the Boulder-clay. This re-sorting action may have chiefly taken place during the melting of the ice, in the later stages of the Glacial period, and during the time of heavy rainfall which accompanied the gradual increase of temperature, but the process has no doubt been a continuous one up to the present time, owing to ordinary sub-aerial denudation.

The material of these gravels is essentially the same as the larger and harder constituents of the Boulder-clay, except that Chalk occurs in very much smaller proportion. This fact suggests that much of the Chalk may have been removed by solution. Flints are, of course, by far the commonest constituent, but there also occur in much smaller proportion fragments of other local and far-travelled rocks, exactly as in the Boulder-clay, and these are sometimes striated. The best exposures of these high-level gravels are on the east side of Barrington Hill, near Linton, and on the golf links on the summit of the Gogmagog Hills, some four miles south-east of Cambridge. Farther east they are represented by the Cannon-shot gravels of Norfolk.

At certain localities, as, for instance, at Whittlesford and Chesterford, south of Cambridge, there are to be seen great masses of gravel lying at a somewhat lower level, often in the line of old Pre-glacial valleys. Associated with these gravels there are often masses of a loamy nature, and frequently streaks of what appears to be true Boulder-clay. It seems probable that these also represent material of the Boulder-clay, which has been re-sorted and has probably undergone more or less transport, as well as washing, since there are commonly indications of stratification, showing that the material in its present form was laid down in water. These deposits cannot, however, be ascribed to the existing rivers, and probably represent a very late stage in the Glacial period. They are difficult to separate from the next succeeding division.

With regard to special Glacial phenomena, apart from sheets of Boulder-clay, there is little to be said. The rocks of the district do not lend themselves readily to the formation of glaciated surfaces, *roches moutonnées*, etc., owing to their natural softness and rapid denudation, and over the greater part of the area such structures as *eskers*, *drumlins*, etc., are conspicuously absent. There is an exception at Hunstanton, where an esker exists, and was visited by the Association in 1883 (see Fig. 28). In the rest of the district the final result of glaciation has been a smoothing of contours and filling up of irregularities, so that at first sight the former occurrence of an extensive ice-sheet is not at all obvious, and the scenery of the glaciated Chalk tracts of Bedfordshire and Cambridgeshire in particular differs little from that of the non-glaciated areas farther south. It may be pointed out here that the Royston line of flexure, before described, is attributed by Mr. H. B. Woodward to the thrust of the edge of the ice-sheet acting on soft and easily-disturbed Chalk.*

POST-GLACIAL AND RECENT DEPOSITS.

The most important deposits which have been laid down since the final disappearance of arctic or sub-arctic conditions are the river-gravels and alluvium. These mostly occupy the lower levels, and in particular the alluvial deposits cover a great stretch of low-lying country—the Fenland. Consequently these very recent formations are here of greater importance, both scientific and practical, than in perhaps any other district in the British Isles.

For our present purpose the Post-glacial accumulations may be conveniently dealt with under three headings, as follows:

- (1) The Gravels of the Ancient River System;
- (2) The Gravels of the Present River System;
- (3) The Peat and Alluvium.

It is quite clear that the first of these divisions is older than the second, as will be seen from the description which follows; but it is somewhat uncertain to what extent the second and third divisions overlap. On the whole, however, the peat and alluvium appear to be newer than even the most recent of the gravel deposits. The latter seem to indicate a period when denudation was somewhat more active than it is now and the currents of the rivers more rapid, whereas the peat and alluvium indicate a phase of sedimentation. The deposition of alluvium in the upper parts of the stream-courses indicates that the streams have reached base-level. The formation of the Fen deposits, on the other hand, is of quite peculiar type, as will appear later. It is still in progress, but in modern times the physical conditions of the Fen district have been so much altered by artificial drainage

* See ante, p. 161.

and reclamation of land that it is not possible to say what its actual condition and extent would have been if left undisturbed.

The Gravels of the Ancient River System.—These gravels occur in some of the dry valleys of the higher part of the Chalk escarpment, especially in the district between Cambridge and Newmarket; they are continued over the lower ground to the west as broad and conspicuous ridges, sometimes as much as 30 or 40 ft. high, and they can be traced for long distances. Occasionally gravel trains from two or more valleys can be seen to join, like the tributaries of a river. The most conspicuous of these systems takes its rise near Westley Waterless, and runs by Six Mile Bottom to Wilbraham. Here tributaries seem to come in on both sides, one from Dullingham and another from the neighbourhood of Balsham. The united gravel-stream forms a broad ridge extending past Quy to Barnwell, in the suburbs of Cambridge. Here it is cut through by the Cam, but re-appears near Histon, with a tributary running from the Observatory past Girton. It then extends to Oakington, Swavesey, and Bluntisham towards Chatteris and March. In the latter part of its course the ridge is very discontinuous, being represented by scattered patches capping islands in the Fens. Thus it will be seen that the general direction of this ridge is approximately at right angles to the course of the Cam—at any rate in its southern half. Towards the north it swings round and becomes more or less parallel to the river.

The constituents of these ridges vary a good deal, and include gravel, sand, and loam. The coarser portions consist chiefly of flint and chalk, but there are also many pebbles or boulders of rocks which must be of more distant origin, and have evidently been derived from glacial deposits. The deposits are generally more or less stratified, and false bedding can often be seen. The major part consists of gravel, and the sands and loams occur in wisps and inconstant beds of varying thickness. In several localities in Cambridgeshire mammalian bones have been found, together with shells of fresh-water origin and some palæolithic implements, but in the March gravels an extensive marine fauna exists, which appears to be of a somewhat Arctic type, or, at any rate, of a more northern character than the present inhabitants of the North Sea. It is a curious fact that both here and in Holderness there is found associated with northern shells *Cyrena fluminalis*, a form extinct in Britain, and only now found in much warmer climates.

The origin of these great gravel ridges is somewhat obscure; it is clear that they were formed by water action, and it is generally believed that they are due to a river-system anterior to the present one. This view presents certain difficulties, the chief of which is the great amount of denudation which must have taken place in post-Glacial times, so as to leave what were formerly the

floors of valleys projecting as ridges, elevated sometimes 40 or 50 ft. above the general surface. However this may be, it is quite clear that the fresh-water gravels of the south of the county gradually pass into marine gravels in the neighbourhood of March, so that the land must have stood lower and the sea extended much farther up the Wash depression than it does now.

The Gravels of the Present River System.—Along the courses of the modern rivers of the district, the Ouse, Cam, and their tributaries, there are to be found more or less extensive deposits of gravel. Such are largely developed along the Great Ouse in the neighbourhood of Bedford; a very interesting exposure is to be seen in some large pits at Biddenham, and this locality is of special interest, since it was one of the earliest localities in which Palæolithic implements were actually found in place. This gravel also includes a large number of boulders which must have been washed out of the drift, and several unusually fine specimens of rhomb-porphyr and other Scandinavian rocks have recently been found there.

However, it is in the neighbourhood of Cambridge that the river-gravels have been most completely investigated, and the results obtained are of the highest interest. The gravel deposits of the river Cam evidently represent a long lapse of time, and according to Penning and Jukes-Browne, they can be divided into three series, or terraces, at different heights above the present level of the river. The highest of these terraces is naturally the oldest, and it is likewise the most interesting.

The Highest Terrace; the Barnwell and Barrington Gravels.—This terrace has been traced more or less continuously up the valleys of the Cam and its tributaries for some miles above Cambridge, and it is also found in the neighbourhood of Histon. The best-known localities, however, are at Barnwell and Barrington, and from both of these localities abundant fossils have been obtained. Unfortunately at the present time exposures are rare at Barnwell owing to extensive building. Formerly good exposures were plentiful, and the deposit was seen to consist of a succession of light-coloured sands and fine gravel, with bands of loam and marl. As in so many of the gravels of this district, the upper surface frequently showed pockets or pipes of dark brown sand or loam. These are probably due to the decay of tree-trunks. From the Barnwell terrace a very extensive mammalian and molluscan fauna has been recorded, including *Bison*, *Bos primigenius*, *Cervus giganteus*, *Elephas antiquus*, *E. primigenius*, *Equus*, *Hippopotamus*, *Rhinoceros tichorhinus*, and *Ursus spelæus*, besides more than 80 species of mollusca, of which some of the most important are *Cyrena fluminalis*, *Unio littoralis*, *Cycas cornea*, *Bithynia tentaculata*, *Helix ericetorum*,

and *Helix nemoralis*. The whole fauna indicates a warmer climate than at present, and continental conditions.*

A very interesting special development of this deposit is to be seen at Barrington, and this indicates a peculiar state of affairs. In some now disused cement pits there rests on the Cretaceous rocks a remarkable accumulation of a fine-textured gravel or silt, with some larger pebbles, chiefly flint, though some foreign rocks are found. Embedded in this silt are a very large number of bones and teeth of mammals, together with a few fresh-water shells. The most important species of mammals discovered in this locality are as follows: *Ursus spelæus*, *Felis spelæa*, *Cervus giganteus*, *Bos primigenius*, *Hippopotamus major*, *Rhinoceros tichorhinus*, *Elephas antiquus* and *E. primigenius*. Remains of some of these animals occur in great profusion, and it is evident that peculiar conditions must have prevailed at the time of their deposition. Barrington is situated in a broad valley between the main escarpment of the Chalk on the south and the Haslingfield outlier on the west, and at a little distance to the north-east the Chalk hills approach one another somewhat closely so as to form a partially enclosed area. It is supposed that a lake existed in this basin, and that the carcasses of animals floated about in the waters of this lake and gradually disintegrated, so that their bones became embedded in the silt on its floor. The general assemblage of animals found in this deposit probably indicates a somewhat warm climate, though it is noteworthy that *Cyrena fluminalis* and *Unio littoralis* have not been recorded from this locality. The total number of species of mollusca from this deposit is only about 23, as compared with 80 or 90 from Barnwell, so the absence of particular forms is not conclusive as to a change of fauna.

The Intermediate Terrace: Shelford and Cambridge Series.—The gravels of this series are well developed about Shelford; they extend largely under the town of Cambridge. There are few remains of mollusca, but the following mammalia are recorded: *Equus fossilis*, *Hippopotamus major*, and *Elephas primigenius*. From this assemblage it is clear that these gravels are not much later than those of the higher terrace, which they closely resemble. According to Penning and Jukes-Browne these gravels were formed at a time when the Cam flowed in a more direct course from Shelford past Trumpington towards the present site of the Cambridge station, instead of forming the wide meander to the north through the town as it now does.

The Lowest Terrace: Gravels of the River Cam.—The gravels of the lowest terrace have been formed since the river settled down into its present course, and consequently they follow its direction very closely. They underlie the northern or older part of the town of Cambridge, and extend over Ches-

* Mrs. McKenny Hughes, *Geol. Mag.*, dec. 3, vol. v (1888), p. 193.

terton Common towards Milton. The fauna of the lowest terrace is very scanty, but *Bos longifrons* and *Elephas primigenius* have been recorded.

It is a somewhat doubtful question to what extent gravels are being formed by the rivers in their present condition. The formation of gravel seems rather to point to processes of destruction, *i.e.*, active erosion, whereas the rivers now seem to be rather engaged in deposition and formation of alluvium, at any rate in the lower parts of their courses. In the upper reaches, where the current is swifter, formation of coarser types of sediment is no doubt in operation. In recent times, however, the natural courses of rivers have been so much interfered with by locks and artificial embankments that it is difficult to form any certain conclusions on this point.

The Peat and Alluvium.—The present courses of nearly all the rivers of this district are fringed with a deposit of very recent origin, the formation of which is still in progress. This may be spoken of as alluvium; it is not of much interest, and may be dismissed in a few words. Since our rivers appear to have reached base-level, their erosion is almost confined to cutting sideways, and, therefore, for the most part working over and redepositing already existing material, hence the constituents of the older gravels will go to some extent to form part of the modern alluvium. But this deposit is mostly of a somewhat finer texture, rather in the nature of soil, and occasionally peaty, from the amount of vegetable matter contained in it.

In the northern part of Cambridgeshire, however, there is a great deal of level or nearly level land—the Fenland—the surface of which is composed almost entirely of alluvial deposits of various kinds. Now, the Fenland is not, as is very commonly supposed, a great river delta, formed by deposition of material brought down by the Ouse, Nene, Welland, Witham, etc. In its inception it was an arm of the sea, due to the submergence or drowning of a great valley hollowed out of the soft clays of the Secondary strata by sub-aerial denudation, and this gulf, or bay, has been gradually filled up by material for the most part brought in from the sea. On this part of the English coast the general set of the tides is from north to south, consequently tidal currents tend to carry into the opening of the Wash the material derived from the destruction of coasts farther north, especially from Yorkshire and parts of Lincolnshire. This material is there deposited and forms the marine silt, which is one of the most conspicuous features in the deposits of the Fenland. When this silt had accumulated to a sufficient depth, so as to raise it up to or above water-level, plants began to grow on it, and by their decay eventually gave rise to a deposit of peat.

According to Mr. Skertchley in his *Memoir on the Geology of the Fenland*, three types of deposit can be traced, (1) gravel,

(2) peat, (3) silt. As would naturally be expected, the gravels occur farthest inland, forming a continuation of the river gravels, last described; next comes the peat, while silt is now chiefly seen at the seaward margin. However, the peat of the landward region is nearly everywhere underlain by silt, and the relations of the different deposits are in reality more complex than is here indicated, since the different types may alternate vertically as well as horizontally. Moreover, at different levels in the Fen deposits there are found buried forests, which are supposed to indicate a cessation of the growth of peat and temporarily drier conditions. In one place near Ely five such forests have been discovered lying one above the other; this indicates repeated variations of climate. According to Mr. Skerchley alternations of peat and silt indicate variations in the relative level of land and sea, whereas alternations of peat and forest growth are evidence of climatic changes.

The marine silt occurs under two distinct types—one is a clay, the so-called *Buttery Clay*, while the other more sandy type is often spoken of as *Warp*. Mr. Skerchley has shown that the clay and warp pass laterally into each other, and their different characters are due to varying conditions of deposit. He proposed to include both under the general designation of *Fen Silt*.

The Buttery Clay is a stiff clay of a dark-blue colour, containing fragments of wood and sometimes lumps of Vivianite (phosphate of iron). The most common shell is *Scrobicularia piperata*; *Tellina balthica*, *Cardium edule*, and *Mytilus edulis* also occur, and Foraminifera are very plentiful.

More recent than the peat and forest growths are the deposits of shell marl, which are found on the sites of some of the meres of the Fenland, now drained; a similar accumulation is even now being formed in the ditches and water-courses of the district. It is chiefly composed of remains of Chara, with numerous shells of mollusca, of which the most important are *Bithynia tentaculata*, *Succinea putris*, *Limnæa peregra*, and *Planorbis spirorbis*. It is usually about 2 or 3 ft. thick.

This is the latest deposit which can be considered of definite geological interest. Everything newer than this may be considered as soil, and in a district which is almost wholly under cultivation the nature of the latter has been so much modified by human handiwork that it is of more importance to the agriculturist than to the geologist.

In the foregoing pages little or nothing has been said about the evidence for the existence of man in the remote past; this is a subject of great interest, and in our district the field of prehistoric archæology is a wide one. Considerations of space, however, prevent its treatment here, and the above brief description of the deposits of the Fenland must bring this chapter to a close.