OLOGICAL SURVEY OF ENGLAND AND WALES.

GUIDE

TO THE

GEOLOGY OF LONDON

AND THE NEIGHBOURHOOD.

(AN EXPLANATION OF THE GEOLOGICAL SURVEY MAP OF "LONDON AND ITS ENVIRONS," AND OF THE GEOLOGICAL MODEL OF LONDON, IN THE MUSEUM OF PRACTICAL GEOLOGY.)

BY

WILLIAM WHITAKER, B.A., F.G.S.

THIRD EDITION.

LONDON:
(PRINTED FOR HER MAJESTY'S STATIONERY OFFICE)
LONGMANS & Co., PATERNOSTER ROW, E.C.,
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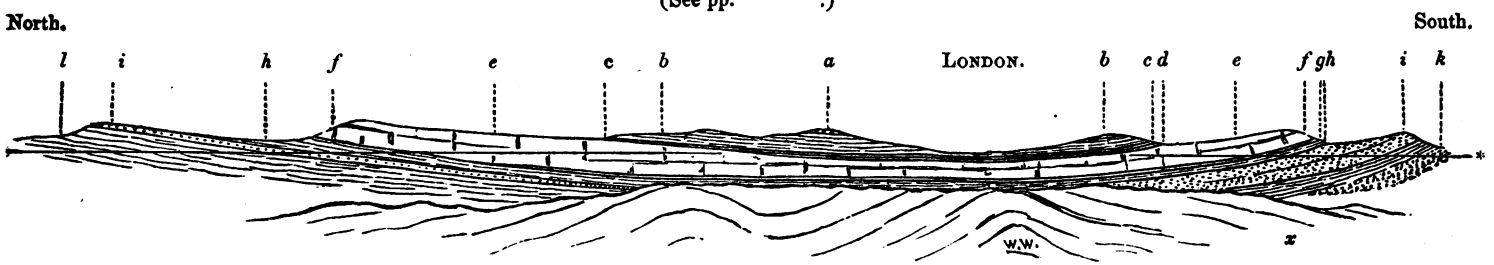
1880.

Price One Shilling.

SECTION ACROSS THE LONDON BASIN.

SHOWING THE PROBABLE RIDGE OF OLD ROCKS.

(See pp. .)



** Sea-level.

a Lower Bagshot Sand (of Hampstead).
b London Clay.
c Woolwich and Reading Beds (including the Oldhaven Beds, which occur on the south only).
d Thanet Sand (crops out on the south only).
e Chalk with flints.
f Chalk without flints.
g Upper Greensand (crops out on the south only). Made too thick in the middle part.
h Gault.
i Lower Greensand.
k Wealden Beds (on the south only).
l Oolitic clays (shown only on the north, but proved to occur on the south, beyond the range of the section, by the Sub-Wealden boring, near Battle in Sussex.
x Old Rocks.

Vertical scale much exaggerated.

"Presented on behalf of H.M. Government."

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The call for a third edition of the following brief sketch of the Geology of London and the Neighbourhood proves how acceptable it has been to those who, without going into extreme details, are anxious to acquire a general knowledge of the arrangement, characters, and thickness of the various formations that lie beneath and around the Metropolis. The geological map, and the model of London and its surroundings exhibited in the Museum of Practical Geology, explain themselves to all experienced geologists, while to those who have not been regularly trained in the science this Guide is of essential service.

Andrew C. Ramsay,
Director General.

Geological Survey Office,
28, Jermyn Street, London, 1880.

NOTICE.

It is hoped that the "Guide to the Geology of London and its Neighbourhood" will be found useful to those who may desire to do some field-work for themselves, giving as it does many of the localities in which sections of the various formations may be seen.

The mapping of this large district was the work of Messrs. Whitaker, Polwhele, Trench, Dawkins, Woodward, Penning, Bennett, Ussher, Blake, Hawkins, and myself; some of whom, however, left the Geological Survey before the completion of the work.

In the year 1863, Sir Roderick Murchison, the then Director-General of the Geological Survey, decided "that as the superficial drift-deposits attain a thickness so considerable in many parts of England that they conceal the solid geological formations, and as I have lately determined to publish in these districts, in addition to the usual geological maps, special maps showing the superficial deposits (agricultural maps, in fact), it became necessary to re-survey certain areas and insert the superficial drifts and gravels."

The map which this "Guide" illustrates is one of the earliest surveyed on the plan determined on by Sir Roderick Murchison, and it has always been a matter of regret to me that he did not live to see its completion and publication.

The construction of the large Geological Model of "London and its Neighbourhood" to which this "Guide" also refers, was due to the representations of the late Mr. Trenham Reeks, the Curator of the Museum, who saw the value such an addition would be, especially with regard to the practical applications of Geology.

H. W. Bristow,
Director for England and Wales.

Geological Survey Office,
28, Jermyn Street,
April, 1880.

LIST

OF

GEOLOGICAL SURVEY PUBLICATIONS

RELATING TO THE

NEIGHBOURHOOD OF LONDON.

Map; scale an inch to a mile.

London and its Environs (made up from other sheets, see p. 1), without the Drift Beds (1873), 22*s.*; with the Drift (1874), 30*s.*

Sections ("Horizontal"); scale 6 inches to a mile.

Sheet 74 (Part). Through Virginia Water, Windsor, Stoke Poges, and Hedgerley. 5*s.*

Sheet 75 (N. end). From E. of Cobham, through Esher to Hampton. 5*s.*

Sheet 79. From Beddington, through London (from Clapham Common to Hampstead), Hendon, Elstree, and Aldenham. 5*s.*

Sheet 120. From S.E. of Farningham, Kent, across the Valley of the Thames below Greenhithe, across Warley Common, Epping Plain, &c. 5*s.*

Memoirs.

Vol. IV. The Geology of the London Basin. Part 1. The Chalk and the Eocene Beds of the Southern and Western Tracts. Pp. xii. 619. 1872. 13*s.*

On Sheet 7. The Geology of Parts of Middlesex, Hertfordshire, Buckinghamshire, Berkshire, and Surrey. Pp. vi. 112 1864. (The Chalk and Eocene Parts are included and re-edited in the above.) 2*s.* (Out of print.)

Guide to the Geology of London and the Neighbourhood, Eds. 1 and 2. 1875.

PREFACE.

THE object of the following pages is to give a general account of the geology of London and the surrounding country, without entering into particulars of the various sections and other details, which have either been already published by the Geological Survey, or will be given in future Memoirs.

Originally planned as an illustration of the "Geological Model of London," in the Museum at Jermyn Street, which was constructed under my superintendence during the years 1872 and 1873, this sketch has been extended so as to form a general explanation of the large Map of "London and its Environs" published by the Geological Survey.

Though the accumulated knowledge of many observers is drawn upon, yet references to authors who have written on the geology of the district have been avoided, having been fully given elsewhere (Geological Survey Memoirs, vol. iv.), and it being undesirable to burden a sketch such as this with footnotes.

The aim of this essay is, in fact, to give those interested in the subject an account of all the beds that occur in and near the metropolitan area, leaving those who may wish to study them thoroughly, and the inquirers who want detailed information on particular subjects, to refer to more elaborate works. This will serve, therefore, as an introduction to the severer study of London

geology, and may be taken as a summary thereof by those who have neither time nor wish to make one for themselves.

The following are the chief points in which this edition differs from the last, the pages first numbered being those of the last edition, and those in brackets the corresponding pages of this edition, where they differ:—

Note of the large Map of London, p. 2.

Addition to List of Formations, p. 4.

Fresh paragraph added (partly from p. 18), p. 14.

Large additions and corrections to Chap. 2, pp. 15–18 (16-22).

Paragraph on the thickness and further remarks on the composition of the Chalk added, p. 19 (pp, 23, 24).

Paragraph on Water from below the Chalk added, p. 22 (pp. 26, 27).

Additional sections in the Chalk noted, p. 23 (28).

Paragraph on the Pebble-gravel added, p. 52 (57).

Alteration of description of Boulder Clay, p. 55 (60).

Paragraph on the local sense of "Post-glacial," added, p. 61 (66).

Notice of peat and canoe at Victoria Docks, p. 69 (75).

Addition of an Index of Places, at the end.

WILLIAM WHITAKER.

Geological Survey Office,
February 1880.

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CHAPTER 7.

Causes that have brought about the present Features of the District.

CHAPTER 1.

INTRODUCTION.

1. The Map of "London and its Environs."

The "London Sheet" of the Geological Survey Map, which was published at the close of 1873, the Drift being added in 1874, is of larger size than any other sheet, and represents an area of 1,111 square miles, 42¾ miles from east to west, and 26 miles from north to south, on the scale of an inch to a mile. This sheet was made by the Ordnance Survey, by a combination of seven separate plates, in order to get a map with London in the centre. These component plates are as follows:—

Sheet 1, S.W. the whole.
„ 1, S.E. the N.E. corner.
„ 1, N.W. the S. part.
„ 1, N.E. the S.W. corner.
„ 6, the W. and central part of the N. edge.
„ 7, all but the N. and W. parts.
„ 8, the E. and central part of the N. edge.

The "London Sheet" also enters into seven counties:—

1, *Berkshire* (Windsor); 2, *Buckinghamshire* (Amersham, Colnbrook, and Eton) 3, *Essex* (Barking, Brentwood, Romford, and Waltham Abbey); 4, *Hertfordshire* (Barnet, Rickmansworth, and Watford); 5, *Kent* (Bromley, Dartford, Gravesend, Greenwich, and Woolwich); 6, almost the whole of *Middlesex*, of which county, indeed, only a small northern point is beyond the limits of the Map; and 7, *Surrey* (Chertsey, Croydon, Epsom, Kingston, and Richmond).

The valley of the Thames, from Windsor on the west to Gravesend on the east, is represented on this Map,

and also the valleys of the following tributary streams, to a greater or less extent:—On the north of the Thames the *Colne* (with its affluents, the *Misbourn* and the *Chess*), the *Brent*, the *Lea*, and the *Roding;* and on the south of the Thames, a little of the *Wey*, a little of the *Mole*, the *Wandle*, the *Ravensbourne*, and the *Dart*, with its affluent the *Cray*.

A large map of London, on the scale of six inches to a mile, was coloured geologically in 1876, and hung up in the Jermyn Street Museum. It covers almost exactly the same ground as the Model, being a trifle larger southwards; and the same colours have been used in both. The list of formations and the description of the Model therefore (pp. 4, &c.) make it needless to say more of this map. In 1878 Mr. Stanford published a similar geological map, which was compiled by Mr. J. B. Jordan.

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2. Geological Formations of the District and their general relations to one another.

From the accompanying list of the Geological Formations of the district (p. 4), it will be seen that all do not occur in the model, but some on the map only; whilst some are shown only at a great depth in the sections of the model. They will be described in chronological order as far as possible, that is beginning with the oldest or lowest, although in the table they are arranged in descending order.

It will be seen that of these all but the Chalk and the beds below (which do not crop out to the surface anywhere in the district), belong to two divisions of the last or newest of the three great groups of sedimentary rocks, the Tertiary group, as it is called. The lowest of these divisions, known as the Eocene, or older Tertiary beds, is well represented in the London Basin, of which great geological tract the district now to be described is a part. The succeeding divisions, however, the Miocene and the Pliocene, are entirely unrepresented, either through not having been deposited in this area, or from having been swept away by denudation; and the next deposits are of later age, consisting of various members of the Post Pliocene, or Drift Series, which rest indiffe-

rently on the various older formations, and occur in a less orderly and constant way than these latter, although not without distinct local order.

The term "London Basin" was given to the tract in question from the more or less basin- or trough-shaped arrangement into which the beds have been thrown; but without some caution it may lead to misunderstanding, and therefore it may be as well at once to state that the basin or trough is of the shallowest description, comparatively to its large length and breadth, and that it bears no resemblance to the familiar basin or trough, the general inward dip of the beds being very small. Another far more erroneous idea is sometimes held, even now I fear, from diagrammatic sections giving the Tertiary beds the appearance of having been deposited in a basin or hollow cut out in the Chalk; this should be clearly and wholly got rid of, for the slight trough has been caused by disturbance that affects the Chalk equally with the Tertiary beds, which latter, moreover, do not lie in an eroded hollow, except perhaps locally.

In the section (*Frontispiece*) the Chalk under London is shown as thinner than at its outcrops, which seems to favour the idea of erosion. This thinning, however, is partly owing to the Upper Greensand having been drawn far too thick, at the expense of the Chalk, whereas it is really so thin that it should have been disregarded in the central part of the trough. Nevertheless this correction still leaves the underground Chalk thinner than that both north and south; but this would seem to be owing to a certain extent to the thinning of lower as much as to the erosion of higher beds. Moreover the whole of the Chalk shown was once covered by Tertiary beds, which, before the disturbing forces brought about the trough-shaped arrangement, spread far beyond the tract shown in the section; so that even should there have been erosion of the Chalk before the deposition of the Tertiary beds (as has been inferred from the fossils of the higher Chalk near London, which are said to differ from those of the highest Chalk in England), that erosion is merely local and in no way affects the question of the basin resulting from disturbance.

List of Geological Formations and Divisions.

		Divisions that have a distinct Colour on the Map and Model.	Probable greatest Thickness in the District.
Post Pliocene Tertiaries.		Alluvium (recent river-deposits).	15
	Old River Drift, Post-Glacial	Brickearth (loam)	30
		Gravel and sand	20
		*Plateau gravel (of doubtful age).	20?
	Surface-deposits on the Chalk-tract	*Brickearth (and pebbly loam).	30?
		*Clay-with-flints (of doubtful age).	—
	Glacial Drift	*Boulder Clay	40?
		*Loam	20?
		Gravel and sand	20?
	? Pre-glacial	Pebble-gravel	20?
Eocene Tertiaries.	Bagshot Beds	*Upper Bagshot Sand	20?
		*Brackelsham Beds (Middle Bagshot).	10?
		*Pebble-beds / Sand and loam — Lower Bagshot.	30? / 150?
		London Clay	450
	Lower London Tertiaries.	Oldhaven or Blackheath Beds.	50
		Woolwich and Reading Beds	90
		Thanet Sand	50
	Cretaceous	Chalk	800
		†Upper Greensand	30?
		†Gault	180 (over 300 at S. edge, near Caterham).

To these we may now add, from the evidence of deep wells, sunk since the model was made:—

Cretaceous - - - Neocomian (Lower Greensand).
Triassic? - - - New Red Marl?
Devonian.

* These do not occur in the model, but only on the map.

† These do not crop out within the area of the map, but are shown only in the sections of the model.

3. The Model of London.

General Description.

The Model of London and the neighbourhood was placed in the Geological Museum in the summer of 1873. Whilst the area it represents is of course much smaller than, and is wholly contained in, that of the London Sheet, yet, from its being on a much larger scale, its surface is far larger than that of the map. The horizontal scale is 6 inches to the mile (a scale that was taken of necessity, because it is that of the Ordnance County Maps), and as the dimensions represent a length of about 15 miles from east to west, and a breadth of about 11 miles from north to south, it follows that the area shown is about 165 square miles. The boundaries of this area may be seen from the description of the four sections along the edges of the Model (pp. 9–11).

From the great size of the model it was inconvenient to make it all in one piece, and therefore the area to be represented was divided into nine, and advantage was taken of this arrangement to make the divisions in such a way that they should run along lines that would offer good sections. The nine parts are therefore irregular-shaped four-sided masses of unequal size. Of these the four at the corners are fixed; but each of the other five can be independently moved, so as to bring up and show the sections along its inner sides.

It was at first intended to make the vertical scale the same as the horizontal, but it was soon seen that if this were done the undulations of the ground would hardly be visible in the model, the greatest difference of level in the area represented, namely that between the Thames and the top of Hampstead Heath, being little more than half an inch on that scale; consequently all the minor features would have been entirely lost, and even the chief slopes would have been indistinct, so that one of the objects of the model would have been defeated.

Should the adoption of an exaggerated vertical scale need any further apology I would remark that in nature our eyes nearly always exaggerate. We see hills foreshortened, so that, whilst nearly their whole height is impressed on our vision, the more or less gradual nature of their slope is lost; therefore, for a model such as that described to look like what we *see* in a tract without

great or sudden elevations, it should not be absolutely true to nature, but should be somewhat exaggerated in height. It was found that the lowest amount of exaggeration of the vertical scale that could be conveniently adopted was four times the horizontal. This would have given 220 feet to the inch; but as, for constructional purposes, it would be very useful to have a simple vertical scale, it was decided to take one slightly in excess of this, namely, 200 feet to the inch, and the vertical scale is therefore about 4·4 times as large as the horizontal, though to few eyes, perhaps, will there seem to be any exaggeration, for the model is seen as if from a great elevation.

The geological lines drawn on the maps that form the upper surface of the model must not be taken as a specimen of Geological Survey work on a 6-inch scale, for with but very trifling exceptions they were not surveyed on these finished 6-inch maps. The greater part, indeed, were originally drawn on the old 1-inch map, and have been merely enlarged for the purposes of the model, and slightly corrected from personal knowledge; whilst a smaller part were surveyed on a skeleton 6-inch map. A small piece at the western edge (Acton) was reduced from a 25-inch map made by Major-General A. L. Fox, who kindly gave me a tracing of his work. It will be seen, therefore, that the geological lines pretend to no more than being the best that could be drawn with the information and the data possessed, without waiting for a fresh survey on the newer and far more detailed maps, which it is to be hoped may be made some day.

Construction.

For the following description of the process of making the model I am indebted to Mr. T. B. Jordan, by whom it was carried out, all the constructional arrangements having been intrusted to him.

"The size, scales, and divisions of the model having been decided on, the work of framing and modelling the surface was proceeded with in the following manner. A firm foundation-table was made with great care, to avoid any alteration of form or size by shrinkage or warping of the timber; nine deep frames of the proper

form (one for each division of the model) were then made with equal care, and fitted together on the foundation; each frame-top was then covered with cotton cloth, and on this was mounted a set of the 6-inch Ordnance Maps of the district."

"These maps were the foundation, or datum-plane on which, and by the aid of the information they gave, the undulating surface of the model had to be raised. As there was no regular system of contour-lines on the maps then available, though they had heights thickly studded over them, the system adopted was to drive measured pins into the points where heights were marked, the pins, of which some thousands were used, being cut so that they should exactly agree in height (on the scale of 200 feet to an inch) above the datum-plane with the figures at the points through which they were driven. After driving in these pins over a space which represented about a square mile of surface, that space was covered with soft wax to above the pins, and then the wax was nicely worked off so as just to show the bright end of each wire. By patiently carrying on this process over the whole area the surface of the model was brought out in accordance with the datum-heights; but for many reasons this wax surface could not be used for a permanent model, and therefore it was needful to obtain a fac-simile in a more manageable and permanent material."

"The next process was to raise a wall round each division, and then to cover each with plaster to form moulds, which, after due preparation, were placed in frames of the proper depth, and served as the matrices for taking plaster casts, these last being fac-similes of the wax surface and forming the divisions of the permanent model."

"All the divisions, after being carefully dried, were fitted together, thoroughly examined over the whole surface, and mounted on bottom frames (requisite for fixing the machinery for raising the moveable divisions). In doing this many errors of surface were corrected, and the plaster was strengthened by sizeing and a covering of muslin. The model was then ready to receive the machinery for raising the five moveable blocks. This consists of strong iron screws fixed to each of these blocks (which are somewhat in the shape

of inverted boxes) in the vertical lines through their centres of gravity, and passing through long brass nuts that turn in iron frames bolted up to the fixed frame of the model. These nuts are geared with long horizontal shafts in the bed of the model by bevelled brass wheels: so that when any of the five shafts are turned (by means of a handle), the division to which it belongs rises or falls, and by this means the sections on its sides may be brought into view."

"The finishing process, and a very difficult one, was the mounting of a set of maps on the undulating top surface of the model (the sides being covered with drawing paper afterwards). The difficulty of this part of the work was much enhanced by having to mount the maps on a surface of exaggerated undulation, a task needing much care and patience."

I should mention that this last operation, with some corrections of surface that were found to be wanted during its progress, was carried out by Mr. H. F. Brion, so well known for his series of "Relief Maps," whose great experience in this sort of work was gladly made use of. The care required may perhaps be more readily understood from the fact that the maps had to be so thoroughly saturated as to be little better than pulp before they were fixed on the surface of the model.

The model was now, of course, merely a topographical one, and it only remained to make it geological also. This last addition, however, took much time, from the amount of surface to be dealt with and from the frequent shifting of the heavy but somewhat fragile blocks that was needful.

All the geological lines on the model were drawn by myself, and both in the case of the maps and sections these had to be drawn after the paper had been fixed to the parts of the model. In the duplicate sections, on opposing faces, a transfer was made, from my original section on one of the faces, by my colleague, Mr. J. B. Jordan, of the Mining Record Office, who also did the colouring, a task of some difficulty in the case of the map, both from its being on an uneven surface, and, what was worse, consisting of different sorts of paper (that of the Ordnance Map and that of Stanford's Map) which took the colours very unequally.

Description of the Sections.

Of the eight lines of section in the model, four, of course, are along its edges, and run either due N. and S. or due E. and W.; but the other four do not run in quite the same directions, the divisions of the model having been laid out to carry these lines through particular points.

Of the first four, the *Western Section*, starting from the north, runs from the London Clay west of the Brent Reservoir, across the gravel of the Brent west of Willesden, again over London Clay to the higher terrace of gravel at Acton, and then, crossing a narrow outcrop of London Clay on the slight southern slope, over the brickearth flat to Turnham Green and the still lower gravel to the south, with the narrow fringe of alluvium on the left side of the Thames. Crossing the river to Mortlake it continues over the gravel to East Sheen, and then over the rising ground of London Clay in Richmond Park (with its cappings of gravel on the higher parts) to Combe Wood.

Along this section the gravel is everywhere underlain by London Clay, no lower bed coming to the surface, or even near to it, and the beds are even, with a slight southerly dip. There seems to be no Thanet Sand, except at the southern end, and the Blackheath Beds are absent throughout.

The *Southern Section*, beginning from the high gravel of Combe Wood on the west, runs across the London Clay of the valley of the Beverley Brook and of the southern slope of Wimbledon Hill to the gravel of Merton, then, crossing the Wandle, with its narrow alluvium, and the equally narrow outcrop of London Clay on its right bank, it passes over the gravel of Tooting and the low gravel-capped hillock on the east, again returning to the gravel S.W. of Streatham Common, and then crosses the London Clay hill of Upper Norwood, with its small thin gravel-cap, to the outcrop of the Blackheath Beds, east of Penge, and over that series to the Ravensbourne. Crossing the alluvium and gravel of that stream and the narrow outcrop of the Woolwich Beds on its right side, it runs across the Blackheath Beds north of Bromley and the successive outcrops of

the Woolwich Beds, the Thanet Sand, and the Chalk on either side of the valley of Sundridge and Camden Parks, to the Blackheath Beds at Prick End, Chiselhurst.

Along the western half of this course the London Clay is the lowest bed that occurs at the surface, or under the patches of gravel; but, eastwards, from an uprise of the beds, the various lower formations have been brought up so as to have been laid bare by denudation, the effect of which just extends through to the Chalk at one spot. The Thanet Sand thickens eastwards. The Blackheath Beds are absent on the west, but come in at the east and thicken until they are in force.

The beds are slightly waved, and with a general dip westwards.

The *Eastern Section*, from the Blackheath Beds near Chiselhurst, runs through the lower ground of London Clay on the north; then up the slope east of Eltham, with its successive outcrops of Blackheath and of Woolwich Beds, the former of these coming on again, with a change of dip, higher up northwards, and then the London Clay, in its course across which the line of the section rises to Shooter's Hill, and then, after passing along the northern slope, crosses the outcrops of the Blackheath Beds at the western end of Plumstead Common, and of the Woolwich Beds and Thanet Sand at Woolwich, to the alluvial flat of the Arsenal. Crossing the Thames and the broad spread of alluvium on its left side to Barking, it runs through the gravel-tract and the brickearth at Ilford to the gravel and narrow outcrop of London Clay on the north.

Along the southern half of this course the beds are slightly waved, and from this cause and the varying level of the surface all from the London Clay to the Thanet Sand occur at the surface, and the Chalk seems to underlie the gravel at Woolwich Arsenal. At (or near) the Thames the beds are thrown down on the north by a fault which has been proved to run along the valley for some miles, and by means of which the beds that form the plateau of Plumstead Common, &c., are brought below the marshes of the river. Beyond the fault the beds are nearly flat, and from Barking northwards the gravel is underlaid by London Clay. The Blackheath Beds seem to thin out on the north.

The *Northern Section* starts, on the east, from the gravel and London Clay of Valentines (near Ilford), cuts across the valley of the Roding (which consists on both sides of gravel at the top, London Clay on the slope, and alluvium at the bottom) to the gravel and London Clay of Wanstead and Leytonstone; then down the gentle gravel-slope of Leyton, across the Lea and its marsh, and up the short clay slope on the right bank of the river to the gravel of Stamford Hill, whence it crosses the London Clay tract to the west, rising up to Highgate with its cap of Bagshot Sand, and, after passing the London Clay between, to the northern part of the same sand at Hampstead, and thence across the London Clay to beyond the Brent reservoir.

In this section the beds are nearly flat, with a very slight rise at the west, and the London Clay is the lowest outcropping formation. The Blackheath Beds are absent and the Thanet Sand seems to thin out at the west.

Of the second four sections, all of which pass through the inner parts of the model, and can only be seen by raising its moveable divisions, the *West Central Section* starts on the north from the Bagshot Sand of Highgate and runs southward over the London Clay of Kentish Town and the eastern side of Regent's Park, across the gravel to Oxford Street and Grosvenor Square, between which places it cuts the North Central Section and changes its direction a few degrees to the east, then running, still over gravel, to the narrow London Clay outcrop of Buckingham Palace Gardens (and of the Green Park), across the lower gravel-flat by Eaton Square to the Thames at Victoria Bridge. Crossing the river it passes through the flat of brickearth at the eastern side of Battersea Park, the low gravel beyond, and the narrow strip of alluvium that runs eastwards to Vauxhall, up the narrow outcrop of London Clay on the south and over the gravel of Clapham Common (at the southern end of which it cuts the South Central Section), the London Clay of Balham, and the gravel of Streatham Park, to the clay and gravel on the south.

Along this section the London Clay is the lowest bed that comes to the surface, or that occurs next below the gravel. In the northern half the beds are waved, the Chalk rising up considerably at Regent's Park; but in

the southern half they are almost flat. The Blackheath Beds are absent and the Thanet Sand thickens southwards.

The *East Central Section* begins on the north at the gravel of Stamford Hill, and, passing across the narrow outcrop of London Clay in the hollow to the south, runs through the brickearth of Stoke Newington and the gravel-flat beyond, along a line east of and roughly parallel to the Kingsland Road, to the Great Eastern railway, near Bishopsgate Station, where it cuts the North Central Section and changes its southerly for a S.S.E. course, still across gravel, by Spitalfields, to the "made ground" and alluvium of the London Docks. Crossing the Thames to Rotherhithe it passes through the broad alluvial flat and its southern border of gravel to the outcrop of Woolwich Beds and the thin spurs of London Clay near New Cross, across the patch of gravel on the south, through Loam Pit Hill, with its outlier of London Clay, across the gravel of the Ravensbourne at Lewisham, the rise of London Clay eastward of Southend, and the outcrop of the Blackheath Beds north of Bromley.

At the northern end the beds are level, but for the rest of the course slightly waved, the slight general dip being to the north, so that lower beds are brought up southwards. The fault crossed between New Cross and Lewisham is a continuation of that noticed in the Eastern Section, but with a much smaller downthrow (on the north). North of the Thames the London Clay is the lowest outcropping formation, but south of the river lower beds mostly occur, either at the surface or under the gravel, and in the central part of the section an uprise brings the Chalk near to the surface, so that it next underlies the gravel midway between Rotherhithe and New Cross. North of Lewisham the Blackheath Beds are absent, but at the southern end of the section they crop up in force.

The *North Central Section* runs in a straight line north of east from the north of Turnham Green over the broad spread of brickearth by Shepherds' Bush to the foot of Notting Hill, up the London Clay slope (at the north of Holland Park) to the gravel at top, and then along a line just south of the Uxbridge Road, Oxford

Street, and Holborn (as far as Gray's Inn Road), wholly across gravel, except for the small outcrop of London Clay in the hollow at the head of the Serpentine and some small patches of loam, at one of which it cuts the West Central Section (north of Grosvenor Square). Then crossing the flat valley with its London Clay bottom, it again runs across gravel, by the Aldersgate Street and Bishopsgate Railway-Stations (cutting the East Central Section just beyond the latter) and nearly along the line of the Great Eastern Railway to Bromley-by-Bow, when it crosses the marsh of the Lea and the gravel-flat beyond, from West Ham, by the north of Plaistow and East Ham, to the alluvium of the Roding and the gravel on the left bank of that stream at the northern end of Barking.

At the western end the beds are flat, but over the rest of the course slightly waved, especially at the central part. The London Clay is the lowest formation at the surface, but at Stratford, from a slight local rise, the Woolwich Beds are next beneath the gravel. The Thanet Sand seems to thin out at the western end, but it must soon come in eastward, in which direction it thickens. The Blackheath Beds are absent except at the eastern end, unless the upper part of what has been coloured as Woolwich Beds at Stratford should turn out to belong to that division.

The *South Central Section* also runs in a straight line and nearly parallel with the last, but slightly diverging from it eastwards, from its course having a little less northing. Starting at the London Clay just south-west of White Lodge, Richmond Park, it cuts the small gravel-patch there, and passes across the clay valley of the Beverley Brook, the high gravel of Putney Heath, down the London Clay slope beyond to the Wandle. Crossing the alluvium of that river, the border of gravel on its right side, the narrow outcrop of London Clay on the slope, and the higher gravel of Wandsworth Common, it passes over the London Clay (in the little hollow to the east) to the corresponding gravel at the southern end of Clapham Common, where it cuts the North Central Section, and then runs across the London Clay of Clapham Park, and, touching the southern end of the bay of gravel east of Herne Hill, over part of that hill to the

outcrop of the Woolwich Beds on the east (with a spur of London Clay in the middle), across the London Clay of Peckham Rye and the rising ground on the east to the outcrop of the Woolwich Beds on either side of Lewisham (with the London Clay outlier of Loam Pit Hill, where it cuts the East Central Section), and across the gravel of the Ravensbourne and its affluent the Quaggy Brook to the Blackheath Beds at Lee, and then up the London Clay slope of Shooter's Hill. It was intended to have taken this Section a trifle further North, so as to pass through the highest part of this hill, with its capping of pebble-gravel; but the original course was slightly changed in the construction of the model.

The beds are flat at the western end, they rise to the centre, and then are nearly flat to the east. The London Clay is the lowest formation that crops out on the west; but lower beds are brought up to the surface at the central part, the Woolwich Beds being the lowest thus seen. The Thanet Sand is very thin on the west, but thickens eastward, and the Blackheath Beds are present only at the eastern part of the course.

The total length of these eight sections is about 52½ feet, representing 105 miles, and they are all carried down far below the level of the "Ordnance Datum" (sometimes to more than 1,000 feet). They have been drawn to the probable position of the base of the Gault, as well as that geological horizon could be estimated, beyond which it would have been vain, at the time the model was made, to do more than speculate on the downward succession of the beds.

The Gault had then been touched in only two borings within the area of the model, in one (Kentish Town) having been pierced through, with a thickness of over 130 feet, whilst in another (Crossness) it was still unbottomed, with a thickness of 148 feet. I thought that these two borings justified me in drawing all the sections on the London Model to the base of the Gault, and left small room for doubt that this formation is continuous underneath the London Basin, a conclusion justified by the borings since made.

Deep wells that occur on or close to the lines of section, and of which any sufficient record exists, are drawn

thereon; but besides these, many others, though more removed from the sections, were available in calculating the thickness of the beds. Wells of later date than the model could not be added without great trouble (in moving parts of the model), so that the beds now proved to occur beneath the Gault (see p. 17) have not been coloured.

It should be remembered that from the exaggerated vertical scale of the model (see pp. 5, 6) all the dips are also exaggerated.

CHAPTER 2.

CRETACEOUS AND OLDER BEDS.

1.—Range of Old Rocks underground.

Although the Chalk may be called the basement-rock of the London Basin, yet in the midst of that tract some wells have been sunk to so great a depth as to pass through it into the beds below. In each case the Upper Greensand and the Gault succeeded in due order; but beneath the latter there is great variety in the beds found, as will be seen from the following account of the wells in question:—

Kentish Town.—The lowest 188 feet of the well-known boring at the S.W. foot of Highgate Hill passed through a set of clays, sands, sandstones, and conglomerates, of various kinds and colours, that have much puzzled geologists. Some look on them as an exceptional condition of the Lower Greensand, differing from that formation at its outcrop, beyond the London Basin, in having a more conglomeratic or shore-like character, as would naturally be the case if a ridge of older rocks had been present there in the seas of the period. Some again, from their general red and mottled colour, would refer them to the New Red Sandstone Series or to the Old Red Sandstone. The evidence of fossils has been but slight, consequent on the small quantity of earth brought up in boring, and also from its more or less crushed state; but fragments of *Ammonites* and of *Belemnites* were found, which favour the reference of the beds to the Cretaceous Series.

Harwich.—Soon after the Kentish Town boring was made a trial-bore at Harwich, after passing through a small thickness of Gault, reached, at the depth of 1,025 feet, a dark grey shaly rock. In the cores brought up from this rock both bedding and joints are well shown, and from the occurrence of *Posidonia* it has been determined to be of Lower Carboniferous age.

Loughton.—The Great Eastern Railway Company successfully made a boring for water at their station here, which, after passing through a good thickness of Gault, reached a water-bearing bed at the depth of nearly 1,100 feet. Presumably the bed in question is Lower Greensand, although we have no direct evidence.

Crossness.—At the Southern Outfall Works of the Metropolitan Board of Works a trial-bore was originally carried some depth into the Gault, and then abandoned. Afterwards another trial was made and carried through the Gault, until, at a depth of 1,008 feet, a set of red marls and sandstones was found. These have been classed as Old Red Sandstone; but I am disposed rather to think them of New Red age, some of the purplish clay being exactly like New Red Marl.

Meux's Brewery.—At about the same time as the last boring was made Messrs. Meux's finished the deepening of their well, at the junction of Oxford Street and Tottenham Court Road. The work was done by diamond-boring, and a very fine and perfect set of cores was brought up, specimens of which may be seen in the Museum at Jermyn Street. Below the Gault there occurred more than 60 feet of beds which, from their fossils, have been determined as Lower Greensand; though lithologically for the most part very different from that formation at its outcrop, being to a great extent composed of a limestone of oolitic structure. Beneath these beds there was found, at a depth of 1,066 feet, a hard purple shale, the frequent bedding-planes of which showed a dip of about 30°, whilst the contained fossils clearly proved it to be Devonian.

Cheshunt (or *Wormley*).—The New River Company have lately finished a deep well at Turnford (the N. part of Cheshunt) in which purple Devonian shale was found, directly beneath the Gault, at the depth of 980 feet. I have seen the last core brought up from this boring: it was a column 15 feet long originally, but since broken along the bedding-planes, and 15 inches in diameter, with fossils in certain layers, and is a fine specimen of the work of the diamond-drill.

Ware.—At about the same time the New River Company had another well made by diamond-boring, which reached the old rocks at a less depth than at any of the above wells; for at Ware, below the Gault (with perhaps a trace of Lower Greensand) the tool passed, at a depth

of 796 feet, into shales with thin patches of limestone, the fossils from which proved that these beds are of Upper Silurian (Wenlock) age. These rocks have a dip of about 30°, which has been found to be in a southerly direction, whilst in the other wells the direction is unknown.

It may interest the reader to compare the sections of these wells, and therefore an abstract of the beds passed through is given in a tabular form on p. 19. In this table I have also inserted accounts of six other deep-well sections, all but one of which are in the Chalk-tract beyond the Tertiary beds and go through to the Gault at least.

One of these, near the chalk-escarpment above Caterham, in Surrey, a little beyond our limits, has been sunk through more than 340 feet of Gault, the greatest thickness of that formation yet found in England.

Another, at Holkham Hall, near Wells (Norfolk), has been carried some depth into the Neocomian (Lower Greensand) which crops out about 12 miles to the west, where however it next underlies the "Red Chalk," the Gault being absent.

The only one that has not been carried into the Gault is in London, at Mann and Crossmann's Brewery, Mile End, and is remarkable as getting a supply of water from the Upper Greensand.

Whilst treating of wells I may remark that accounts of 572 in the London Basin are to be found in the following *Geological Survey Memoirs*:—

Vol. IV., pp. 422–563=488 well-sections.
On Sheet 47, pp. 74–84, 89=61 „
„ 48, S.W., pp. 13–18=15 „
„ 48, S.E., pp. 21–25=8 „

Abstract Account of Deep Borings (through the Chalk) in the London Basin, showing the Thickness in Feet of the Beds passed through.

Geological Formations found.	Meux's Brewery, Tottenham Court Road.	Kentish Town.	Mann & Co.'s Brewery, Mile End.	Cheshunt (Turnford).	Ware.	Caterham.	Loughton.	Cross Ness, near Erith (2 borings).	Chatham Dockyard.	Harwich.	Coombs, near Stourmarket.	Norwich.*	Holkham, near Wells (Norfolk).
Alluvium, Drift, &c. -	22?	—	20½	35?(?—)	14	—	—	about 33 & 39	17½	25	57	12	20
London Clay - -	64	236	84½	30	—	—	167	—	—	23	—	—	—
Lower London Tertiaries -	72½	88½	96	50	—	89	76	about 111 & 98	3½	28½	—	—	—
Chalk - - -	655½	645	654	670?(?+)	544	369?	651?	646 } 696?	689	888	817?	1,042	635
Upper Greensand -	28	13½	20	31?	77?(a)	53?	30?	12 }	—	nearly 22	10	6	(Red Chalk) 8
Gault - - -	160	130½	—	164?	160	343?	172	175	193⅓	over 39	11	36	10
Lower Greensand -	64	—	—	—	1½	20	? touched	—	touched	—	—	—	70
Red Marl and Sand (?"New Red.")	—	—	—	—	—	—	—	52	—	—	—	—	—
Doubtful beds - -	—	188½		—	—	—	—	—	—	—	—	—	—
Dark slaty rock (Carboniferous).	—	—		—	—	—	—	—	—	44½	—	—	—
Purple Shale (Devonian)	80	-	—	30	—	—	—	—	—	—	—	—	—
Wenlock Shale (Silurian)	—	—	—	—	35	—	—	—	—	—	—	—	—
Total depth -	1,146?	1,302	875	1,010	831½	874	1,096?	1,060	903½	1,070	895	1,096?	743

(a) Probably in great part Chalk Marl.

* Other accounts of this well vary. One makes the Chalk 1,152 feet, and the total, 1,206. Another makes the Chalk 1,135, and the total, 1,198. Another makes the Chalk 1,030, the Upper Greensand 16, and the total, 1094.

One of the most striking pieces of theoretical geology, or of philosophical inference from observed facts, is Mr. Godwin-Austen's argument that the two exposures of the older rocks in the Ardennes (Belgium) and in our own Mendip Hills (Somerset) are parts of one great axis, or line of elevation, and that they are most likely connected underground by a hidden range of those older rocks, nearly along the valley of the Thames and the Wealden elevation; an important conclusion, that was to a great extent at once verified by the sinking of the Harwich well, and also by the doubtful nature of the bottom beds in the Kentish Town well.

Absolute proof of the occurrence of an underground ridge of the older rocks under London was given in 1877, by the deepening of the well at Meux's brewery, and the consequent discovery of Devonian shales, as well as by the second Crossness boring with its red rocks, and in 1879, by the borings at Cheshunt and Ware.

It has been said that although, from the cores brought up from some of the deep borings, we can estimate the angle of dip of the rocks, yet for calculations as to the probable extent of any of these rocks, and as to where other rocks may be expected either to come on above or to rise up from beneath them, it is needful to be able also to approximate to the *direction* of dip. I am led to think, however, that this is really of less importance than at first sight seems to be the case; for judging by what we generally see of the older rocks in districts where they are at the surface, they are much subject to disturbances and are thrown into great rolls or folds, so that whilst at one spot dipping north near by they may turn over and dip south. We find, too, in the coal-fields of Belgium and of the North of France frequent evidence of sharp folding, and indeed of inversion of these older rocks underneath the even and almost undisturbed Cretaceous and Tertiary beds. I think therefore that were we able to find the direction of the dip of the rocks in any of our deep wells it would be unsafe to argue from that alone as to the probable succession of the beds in any direction for a considerable distance.

We are not however, I think, without some grounds for speculation concerning the lie of the older rocks under London and the neighbourhood, for, taking the information already yielded by the various borings,

what do we find? Starting from Meux's, where Upper Devonian beds occur, and going northwards, we must pass over the Kentish Town section, as the age of its bottom beds is uncertain; we then come to Cheshunt, still in Devonian, but at a slightly higher level, and then to Ware, when we find lower rocks, belonging to the Upper Silurian.

Again at Crossness we have beds which seem to me to be Triassic, though very high authorities have classed these also as Old Red (the equivalent of Devonian), and then, far beyond our district, the boring of the Subwealden Exploration, near Battle, proved a great thickness of Jurassic clays beneath the Purbeck Beds.

I may here remark that there is a strong reason against the classification of the bottom beds at Kentish Town and Crossness with the Old Red Sandstone, which seems to have escaped notice. Having the series unmistakeably present in the Devonian type at Cheshunt and at Meux's, it would be strange indeed were it to occur in its wholly distinct Old Red type at Kentish Town, between those two places, and at Crossness, not very many miles from the latter of them! I believe that no such thing is known to occur anywhere; the two types of what is generally taken to be one great geological system being limited to separate districts, and not occurring together.

The general tendency of the known facts is therefore to show that, whilst northwards from London older rocks rise up, for many miles at least, south-eastwards, on the other hand, newer rocks come on above. The inference from this is of course that it is in the latter direction we should, in the first place, expect to find Carboniferous rocks of some sort, if not actual Coal Measures. That disturbances of the beds may bring in such rocks elsewhere is of course likely; but we have no evidence of the whereabouts of the lines of disturbance that doubtlessly occur.

Although the further argument that true Coal Measures may occur along the lines indicated has not yet passed out of the domain of inference, and though, should such beds occur, we cannot be certain that they would contain workable coal, yet geologists are fully justified in pointing to the whole chain of reasoning as one that shows how pure science may have a direct

bearing on questions of the highest importance from a most utilitarian point of view.

The section given as a frontispiece may serve to illustrate the presumed occurrence of older rocks under the London Basin, as well as to show the general lie of the beds therein. It is but fair to state, however, that this woodcut was made when the Kentish Town boring was the only one in our district that had passed through the Chalk.

2. Gault.

The formations below the Gault have been already noticed in describing the deep wells that pass through them, and therefore the stratigraphical account of the beds of our district may begin with this formation.

The Gault is a bluish clay, often with interrupted layers of small phosphatic nodules, and nearly always with a marked layer of these at the base.

In the four wells that pass through it in our district, the Gault varies in thickness from 130 to 175 feet (and these figures are not altered by including the wells at Cheshunt, only just outside our boundary, and at Ware); but just to the south, at Caterham, near by its outcrop, it reaches the exceptional thickness of over 340 feet.

The Gault is a marine deposit, and from its evenness of character leads one to infer a corresponding evenness of deposition; in other words, this clay seems to have been deposited in a moderately deep, quiet sea, not along a shore-line; so that the tract with which we are now concerned must have been wholly under water at the time of its deposit, and most likely at some distance from land.

3. Upper Greensand.

This formation has been found in the same deep borings as the Gault. Where thin it consists of a few feet of clayey green sand, probably its upper member, as seen at the outcrop; the lower member (a sandstone, sometimes more or less calcareous) having thinned out, as also happens on both the northern and southern outcrops in going eastwards. In those wells where a greater thickness of this formation has been found, however, the pale green-grey sandstone so characteristic along the outcrop on the south of London chiefly occurs. It generally passes

upwards into the Chalk Marl, the green grains getting less and less in number, and the calcareous matter getting more and more in quantity, so that often there is no sharp line of division between it and the Chalk.

In the sections of the model the Upper Greensand has been drawn of nearly uniform thickness (between 10 and 20 feet) as it was thought unlikely that it would vary much within so comparatively small an area. The borings since made, however, extend the thickness to nearly 30 feet.

The Upper Greensand is of marine origin, but has less of the characters of a deep sea deposit than the underlying Gault, and indeed has been taken by some geologists to be the fringing shore-deposit of the Chalk Ocean. It is sometimes sharply divided from the Gault, which fact points to a break in the continuity of deposition.

4. Chalk.

Composition and Origin.

Chalk is perhaps the best known rock in England. It is essentially a soft white limestone, but contains beds of a harder and more crystalline nature, and consists almost wholly of carbonate of lime, though, in the lower beds especially, with small quantities of silica and alumina and traces of other matters. It is broadly divided, in the south of England, into an upper member, Chalk with flints, and a lower member, Chalk without flints, the bottom and more clayey part of the latter being known as Chalk Marl. In our district the Chalk with flints alone occurs at the surface, the lower beds being known only from well-sections, and then but rarely, for besides the six deep borings already noticed (at Kentish Town, Crossness, Meux's Brewery, Mann's Brewery, Loughton, and Cheshunt), I know of but three others in the neighbourhood of London that reach to the Lower Chalk, at Plumstead, Woolwich, and Grays Thurrock.

It is notable that in the six wells above mentioned, which alone pass through the Chalk from top to bottom in our district, the variation in thickness of that formation is no more than from 645 to 670 feet, or, if we omit the one at Cheshunt, which is really just outside our district, only from 645 to 655. At its outcrop both

north and south however the Chalk seems to be thicker than under London.

By its fossils the Chalk is proved to be the deposit of a deep sea, a deposit of much the same character as that now forming in mid-Atlantic, and which, like the Chalk, is largely composed of the remains of microscopic animals (*Foraminifera*, &c.). It has indeed been taught that Chalk is often almost wholly composed of the remains of *Foraminifera;* but it has been lately shown that this rock is very largely made up of small fragments of shells (notably *Inoceramus*) as well as of Echinoderms, and that although sometimes *Foraminifera* are abundant, yet, on the whole, the calcareous remains of the larger animals mentioned make up the greater part of the Chalk, which cannot therefore be truly said to be identical with *Globigerina* ooze.

Amongst the chief fossils of the Chalk around London are many species of *Echinoidea*, or sea-urchins, chiefly belonging to the genera *Ananchytes*, *Cidaris*, *Galerites* and *Micraster*, and besides these, two genera of bivalve shells, *Inoceramus* and *Spondylus*, are common, and also two genera of Brachiopods, *Rhynchonella* and *Terebratula*. Univalve shells, whether Cephalopods or Gasteropods, are very rare; but besides the above, the higher ranks of the animal kingdom are often represented by the teeth of fish, and the lower ranks by *Serpulæ* and Corals.

Professor Hébert has divided the Chalk of France into "zones," from the prevalence of certain species of fossils in definite horizons, and these palæontological divisions have been shown to hold good in England. The careful collection and determination of fossils from special localities is a work much to be desired, and which cannot fail to reward observers.

Flints.

The flints of the Upper Chalk have ever formed a subject of speculation to geological inquirers. At one time thought to be of purely mineral origin, at another to have been deposited solely around organic matter, they are now generally accounted for by a mean between those two opinions; for whereas there is no doubt that the silica of which the flint is formed has very commonly been deposited around the remains of animal or vegetable organisms, whose substance, moreover, has often been

replaced by flint, yet there are other cases, notably the more or less vertical or highly inclined layers that run along joints in the Chalk, in which a purely mineral origin is clear, the flint being simply deposited from solution along those lines. Flint is thought indeed to be formed by the slow replacement of amorphous carbonate of lime by silica, held in solution in water, and this view harmonises with many facts, with regard not only to the Chalk but to other calcareous formations that contain siliceous masses.

The flint in the Chalk occurs in two forms; either as irregular-shaded isolated nodules, mostly in definite lines, but sometimes sparsely scattered, and often with an organic centre; or as continuous layers, mostly thin, but sometimes half-a-foot thick. As a rule the outer coat of flint is white and the inside of a dark colour; but the white coating, though differing so much in look from the rest, is really of the same composition, the difference being caused simply by a molecular change in the condition of the silica, the particles of which would seem to have been rearranged through long continued, though partial, exposure to some external agencies. In the tabular layers of flint, however, there are sometimes alternations of black and white layers with some of the latter internal, in which case exposure would not account for the difference.

A peculiar occurrence may be seen sometimes in flint, but only, as far as I know, in a bed that is often found at the very top of the Chalk; it is the breaking up (or faulting on a small scale) of the flint, and the subsequent rejoining of the slightly shifted pieces of fresh infiltration of silica. This, together with the occurrence of flint along joint-lines, lines which could not have been produced until after the Chalk had become solid, tends to show that the formation of flint is not a process that was effected at one particular time, but that it was gradual, and spread over a long period; not confined indeed to the age of the Chalk, but continued in the Lower Tertiary age, and perhaps to the present time.

Water.

The Chalk is the chief source of water-supply for the deep wells in the London district. Not very many years ago the overlying Thanet Sand was the great water-

bearing bed, but its limited outcrop and small thickness soon caused it to be unable to bear the greatly increasing drain on it, and most London wells were then deepened, new wells being almost universally carried into the Chalk. Water flows through the joints and fissures in the Chalk, besides being largely absorbed in the body of the rock, and it seems to be got in wells chiefly in the fissures, which allow more or less communication. There is, however, a great deal of uncertainty in this source of supply, water sometimes being found in plenty, but at others hardly at all.

From the general troughed form into which the Chalk has been thrown, in the formation of the very slight hollow of the "London Basin," it follows that its outcrop is in the main at a much higher level than its underground extension beneath the Tertiary beds, and therefore, when wells are sunk through these latter to the Chalk, the water tends to rise, although rarely to such a height as to form a true Artesian, or overflowing, well. Such wells, however, do occur in some of the low grounds of the valleys of the Thames and the Lee, but there seems to have been a gradual lowering of the water-level in the Chalk under London, in consequence of the increase in the number of wells and of the water drawn from them.

The great fault of the water from Chalk and other limestones is "hardness," that is, the containing a quantity of bicarbonate of lime, dissolved out of the rock through the carbonic acid contained in water. In some waterworks, as at Caterham and Canterbury, the hardness is got rid of by what is known as "Dr. Clark's process;" this is the at first sight paradoxical addition of more lime (in the form of lime water), the result of which is that the carbonic acid in solution in the water (as bicarbonate of lime) combines with it, forming normal carbonate of lime, which, being insoluble, falls to the bottom, together with that already in the water (resulting from the abstraction of carbonic acid from the bicarbonate), and thus nearly the whole of the lime is got rid of. The process is extremely neat, and the arrangements for carrying it out are well worthy of inspection by all interested in water-supply from the Chalk.

Attempts have been made to get water from below the Chalk in the neighbourhood of London, some geo-

logists and engineers being much impressed with the idea that in order to get a large supply nothing is to be done but to tap the Lower Greensand. These attempts have been mostly failures, the Lower Greensand having generally been conspicuous by its absence. Should that formation, however, be present, I doubt whether it can be relied on for the large supply usually put to its credit, for it is not only thinner than the Chalk, but has also a much smaller outcrop, and therefore a much less catchment area.

Features and Scenery.

In our district the Chalk has none of those bold features that commonly characterize it, for we do not anywhere reach to the escarpment, that marked range of hill with which this formation ends off both on the north and on the south; moreover, on the area included in the map of "London and its Environs," the Chalk is to a very great extent covered with deposits of clay, loam, and gravel, of comparatively late age, which capping the higher parts, give the whole a more or less wooded character, distinct from the bare open downs of uncovered chalk.

In Surrey, however, near Epsom and Croydon, are some delightful spreads of "downs," with the usual soft turf that grows on the dry but never parched Chalk, and here and there with evergreen clusters of the shrubs that love the same soil. Riddlesdown (near the Caterham Junction Railway Station) is a good example of these; but the plough is slowly invading hitherto undisturbed tracts of grassland, and changing the aspect of the surface, not for the better as far as scenery is concerned.

In the north-western corner of our district, in Bucks. and Herts., there is absolutely no downland, and the greater part of the tract consists of ploughed land diversified by woods and parks. The same, too, is the case in Kent, at the south-eastern corner. Although the most striking characters of Chalk scenery are absent, yet there are many good points; for we have the usual undulating country, with its constant succession of hill and valley; and the main valleys with their streams give many a rich and pleasant view.

At Windsor, where the Chalk comes to the surface through an elevation of the beds (by means of which it has been brought up within reach of denuding agents) it has been cut through by the Thames, which has left a good example of a sharply-sloping river-cliff, in the hill on which the Castle stands. This cliff, though of no great height in itself (about 100 feet), forms a marked object in the landscape, because its abruptly denuded face is in sharp contrast with the river-flat and gravel-plain on the north.

Sections.

On the north-west there are few remarkable sections of the Chalk, the finest being a large pit close to the Colne just above Harefield, north of Uxbridge, where some huge pipes of gravel are to be seen in the Chalk. Just below Harefield is another pit. At Watford the Chalk is shown beneath Glacial brickearth, in a pit close to the Bushey Railway Station, and irregularly overlain by Glacial gravel in the railway-cutting northward of the town.

On the south-east, there are many large pits eastward of London where the flinty Chalk may be well seen,—near Lewisham, Charlton, Dartford, Greenhithe, and Gravesend, in Kent, and at Purfleet, West Thurrock, Grays, and Stifford, in Essex, most of which places have yielded fossils, as also have the pits in the inlier at Camden Park, between Bromley and Chiselhurst.

On the south there are pits at Sutton, in Surrey. At a pit near Purley Farm, south of Croydon, a waterworn boulder of granitic rock was found in the Chalk, with some smaller pieces of other igneous rocks; small pebbles, too, have been found in the Chalk near Gravesend. There is also a large pit at Caterham Junction Railway Station.

Those sections where the Chalk may be seen capped by Eocene Tertiary beds are noted in the lists at pp. 34, 38. For a fuller account of the Chalk south of London, the reader is referred to Vol. IV. of the *Geological Survey Memoirs*, pp. 21–26.

CHAPTER 3.

EOCENE TERTIARY FORMATIONS.

LOWER LONDON TERTIARIES.

1. General Description.

It has sometimes been inferred, on palæontological grounds, that the Chalk next under the Tertiary beds near London is not the highest part of the formation, but might be classed as "Middle Chalk" rather than as "Upper," meaning, I presume, by the former term, what is generally taken as the lower part of the Chalk with flints. The very even way in which the Tertiary beds come on above the Chalk in all good sections seems, however, somewhat against this view, as it is hard to suppose that a considerable thickness of Chalk should have been so evenly denuded away over a large area before the deposition of the lowest Tertiary beds. Nevertheless, there is so great a change at the junction of the two, both in mineral character and in forms of life, that we are led to conclude that great time must have passed between the deposition and consolidation of the Chalk and the beginning of our Tertiary epoch. The change from a deep sea, with its regular deposit of limestone, to a shallow sea and estuary, with alternating deposits of sands, clays, and shingle, could hardly have taken place except during a very long period; yet I am not sure but that there has been a tendency to exaggerate its length.

As will be pointed out further on, there is evidence that the very topmost part of the Chalk has been dissolved away by underground water, after the deposition of the beds above; so that it is possible that in the course of this process some slight irregularities in the junction may have been effaced, although others (pipes) have been formed.

The term "Lower London Tertiaries" is applied to the comparatively thin but varying set of beds between the London Clay and the Chalk. At one time massed under the name of "Plastic Clay Series," they were thought to be a perfectly irregular mixture of sands, clays, and pebble-beds, often marked by the occurrence of richly coloured mottled plastic clay. But this name is now discarded, as like plastic clay occurs in other Tertiary formations, and as it is in the present case confined to the middle part of the series. The researches of Prof. Prestwich, moreover, have shown that these beds are not the irregular mixture that was once supposed; but that they have a certain order amongst themselves, although that order is not everywhere apparent, from the fact that the series is not generally complete at one spot.

The comparison of a large number of sections has resulted in the threefold division of the group, the middle member being the most changeful in structure, but by far the most constant in occurrence, and indeed very rarely wanting, whilst the upper and lower members, but especially the upper, are more local, though of much more uniform character. To each of these divisions a local name has been given; to the lowest that of "Thanet Beds," from its being the only old Tertiary formation in that district; to the middle that of "Woolwich and Reading Beds," from its occurrence in two very different conditions in the neighbourhood of those places; and to the upper that of "Oldhaven Beds," from the good section of it at Oldhaven Gap, near the Reculvers. For the purpose, however, of a description of the neighbourhood of London, Blackheath would better give a "local habitation and a name," and indeed the compound term "Oldhaven and Blackheath Beds" may be used with advantage, as the composition is very different in the east and in the west.

Before going on to the description of each of these divisions of the Lower London Tertiaries, I may remark that whilst an observer unskilled in geology could hardly fail to know Chalk in whatever part of England he might see it, with these beds it is very different. In the least varying division, the Thanet Beds, a good observer, who had not worked at this particular subject, would fail to recognise the greater part of the sandy marls and sands of East Kent as holding the same

position as the unfossiliferous sands of West Kent, Surrey, &c., except from seeing them next above the Chalk in all cases; neither could he tell that the fine sharp sand of the Oldhaven Beds in East Kent was the same thing, geologically speaking, as the pebble-bed of Blackheath, &c., except from seeing both next underlying the London Clay. With regard, however, to the Woolwich and Reading Beds, no geologist could for a moment venture, were he suddenly transported from the west of London to the north-western corner of Kent, and then to the eastern part of the same county, to assert that the unfossiliferous variously coloured mottled clays and sands of the first tract, the thinly bedded clays and sands of the second, with estuarine shells, and the sand with marine fossils of the last, were all parts of one and the same series, dovetailing into and replacing one another, though for the most part occurring separately; yet a careful tracing of the beds along their western and southern outcrop, from end to end of the London Basin, has proved that such is the case. Along the northern outcrop the Reading type alone occurs.

Thin though they may be, therefore, these Lower London Tertiaries have an interest to the geologist greater, perhaps, than that of the thicker masses of the overlying and underlying formations, though these have afforded long suites of fossils; for whilst the latter speak to us of long-continued even deposit, and almost wholly of marine conditions, the former give evidence of shifting and changing, of shores and currents, of river-deltas, and of neighbouring land.

Although the junction of the Lower London Tertiaries with the Chalk is seen to be even in those sections that show a good thickness of the former, yet where these beds are thin they often come on much more irregularly, filling "pipes" or deep hollows in the Chalk. This uneven junction must not, however, be taken as evidence of unconformity, for it is not owing to the wearing away of the Chalk before the deposition of the beds above, but to its having been dissolved away by the chemical action of infiltrating water, holding carbonic acid in solution, long after the deposition of those overlying beds, which have consequently been let down into the irregular cavities thus formed.

2. Thanet Beds.

Structure and Range.

In the neighbourhood of London the structure of this lowest member of the Tertiary series is very simple, for it consists almost wholly of fine soft sand, very pale grey or buff, slightly clayey, and very compact, so that it stands upright in section; it is without pebbles, false-bedding, or other signs of current-action or shore, and it is essentially unfossiliferous; but from the character of the fossils further eastward, and from the very few indistinct traces that have been found in our district, it is inferred to be a marine deposit. The lowest part, for a thickness of a few feet, is more clayey, and so full of green grains as to form a regular green sand or glauconite-sand, and at the very bottom there is a layer of flints, for the most part unworn and in the same state as in their parent rock (the Chalk), except for their dark green coating.

From the unworn character of these flints it is inferred that they have not been derived from the Chalk by mechanical erosion before the deposition of the Thanet Beds, but rather by the chemical dissolving away of the Chalk (by carbonated water) from beneath the Thanet Beds, a process that would leave the insoluble flints behind. Whilst, therefore, the infiltration of water through merely a few feet of these beds gives rise to an uneven surface and to pipes, the same process, when it goes on at greater depths, seems to act in a more equal (because in a more constant) way on the surface of the Chalk, leaving it even.

The Thanet Sand thins out westward and northward of London, as is shown by the outcrop in Surrey, where it can be traced only as far as Ashstead (just beyond the edge of the London Map) and by well-sections.

From Epsom the outcrop runs, at a comparatively low level, by the line of villages to Croydon, the sand thickening from about 15 feet at the former place to more than twice as much near the latter. It then runs along the flank of the hills by Addington, Keston, and Farnborough, and then along the left side of the valley of the Cray to Bexley, whence a large irregular-shaped

spur stretches southwards for some miles. From Crayford the outcrop again runs along the flank of the hills, first northwards to Erith, and then westward, along the valley of the Thames, to Deptford, the sand being throughout this course about 40 to 50 feet thick.

The Thanet Sand is hidden under the alluvium, &c., of the Thames, but on the other side of the river, in Essex, it crops out again north of Purfleet, and runs eastward by Stifford to beyond Little Thurrock.

Besides these outcrops there are small "inliers" in the valleys at Bromley, Chiselhurst, and Eltham, in Kent, where the beds have been brought up by slight local disturbance, so that subsequent denudation has laid bare lower formations than would otherwise have been seen at the surface.

Scattered over the south-eastern Chalk-tract there are many "outliers," or disconnected masses of Thanet Sand, that have been separated by denudation from the main mass, and which, left as landmarks of the former extent of the bed, serve also as signs of the denudation that it must have undergone, as all must once have been connected together with each other and with the main mass. The largest of these are at Well Hill, the hill E. of the Crays, the hills between Swanley and Farningham, and the hills S.W. of Swanscomb, in Kent, and north of Grays, in Essex; the rest range downwards in size to no more than large "pipes" in the Chalk, though some are well-marked small hills.

Sections.

Over the tract just noticed there is as a rule no dearth of sections, the Thanet Sand being indeed noted for its pretty deeply-cut lanes; besides these, however, there are many clearer and larger sections, both in railway-cuttings and in chalk-pits, some of the largest of the latter having been opened in parts where the Chalk is capped by Thanet Sand. I have thought it best to name some of the best or most accessible of these in a tabular form.

Places where the Thanet Sand may be well seen.	Showing the Junction with the Chalk.	Showing the Junction with the Woolwich and Reading Beds.
Surrey.		
Epsom.—Cutting on the South-Eastern Railway, N.E. of station	—	×
Beddington.—Road-cuttings	—	
Croydon.—Pit in Combe Lane, and railway-cutting on the west	×	
Kent.		
Chiselhurst.—Chalk-pits in Camden Park, &c.	×	
St. Mary's Cray.—Cuttings on the London, Chatham, & Dover Railway	—	×
Swanley Station.—Cutting on the London, Chatham, & Dover Railway	—	×
Crayford.—Chalk-pit at the great brickyard	×	
Erith.—Chalk-pit at the great brickyard	×	
Erith.—Sand-pit by the railway-station	×	×
Abbey Wood.—Road-cutting (to station)	—	×
Plumstead.—Chalk-pit in the Wickham Valley	×	
Plumstead.—Road-cutting, Bostal Heath, and sand-pit S.E. of Plumstead Common	—	×
Woolwich.—Large pits, S. of dockyard, and E. of Charlton Station	×	×
Lewisham.—Brickyard at Loam Pit Hill	×	×
Dartford.—Chalk-pit at E. of town	×	
Darent.—Road-cutting, E. of village	×	
Gravesend.—Brickyard, W. of Mt. Pleasant	×	
Essex.		
Purfleet.—Chalk-pit	×	
Gray's Thurrock.—Chalk-pits	×	

Details of these sections and notes of others will be found in Vol. IV. of the *Geological Survey Memoirs*, pp. 60–75.

3. Woolwich and Reading Beds.

Range.

The middle division of the Lower London Tertiaries has a wider range than either of the others, being, indeed, constant in its occurrence between the Chalk and the London Clay, except in the very few spots when for a short distance the overlying Oldhaven Beds have scooped through it, whereas the other divisions are far more local, cropping out only (in our district) on the south and east of London.

From Epsom, on the south, the outcrop follows that of the Thanet Beds to the valley of the Cray, which, however, it does not cross, and then along the valley of the Thames to Dulwich and the southern part of London (Camberwell, Bermondsey, and Rotherhithe), where it is hidden by the gravel and alluvium of the Thames, from beneath which it again shows on the Essex side of the river, following the Thanet Sand from Wennington eastwards by Aveley to beyond Stifford.

The thickness along the above outcrop is variable, amounting sometimes to 50 feet, but generally much less, and the outcrop is mostly of a more irregular character than that of the underlying Thanet Sand, in some places very narrow, in others comparatively broad, and often cut back by small valleys.

At Bromley and Chiselhurst these beds are brought up, with the Thanet Sand, as inliers, and they also occur as outliers, partly on the main mass of the Thanet Sand, and partly on its outliers. The most conspicuous of these are of the latter class at Well Hill, Jerden's Wood, (east of the Cray), and Swanscomb Park Wood.

West and north-west of London the Reading Beds are brought up to the surface at Windsor, by the disturbance through which the Chalk appears there, and thence they seem to run northwards (by the margin of the London Map) through a gravel-covered tract to Hedgerley, whence the outcrop has a very irregular course to the Colne. They then roughly follow the course of that river from the north of Uxbridge along the flank of the hills north-eastward, but are sometimes cut back southward along small side-valleys. On this northern outcrop, where the Reading Beds rest at once

on the Chalk, they are rarely 40 feet thick, but a greater thickness is found in many of the wells sunk through the London Clay south-eastward, which show the continuity of the series underground. There is also an inlier at Pinner, brought about by a line of disturbance that seems to extend for some miles, and there are outliers over the Chalk-tract, the most notable being north of Hedgerley, near Chalfont St. Giles and St. Peter, and west of Rickmansworth, which prove the former continuation of the beds northward.

*Structure and Fossils.**

Though so constant in their presence the Woolwich and Reading Beds are most inconstant in composition, at one place consisting almost wholly of sand, at another of clay, and elsewhere of alternations of the two, with occasional pebble-beds, the colours of the component parts being also very variable. The only constant part is a bed of more or less clayey green sand at the bottom, which, when resting on the Thanet Sand, contains flint-pebbles, but when on the Chalk contains green-coated flints also (at the base), probably owing to the same sort of action that may have produced the like bed at the base of the Thanet Sand.

We have here two types of the series, those that have respectively given the names "Woolwich" and "Reading" to it. Of these the former, which occurs only in the south-eastern part of our district, is marked by the presence of laminated clay, full of shells along the frequent lines of bedding, those shells being of estuarine character and chiefly belonging to the genera *Cerithium*, *Melania*, *Melanopsis*, and *Paludina*, amongst Gasteropods (Univalves), and to *Cyrena*, *Ostrea*, and *Unio*, amongst Conchifera (Bivalves). In some places, indeed, there are layers made up of oyster-shells, and in others of crushed shells (chiefly *Cyrenæ*), whilst sometimes there are sandy as well as clayey shell-beds.

In the neighbourhood of London these shell-beds are not found westward of Croydon, but from there they occur throughout the range that has been described, eastward, and northward, being often accompanied by a

* Readers wishing for figures of the commoner fossils of the district are referred to Lowry's excellent "Chart of Tertiary Fossils."

thin layer of black carbonaceous clay, sometimes an impure lignite. They must have been deposited at or near the mouths of streams, which are inferred to have flowed from land to the south, perhaps from the tract now known as the Weald, which at that long distant time, of course, was far less denuded than at present.

The shell-beds are associated with beds of sand, and they do not occur to the exclusion of the other type of the series, but are sometimes found to dovetail into or alternate with the plastic clays. Near Lewisham the top part of the Woolwich Beds consists of a mass of finely laminated sand and clay, in which impressions of leaves have been found.

In Surrey, west of Croydon, and along the north-western outcrop in Buckinghamshire and Hertfordshire, the other or Reading type occurs exclusively. It is unfossiliferous, and characterised by the presence of soapy mottled plastic clay, of various and often rich colours, some shade of red generally showing; but sand is mostly present also, and sometimes with pebbles. At the northern margin of the district, between Aldenham and Shenley, there is a regular pebble-bed, hardened into stone of just the same kind as the blocks of the well-known "Hertfordshire pudding stone," which are found so commonly over the Chalk-tract beyond, and were indeed most likely derived from this bed.

In many wells in and near London both the shelly and the plastic clays are found together, and the same thing occurs in places along the southern outcrop from Croydon eastward, proving that both are parts of the same series.

Sections.

In the accompanying table the most accessible of the sections are noticed, with the general nature of the beds in each. There are many more, in brickyards, railway-cuttings, and road-cuttings, but either of less importance or more difficult to see, and sometimes much overgrown.

The pits at Woolwich, Charlton, and Lewisham are amongst the best known sections in the kingdom, and very large.

For details the reader is referred to Vol. IV. of the *Geological Survey Memoirs*, pp. 107–141, 146–150, 212–224, 232, 233.

Place of Section of the Woolwich and Reading Beds.	Nature of the Beds.	Showing Junction with Beds below.		Showing Junction with Beds above.	
		With Chalk.	With Thanet Sand.	With Old-haven Beds.	With London Clay.
Surrey.					
Ewell.—Nonesuch Kiln	Clay and sand	—	×		
Dulwich.—Brockwell Hall Brickyard	Laminated sand	—	—	?	?
Kent.					
Erith.—Sand-pit by the railway-station	Clay, shelly clay, and sand	—	×		
Plumstead Common.—Sand-pit near S.E.corner	Green sand with pebbles	—	×	×	
Woolwich.—Pit S. of dockyard	Clay, shelly clay, and sand	—	×	×	
Woolwich.—Pit N. of Charlton	Clay, shelly clay, and sand	—	×	×	
Lewisham.—Brickyards at Loam Pit Hill	Laminated sand and clay, shelly clay, sand and pebbles	—	×	—	×
New Cross.—Counter Hill brickyard	Sand and shelly clay	—	—	—	×
Bucks.					
Chalfont St. Giles.—Frog Hall Kiln	Mottled clay and sand	—	—	—	×
Chalfont St. Giles.—Pit in Pollard's Wood	Clay and sand	×			
Herts.					
Chorley Wood Kiln, W. of Rickmansworth	Mottled clay, sand, and pebbles	×			
Rickmansworth.—Woodcock Hill Kiln	Clay and sand	—	—	—	×
Bushey.—Kiln	Clay, sand, and pebbles	—	—	—	×
Bushey.—Watford Heath Kiln	Clay, sand, and pebbles	—	—	—	×
Middlesex.					
Ruislip Wood.—Pits on N. of	Sand and pebbles	×			
Pinner.—Pit near Pinner Green	Clay and sand.				

4. Oldhaven or Blackheath Beds.

Structure, Range, and Fossils.

Near London this uppermost member of the Lower London Tertiaries consists mostly of a pebble-bed of perfectly-rolled flint-pebbles, in a base of fine, sharp, light-coloured sand; but sometimes there is also like sand without pebbles, or with but few. The pebble-bed is often false-bedded, and sometimes hardened into a conglomerate, and there are occasionally thin layers of clay in the sand. The thickness varies up to about 50 feet, but it is liable to rather sudden changes.

At some places there are no fossils, whilst at others either pebble-bed or sand is full of shells, the prevailing univalves being *Calyptræa*, *Cerithium*, *Fusus*, *Melania*, *Natica*, and *Neritina*, and the bivalves *Cardium*, *Cyrena*, *Ostrea*, and *Pectunculus;* there are also sharks' teeth. From these names it will be seen that marine and estuarine conditions both occur, some of the shells being the same as those of the Woolwich Beds beneath, whilst others are like those of the London Clay above, and therefore we should conclude that the deposit is one formed in a changeful area of sea invaded by fresher water, and the reverse, whether by changes of level or of currents.

The state of the flint-pebbles is also remarkable, for in all of them the process of rounding is complete, and we do not find the intermediate stages between the broken angular flint and the perfect pebble that we see in our present shingle-beaches. From this we may infer that the pebbles must have been deposited at some distance from their parent rock, and not as beaches along a shore.

Though the Blackheath Beds sometimes rest evenly on the Woolwich Beds, yet they often cut into the latter in such a way as to show erosion, which in a few cases has, indeed, gone so far as to obliterate the Woolwich Beds altogether for a short distance, as on parts of the flank of the Addington Hills, at Sanderstead, and at a spot near Chiselhurst Railway Station, where the Blackheath Beds rest at once on the Thanet Sand. Further south, indeed (near Caterham), a little beyond the tract

represented on the "London Map," there are outliers of the pebble-bed resting at once on the Chalk, the whole of the beds between having been denuded away, and apparently much of the Chalk also, leading one to infer that the pebbles have been derived from the flints of this southern Chalk, and that the denudation of the Chalk from off the Wealden District may have begun in early Tertiary times.

It is remarkable that the pebbles are almost without exception of flint from the Chalk, even a solitary quartz-pebble being of very rare occurrence; so that the deposit bears witness to the great wearing away of the upper part of the Chalk that must have taken place in these early Tertiary ages. The same, too, may be remarked of the thinner and less important occasional pebble-beds in the underlying Woolwich and Reading Beds, the destruction of which, indeed, may have helped to a slight extent in the formation of these larger masses. The lowest division (the Thanet Sand), however, very rarely contains a pebble, and therefore we conclude that the great degradation of the Chalk took place after it had been deposited.

The southerly boundary of the Blackheath Beds, the least constant of the three divisions of the Lower London Tertiaries, runs from Croydon eastward, following irregularly the boundary of the Woolwich Beds to Farnborough; its easterly boundary runs irregularly near the top of the hills forming the left side of the valley of the Cray to Bexley, and thence to Belvidere; on the north it is bounded by hills forming the right bank of the Thames Valley, thence westward to Blackheath, and on the west its outcrop from beneath the London Clay has an irregular course from the west of Eltham, by the north of Bromley and Beckenham, to Croydon.

Over the tract thus bounded the Blackheath Beds are not however always at the surface, for there are large spurs of London Clay, as at Shooter's Hill, and outliers of the same, as in the neighbourhood of Bromley, besides occasional outcrops of lower beds; yet there are many broad tracts of the pebble-beds, as near Addington, at Hayes Common and Bromley, from Bexley Heath to Abbey Wood, and at Blackheath.

Sections.

Over the broader outcrops just described there are many pits and road-side sections, besides which railway-cuttings, which in most cases have been recorded but cannot now be clearly seen, have yielded much information about this series. In the table only the more accessible and the most interesting open sections are named, but of these the majority do not show a junction either with the overlying or underlying beds.

Place of Section of the Blackheath Beds.	Nature of the Beds.
Surrey.	
Croydon.—Brickyard at Selhurst (junction with London Clay)	Sand.
Croydon.—Shirley sand-pits	Sand, with layers of clay and pebbles.
Kent.	
Beckenham.—Pit north of railway-station	Pebble-bed and fossiliferous conglomerate.
Bromley.—Cutting at railway-station	Pebble-bed and sand.
Bromley.—Widmore Kiln (junction with London Clay)	Sand and laminated loam with remains of leaves.
Bromley.—Widmore, gravel-pits	Pebble-bed.
Bromley.—Sundridge Park Rock-pit	Shelly pebble-bed and sand, hardened into stone.
Eltham.—Pit at S.E. corner of the Park	Sand and pebble-bed.
Northumberland Heath, S.W. of Erith.—Pits	Sand and pebble-bed.
Bostall Heath E. of Plumstead.—Pit	Pebble-bed.
Plumstead Common.—Pit at S.E. corner (junction with Woolwich Beds)	Pebble-bed.
Plumstead Common.—Old pit on the west	Pebble-bed and conglomerate.
Woolwich.—Pits S. of dockyard and N. of Charlton (junction with Woolwich Beds)	Shelly pebble-bed.
Blackheath.—Pits	Pebble-bed.

For details of these sections and notes of others, see Vol. IV. of the *Geological Survey Memoirs*, pp. 241–261.

5. Features and Scenery.

From the varying nature and composition of the Lower London Tertiaries, the effect they have on the surface is of course variable also.

In Surrey, from Epsom to Croydon, they make but a very slight feature, occurring as they do between the great dip-slope of the Chalk on the south and the low hills of London Clay on the north. Eastward, however, the series is more perfect, and as a rule thicker, and its escarpment or "bounding ridge" is a marked feature in the landscape from Croydon to Farnborough, rising well above the Chalk in the immediate neighbourhood, varying in height according to its extent southwards (or up the dip-slope of the Chalk), and mostly covered with masses of fir. After ascending the sharp rise of the escarpment, we find a much gentler slope in the other direction (northwards with the dip of the beds), which very often consists of open commons or heaths, plentifully decked with gorse and heath, and sometimes with broom, plants that grow freely on the Blackheath pebble-bed, as on the Addington Hills and at Hayes Common.

From Farnborough, north-eastward, the Lower London Tertiaries form the more or less wooded hills of the left side of the valley of the Cray, and near Bexley of the right side also; the outcrop of the more clayey Woolwich Beds giving rise to moist ground and to springs, thrown out from the permeable pebble-beds and sand above, which of course form a dry tract, as also does the Thanet Sand below.

Along the valley of the Thames the sharply-sloping wooded ridge from Erith to Greenwich is the more marked an object in the landscape from the contrast afforded by the broad alluvial flat at its base, whilst the level tracts of the pebble-beds along the top of the hills, nearly 200 feet above the marshes, are brought out by the mass of London Clay that rises on either side to form Shooter's Hill.

These tracts, from their generally good natural drainage, from the quiet beauty of their scenery, and from

the richness of some of the soils, are well populated, and are now being largely annexed by Londoners for residence, for which they are so well fitted, especially the highly permeable pebble-beds. No place gives so good an example, perhaps, of the varied scenery of the Lower London Tertiaries of Kent as the beautiful village of Chiselhurst, with its commons, parks, woods, and hop-gardens, to my mind the loveliest spot near London.

On the left side of the Thames, in Essex, this series makes but little show, owing partly to the occurrence of gravel, hiding the beds below and effacing their features, and partly to slight disturbance, through which the northerly dip is somewhat increased in places; for it is the rule with the soft Tertiary beds that the prominence of their surface-features varies inversely as the amount of their dip, so that where they are flat, or nearly so, there they make the most marked hills. Two of the best instances of this may be noticed, though both out of our district: one is near Farnham, where the lowest Tertiary beds make little outward sign, and dip at a high angle; whilst further north, where the dip lessens, the Bagshot Beds form a sharp ridge: the other is in the Isle of Wight, where all the beds, from the Chalk to the Bagshot Beds inclusive, are vertical, or nearly so, and make no feature, whilst as the dip lessens northwards a slight rise occurs, and at last the flat beds of Headon Hill are well marked.

On the north-west, where the Reading Beds alone are present, there is but a narrow outcrop, often moist and springy, along the flank of the hills, the base of the slope consisting of Chalk and the upper part of London Clay, to which last the main feature of the escarpment is due.

Some of the outliers of the Lower London Tertiaries are wooded hills rising well above the surrounding Chalk, and conspicuous at long distances, as at Well Hill (near Chelsfield) and Farningham Wood, the former consisting of the lower two divisions and the latter of all the three. The much smaller mass of Croham Hurst, south of Croydon (called Combe Hill on the map), which consists of the upper and lower divisions, is another case, and so is the little fir-capped mound of Thanet Sand above

Purfleet, and the larger mass above Grays, which, from the great clearness of their position, can be well made out miles off. The large Swanscomb outlier owes its prominence, to a great extent, to the cappings of London Clay (as also do the sharper of the outliers on the north-west), but even without these it would be a marked object.

It is remarkable that both the sharpest slopes of the hills and the flattest tops are found in one division, the Oldhaven Beds, the pebble-beds of which follow the rule of gravel-deposits, and form flat tracts, whilst on the denuded faces their "angle of rest" is comparatively high.

CHAPTER 4.

EOCENE TERTIARY FORMATIONS (*continued*).

1. London Clay.

Structure and Fossils.

After the deposition of the Oldhaven Beds from shallow water, a gradual depression must have succeeded, and continued for a long time, for the next formation bears evidence of comparatively deep-sea conditions, and of tranquil deposit. It consists almost wholly of stiff clay, but with more or less sandy parts, especially at top and bottom, and it has yielded a great number of fossils, of kinds that must have existed in a fairly deep and warm ocean. At the bottom there is nearly always a bed of loam and pebbles that shows a sort of passage into the beds beneath, both in its structure and, to some extent, in its fossils also; to this the name of "basement-bed" has been given.

It is remarkable that the incoming of the various divisions of the Lower Tertiary series of formations is generally marked by certain special appearances: loamy beds, with green grains and with flint-pebbles, or, where the bed lies directly on the Chalk, with green-coated flints; and the basement-bed of the London Clay follows this rule.

In the neighbourhood of London the clay that bears its name is 400 or more feet thick (from the bottom of the Bagshot Sand to the top of the Lower London Tertiaries), but it is of course only where the Bagshot Sand occurs that the whole thickness is found.

Although so many fossils have been found in this clay, yet observers may in many cases search in vain in pits, &c. Most fossils have been got from large openings, whether in brickyards or railway-works, where the workmen have saved specimens and taken them to collectors, or which geologists have constantly visited. The shells of the London Clay belong chiefly to the genera *Nautilus*, *Pleurotoma*, *Fusus*, *Voluta*, *Cassidaria*, *Turritella*,

Cyprœa, *Dentalium*, *Murex*, *Natica*, and *Pyrula* (univalves), and *Arca*, *Avicula*, *Cardium*, *Corbula*, *Cytherea*, *Modiola*, *Nucula*, and *Pinna* (bivalves). Many species of *Crustacea* and *Echinodermata* also occur, as well as *Corals* and microscopic *Entomostraca* and *Foraminifera*. The most remarkable fossils of the London Clay, however, the Birds, Reptiles, Fishes, and Plants, are hardly represented in our immediate district, but occur chiefly to the east, in Sheppey, where on the other hand there are fewer shells, the plant remains outnumbering all others. The turtles of those long-past days would seem to have avoided the neighbourhood of London, perhaps from an instinctive prophetic vision of the slaughter of their descendants that would take place there in the distant future.

From the frequency of certain fossils at certain horizons the London Clay has been divided by some observers into zones, but I doubt whether these divisions have more than a local value, in face of the difference in the fossils of Sheppey and Highgate, places which, on stratigraphical grounds, we should infer to be at about the same horizon in the formation, which at both is capped by Bagshot Sand and is at a considerable vertical height above the Lower London Tertiaries. The multitude of seed-vessels and other remains of plants found at Sheppey (generally fossilized in iron-pyrites), of course shows that there land, or a great river, could not have been very far off.

Many of the London Clay fossils have been found in the "*septaria*" (large nodular concretionary masses of clayey limestone, with *septa*, or divisions, of crystalline carbonate of lime) that so often occur; indeed, there are cases of certain species that were before rare having been found in thousands in these stones, masses of which are occasionally crowded with one species of shell, for instance *Modiola elegans* and *Corbula globosa*.

There are two fossils that claim a passing notice here; the one is a species of *Teredina*, or ship-worm, a boring shell that has pierced through many of the fragments of wood of the London Clay, just as its living representative riddles the timber of our own day, the destroyer and destroyed having been fossilized together and preserved sometimes in great perfection; the other is a sort of amber, or fossil gum, known as "Highgate Resin," that must have exuded from trees of the time.

Crystals of *Selenite* (sulphate of lime) are of common occurrence in this as in other clays. They are sometimes called by workmen "petrified water," and are remarkable for the extreme thinness of the laminæ into which they may be split in one direction. The crystals are nearly transparent and sometimes of large size.

Range and Features.

The London Clay forms a very broad band right through our district from S.W. to N.E. The southern boundary runs from Epsom, by Croydon and Beckenham to Mottingham; then westward, by Lewisham to Dulwich; then northward, by Camberwell to the Thames at Bermondsey; and then eastward, under the alluvium and gravel of the river, until it appears again on the Essex side at Wennington, and continues its course by Aveley to Orsett. The northern boundary follows that of the Reading Beds from Windsor to Hedgerley and the Colne, and then along the left bank of the valley of that river north-eastward.

Although over the large area thus included this formation is to a great extent covered by various members of the Drift Series, and partly by outliers of the Bagshot Beds, yet there are large tracts of unmitigated clay, which show the usual features of a thick homogeneous mass of this character. We do not find an absolute flat, as some would perhaps expect, but a series of very gentle undulations, with small streams in some of the broad hollows. The chief of these uninteresting clay-tracts are between Ditton, Epsom, Sutton, and Merton, in Surrey, and in Middlesex, between Uxbridge and Hendon.

Along the southern boundary westward of Croydon the escarpment is but a small rise; but northward of that town the hill-forming tendency of the London Clay is well shown by the marked range of Norwood, Sydenham, and Forest Hills, which, rising with a long slope from the ground on the east, form a conspicuous object in the landscape, heightened by the array of houses, with the glittering mass of the Crystal Palace in the midst, along the evenly cut but northerly inclined top. The mass of Shooter's Hill, again, is one of the most prominent objects in the district, rising up on all sides to a height of 200 feet and more above the surrounding

country, sometimes with a slope of 10°, and reaching the height of 420 feet above the sea-level.

Along the northern boundary the escarpment is again conspicuous for the most part, as on the south of Windsor, and along the valley of the Colne, Stanmore Heath, indeed, with its capping of pebble-gravel, being the highest ground in Middlesex.

The left side of the valley of the Lea, from Waltham Abbey to Chingford, consists almost wholly of a fine range of clay-hills, along the flanks of which are sometimes traces of former landslips. The western edge of Richmond Park is the relic of an old river-cliff of clay (capped by gravel), in sharp contrast with the gravel-flat at its foot.

Of course the sharper slopes of the London Clay are naturally well-drained, but the lower and flatter tracts are generally damp, and except in the immediate neighbourhood of London, population has avoided them, the impermeable nature of the soil and the difficulty of getting water, except by sinking deep wells, making them anything but desirable spots of residence.

Sections.

In the following list of some of the sections that can now be seen I have named such as have fallen particularly under my notice; but there are many more, in railway-cuttings and brickyards, though the former are of course to be seen only for a time, and there have been many others that are not now to be seen. Of these some deserve notice here, from having yielded a rich harvest of fossils; for instance, Chalk Farm, Hampstead and Sydenham Hill railway-tunnels, Copenhagen Fields (now the Cattle Market), and Whetstone; whilst at Hedgerley (north of Windsor) there was once a good section of the basement-bed, with a layer of highly fossiliferous stone.

Those sections that show the junction with the beds below have been already noticed in the lists of sections at pp. 38 and 41. For details the reader is referred to Vol. IV. of the *Geological Survey Memoirs*, pp. 281–288, 301–305.

Place of Section of the London Clay.	Part of the Formation shown.
Berkshire.	
Windsor.—Brickyard E. of Cavalry Barracks	Lower part.
Windsor.—Great Park, N.E. of Bishop's Gate.	Passage-beds into Bagshot Sand.
Surrey.	
Egham.—Tile-kiln	Upper part, fossiliferous.
Epsom.—Brickyard at E. of Common	Lower part.
Sutton.—Brickyards on N.	" "
Croydon.—Brickyard, 1¼ miles N.W. of church	" "
Kingston.—Norbiton Pottery	Top part, fossiliferous.
Forest Hill.—Tile-kiln	Middle or upper part.
Kent.	
Penge.—Brickyards on the E.	Lower part.
Beckenham Place.—Brickyard	Bottom part.
Bromley.—Brickyard at Shooting Common	Bottom part, over Oldhaven Beds.
Chiselhurst.—Kiln on the N.W.	Lower part.
Plumstead Common.—Tile-kiln	Bottom part.
Hertfordshire.	
Radlets.—Brickyard N.N.E. of station	Basement-bed (covered by Drift).
Shenley.—Rabley brickyard	Basement-bed.
Middlesex.	
Uxbridge.—Kiln on the common	Lower or middle part.
Barnet.—Brickyard N. of railway-station	Middle part.
Hampstead.—Brickyard, Child's Hill	Upper part.
Hampstead.—Brickyard near Finchley Road Station	Middle part.
Hampstead.—Brickyard E. of Vale of Health	Top part.
Highgate.—Brickyard at Archway, and road-cutting.	" " (fossiliferous) and passage into Bagshot Sand.
Tottenham.—Brickyards on W. and S.W.	Middle part.
Essex.	
Buckhurst Hill.—Kiln	Upper part.
Theydon Mount.—Kiln N. of church	Clay, and passage-beds into Bagshot Sand.
Brentwood.—Brickyard near railway-station.	Very sandy passage-beds into Bagshot Sand.
Stifford.—Brickyard a mile E.N.E. of church	Basement-bed, fossiliferous.
Upminster.—Pottery about 1½ miles N.	Upper part, capped by loam.
Warley.—Brickyard at Little Bredens	Top part.

2. Bagshot Beds.

Structure and Range.

Towards the close of the London Clay period it would seem as if the sea in which that deposit was formed had grown shallower, whether by continual silting up, which was not compensated by gradual sinking as before, or by actual rise of the land; for the top part of the formation is more sandy, the amount of sand increasing, moreover, in successive beds, until from stiff London Clay there is a passage through sandy clay, loam, and clayey sand to Bagshot Sand. It follows, therefore, that between the two formations there is, as a rule, no strongly-marked hard and fast line, and that it is sometimes doubtful with which to group certain of the sandy or clayey beds at the horizon of passage: one observer would carry the boundary of the Bagshot Beds down to the lowest layer of sand, when another would rather class with the London Clay everything from the highest layer of clay downwards. The safer rule perhaps is to take the higher boundary, unless, as a compromise, the passage-beds were separately mapped as such; but actually it is a matter of no great moment, and the junction is generally shown with some clearness by the frequent springs, thrown out from the sandy permeable beds above by the clayey impermeable beds below.

The Bagshot Beds as a whole consist of sand, with occasional layers of clay and loam, and with fine clayey partings: here and there too we find pebble-beds of the same character as those of Blackheath. They are for the most part unfossiliferous in the London Basin, though indistinct remains of marine shells occur here and there; but in the Hampshire Basin, the middle part, there well developed, has yielded many fossils. The series is made up of three divisions, Upper, Middle, and Lower, the last two of which are in their turn susceptible of subdivision.

The main mass takes up the south-western corner of our district, from the southern part of Windsor Park, by Chertsey and Weybridge to Esher, along which course, however, the boundary-line is much hidden by the gravel of the Thames. Far off, on some of the higher grounds of Middlesex and Essex, there are outliers (of the Lower division only), silent witnesses of the

former extension of the beds and of the great denudation that they must have been subjected to in the course of ages; the fragments that remain in our district being but small in comparison with the vast amount of material that has been worn away.

Lower Sand, and Pebble Bed.

It is this lower division that alone takes up any considerable area in our district, where it consists chiefly of fine light-coloured sand, sometimes iron-shot, and sometimes with masses of iron-sandstone: there are also very thin layers of pipe-clay; but we do not find in the London Basin any of those thick masses of valuable pipe-clay that occur in the Lower Bagshot of Dorsetshire.

South of Egham and west of Chertsey a pebble-bed, some feet thick, occurs in places, apparently near the bottom of the sand, and is composed of perfectly rolled pieces of chalk-flints in a sandy matrix, just as the analogous pebble-bed of Blackheath, &c. (in the Lower London Tertiaries): it follows, therefore, that this Bagshot pebble-bed must either have been made up from an older Tertiary pebble-bed, or from flints derived directly from the Chalk, or partly from both sources; in all cases pointing to an overlap of the Bagshot Beds over the London Clay to the beds below. Now we know that the London Clay thins gradually westward, and that in the far west of the London Basin, near Marlborough, it seems to have thinned out altogether, so that the Bagshot Sand is there but little above the Chalk; and we might conclude therefore that these pebbles may have come from the west. It is, however, quite possible that a like thinning may have occurred northwards, though from the denuding away of the beds no evidence of it has been left, and also southwards, over the Wealden area.

In the Essex outliers there is sometimes a bed of brickearth over the sand, and at top of all is a pebble-bed, like that above noticed, but of much more frequent occurrence, (so that it has been mapped,) and reaching a thickness of 15 feet.

Bracklesham Beds.

Of this middle division we have only a spur of the main mass, N. and N.E. of Chobham, and a few outliers. It is of a more clayey and fertile character than the sandy beds below, consisting of loam, clayey greensand, and brown clay, which last is generally found at the bottom. In the small outlier at St. Ann's Hill, Chertsey, there are also pebble-beds of some thickness, so that it is possible that the Essex pebble-bed may belong to this division.

Upper Sand.

In the London Basin the Barton Clay, which in Hampshire forms the higher part of the middle division, is absent, and the upper sand rests on the Bracklesham Beds. Of this we have in our district but three wee outliers, on the high ground north of Chobham.

Features.

The Bagshot Beds as a whole form a more or less barren sandy tract of irregular rising ground, in part open, but sometimes thickly covered with fir and larch, which flourish well on a sandy soil. St. George's Hill, Cobham, is a fair example of a sand hill.

The outliers of Harrow, Hampstead, and Highgate, are perhaps the most prominent objects in Middlesex; but it should be remembered that in these the sand forms merely the highest part of the hills, the longer slopes of which are of London Clay. This is also the case to a great extent in the Essex outliers, but here the larger masses of the pebble-bed on the hill-tops also show the flat-forming feature of gravels.

Sections.

Place of Section of the Bagshot Beds.	Nature of the Beds.
Surrey.	
Virginia Water Station.—Pit -	Sand with a layer of pebbles.
Virginia Water Station. — Pit, ¾ mile N. - - -	Sandy pebble-bed.
Egham Hill.—Large old pit -	Sand, with thin clay-layers, and a layer of pebbles.
Chertsey.—St. Ann's Hill -	Sandy pebble-bed, clayey green-sand with pebbles, brown clay, and sand.
Middlesex.	
Hampstead Heath.—Pits - -	Sand, with thin layers of clay here and there.
Highgate Archway - -	Passage into London Clay.
Essex.	
High Beech.—Small pits - -	Sand with thin layers of clay.
Havering.—Pits and brickyard -	Pebble-bed and sand.
Southweald Park, Langtons -	Sand, pebble-bed, and loam.
Brentwood and Warley.—Pits -	Pebble-bed and sand.
Blackmore.—Brickyard a mile S.E.	Loam and sand. Pebbles higher up.

All these sections are in the Lower Division only, except that at St. Ann's Hill, near Chertsey, which shows the junction of the Middle and Lower Divisions, and also a fault with a northern downthrow of many feet.

Some sections of the passage-beds between the Bagshot Sand and the London Clay are named in the list at p. 44.

Besides the pits named in the above list there are road-cuttings down the sandy slopes, and other small exposures.

For a full account see Vol. IV. of the *Geological Survey Memoirs*, pp. 315–317, 319–326, 332, 333.

CHAPTER 5.

DRIFT SERIES.—GLACIAL AND DOUBTFUL.

1. General Remarks.

In the London Basin, after the Bagshot Beds, we come to a great gap in the series of geological formations, the thick mass of the Fluvio-marine Beds of the Hampshire Basin being altogether unrepresented, and the next deposits being the Crag beds of the Eastern Counties, which last, moreover, are wanting in our special district, where we pass from the older Tertiaries to the far newer set of deposits now usually massed under the term "Drift."

Although, however, the vast time between the end of the Bagshot period and the beginning of the Drift is wholly *unrepresented by deposit*, yet it is to a certain extent *represented by denudation;* for, from the way in which the Drift beds lie on the various older formations, not succeeding in a regular series, but sometimes resting on one and sometimes on another, it is clear that these latter must have suffered great waste before the former were deposited on their denuded surfaces.

Comparatively thin though they may be as a rule, nevertheless, from their wide spread and the great effect they have on the nature of the surface, the members of the Drift are of great importance practically; whilst from the peculiar conditions they point to, and their varying composition, many of them are also of great interest, and the more so as they are the introduction to the present era of the world's history, part of them (in our district the newer part) being the first beds that give evidence of the existence of man.

In classifying the various Drifts we have not the undeniable evidence of superposition (in our own district) to depend on, as with the beds already described, the succession and relative position of which are absolutely certain; nor do we get much aid from the contained fossils, for with the exception of those derived from other formations, and which, of course, are useless for

determining age, these occur only in one set of Drift beds, those that we infer to be the newest, and connected with the present river-system. Although, however, the task of arranging these beds of gravel, sand, loam, and clay in their chronological order might well seem a rather hopeless one, and indeed was thought to be so in the earlier days of the still new science of geology, yet, from the careful study that they have had of late years, the chief points in their stratigraphical relations have been made out, and from their relative positions and mode of occurrence we can generally tell their relative ages.

There are two great groups of these beds, respectively known as "Glacial Drift," deposited at a time when glacial or icy conditions prevailed, and "Post-glacial Drift," deposited at a later period, when the glacial conditions had either passed away (locally at least), or become much modified. It is hardly possible, however, in the present state of our knowledge, to range all the superficial deposits of our district under these two heads, there being a goodly show of beds that refuse to give a clue to their highly problematical age. The uncertainties in the geological sequence are from three quarters: from a pebble-gravel that may be of Glacial age, but is more likely to be Pre-glacial, and therefore the most aged of its family; from another gravel (plateau-gravel) that may be Glacial, but is more likely to be early Post-glacial; and from a sheet of clay and loam (on the Chalk) the formation of which may have taken place during a long period, down indeed to a very late one, if not actually going on now to a slight extent.

In the following pages the various divisions will be described in what seems most likely to be their natural order, beginning with the oldest, but leaving the doubtful beds to the end of the chapter. It must be understood, however, that it is very difficult to classify some tracts of gravel, &c., and that the colour given to them on the map does not always imply that a definite opinion has been come to, but that the balance of probabilities points in the direction indicated.

2. Pre-glacial (?) Pebble-Gravel.

On the tops of the London Clay hills there is often a mass of sandy gravel of an exceptional sort, that is to say, it is almost wholly wanting in the more or less

angular pieces of flint that form the greater part of the other gravels to be described, and, like the far older gravel-beds of the Blackheath and Bagshot series (pp. 39, 51), its component stones have been rounded into the form of pebbles. Showing at first sight a very great likeness to these old Tertiary pebble-beds, after a more careful examination this gravel is seen to be easily distinguished from them; for whilst the former are made up of flint-pebbles, that is not the case with the latter, which contains also a large proportion of pebbles of quartz and quartzite, and here and there a sub-angular flint. Were this gravel roughly sorted, it would mostly be found that amongst the larger pebbles those of flint were in excess, whilst amongst the smaller those of quartz were most common; sometimes, indeed, the small rounded pieces of white quartz give the gravel a very distinctive appearance.

The flint-pebbles have probably been derived from the destruction of the old Tertiary pebble-beds; but the pebbles of quartz, quartzite, and other older rocks that occasionally occur must have been derived from beds that are not found anywhere in our district.

Of the age of this gravel we cannot yet speak with certainty. It is newer than the Lower Bagshot Beds, for it is known to overlie them; and it is older than the Boulder Clay, which is found above it, but between these extremes we are left to reason by analogy and by the evidence given by the manner of its occurrence.

In the first place it is not likely to belong to any part of the Bagshot Beds, as it is unlike any part of them, and as it rests both on their lower member and also on London Clay. Secondly, it is unlike the Crag beds of Suffolk, which, moreover, are not known to occur anywhere near our district. It would seem, therefore, to belong to the Drift, and the question is practically limited to the relation of this gravel to the other Drift beds.

Nowhere do we see its relation to the sands, gravels, &c., which so commonly occur beneath the Boulder Clay, and which have been named "Middle Glacial Drift" by Mr. S. V. Wood, junr., and consequently it is open to class it with those beds, as that observer does, and the opinion of no one is of greater weight on such a subject.

On the other hand, it is urged that this gravel is distinct from that of the "Middle Glacial Drift," and to my mind the balance of evidence is in favour of this conclusion, for the pebble-gravel is very different in composition from the other, and it has never been found to contain the layer of boulder-clay that is so often found in the midst of the "Middle Glacial Gravel."

From its occurrence on the tops of the hills, whilst the Middle Glacial gravel often lies at their base, or on their flanks, it would seem that the pebble-gravel is the older of the two and was deposited long before those hills were cut into their present form, a process which must have been somewhat advanced before the other gravel was laid down. It is possible, therefore, that the pebble-gravel may represent some part of the "Lower Glacial Drift" (of Mr. Wood), any known occurrence of which is, however, as far distant as Crag.

It has lately occurred to me, whilst carrying on the Geological Survey in parts of Suffolk, that this pebble-gravel might represent a very similar bed which occurs, in considerable thickness over certain tracts, as near Southwold and Halesworth, where it underlies the Glacial Drift and overlies the Chillesford Clay (of the Crag period). This gravel has been classed as the base of the Lower Glacial, but my colleague Mr. H. B. Woodward has taken its continuation northward, in Norfolk, to belong to the Crag.

On the whole, it seems safer for the present to regard this gravel as the oldest Drift of our district, and as a bed of somewhat local occurrence.

The chief localities are Stanmore Heath, from Shenley south-eastward, west and north of Barnet, and at Totteridge, in Middlesex; at Highbeech, Jacks Hill, and Gayne's Park, east of Epping, in Essex, and at Shooter's Hill, in Kent.

Some patches of pebble-gravel that may not really be of the same age have been coloured with this on the map, as a matter of convenience, it being almost impossible to give a separate colour to every different indeterminable bed.

3. Glacial Drift.

The deposits we have now to consider give unmistakeable evidence of conditions different from those with

which we have yet had to deal, and they belong to what has been well called "the great ice-age," an age when the northern and other mountainous parts of our island had their valleys filled with glaciers, rivers of ice flowing from snow-capped mountains, and at one time would seem even to have been covered by a great ice-mantle, such as that now found in Greenland, a vast sheet of ice and snow hiding both hill and dale beneath its ample folds. Whilst this state of things occurred in the north, our southern lowlands would seem for the most part to have been no better off, but were subjected to strong ice-action also though in what form is a matter in dispute (see *post.* under *Boulder Clay*).

The lowest of these Glacial Drifts, which are well developed in Norfolk, and may be well seen in the coast-sections of that country, do not occur so far west as our area, where we have to deal only with the middle and upper divisions of the series, unless the pebble-gravel just noticed should turn out to belong to the lower division.

It is remarkable that no Glacial Drift has been found south of the Thames (unless some of the high patches of gravel should turn out to be of that age), whether from having never been deposited over that tract, or from having been since denuded away, both views being held by geologists. I have, however, seen rounded lumps of hard chalk, very suggestive of those found in the Boulder Clay, in Kent, at a high level on Lower Tertiary beds, at Crocken Hill, eastward of St. Mary's Cray; but from the want of any kind of section it was impossible to make out the origin of the clayey soil at the spot.

Gravel Sand and Clay ("*Middle Glacial*" of Wood).

The gravel we have now to describe is made up of a great variety of materials, and these varying in different places. The flints of the Chalk, one of the most indestructible stones, form the chief constituent, whether as partly worn sub-angular fragments that have been derived directly from the parent rock, or as rolled pebbles that once formed part of some old Tertiary formation; pebbles of quartz and quartzite are next in number; but there are also the relics of other rocks, and in places many of their less destructible fossils, notably the *Gryphæa* and

Belemnites of various divisions of the great Jurassic (or Oolitic) series.

Interbedded with the gravel are sometimes masses of sand and sometimes of loam or clay, the latter of which must have been deposited in tolerably sheltered places. Besides these, however, there is sometimes a layer of true Boulder Clay in the gravel, that is, a clay that contains irregularly rounded fragments or boulders of various rocks, the surfaces of which are furrowed and scratched in the way peculiar to stones that have been dragged along by masses of ice and subjected thereby to grinding action. This clay being like that which occurs in force above the gravel, serves to link the two deposits together, and to show that the glacial conditions which seem to have reigned supreme during the formation of the great mass of Boulder Clay existed also during the deposition of the lower bed, though to a less extent.

It is only far to the east that shells (belonging to the deposit) have been found in this set of beds, and these are marine. We may conclude therefore that these Glacial gravels, &c., were deposited in a sea of no very great depth, in which occasional icebergs dropped their freight of clay and stones.

It is not certain that all the gravel coloured with this on the map should be classed with it; thus, that which occurs on the Buckinghamshire hills may turn out to belong to the "plateau-gravel" (of doubtful age) that will be noticed presently. In the absence of Boulder Clay it is often difficult to classify these hill-gravels, and in this particular case it was merely thought safer to colour the gravel as Glacial than to make a division where no good ground for it existed, there being abundance of good Glacial gravel not many miles off.

It should be mentioned that this division is often absent, and that the Boulder Clay therefore often rests at once on the older Tertiary beds.

Boulder Clay ("*Middle Glacial*" of Wood).

"The Great Chalky Boulder Clay," as it has been called, is a bluish-grey clay, mostly of a dark shade, crowded with boulders or transported fragments of many rocks that vary in size from large blocks to mere pebbles. Chalk is the chief material of these boulders, and it is

nearly always hard, so as to have preserved the glacial scratches; the flints of that formation also occur in great numbers. Next to this, the limestone of the Lias is often common, besides remains of other Jurassic rocks. But older beds are represented, pebbles and masses of quartz and of quartz-rock being of common occurrence, and boulders of hard Carboniferous Limestone with well preserved scratched surfaces are found, besides sandstones, and granites, greenstones, &c., generally more or less decomposed. The most plentiful derived fossils are those of the Lias and Oxford Clay, of which, indeed, a very respectable collection might be made in our district, far from those formations.

We see, therefore, that the mass of contained stones, &c., are such as would be derived from tracts to the north, aud not from the south.

Whilst Geologists agree that the Boulder Clay has been formed by ice-action they are far from agreeing as to the form of ice that has done the work, and three theories have been advanced, with much controversy. According to the first it is held that this wide-spread deposit, only the southern edge of which enters the tract just north and north-east of London, has been dropped from the melting icebergs that have floated southwards from the ice-capped northern country, bergs that have been heavily laden with the scratched stones and the glacier-mud from that region.

Of late years many geologists have strongly advocated the theory that Boulder Clay has been formed by land-ice; not by mere glaciers, but by vast ice-sheets, underneath which a "bottom-moraine" has resulted from the constant grinding action of the thick moving mass. Others again hold that the agent employed was coast-ice, acting on a slowly sinking area.

No fossils, except the multitude derived from the various formations over which the ice passed, have been found in our Boulder Clay.

The chief tracts of Boulder Clay in our area are on the north-east of Watford, the most westerly patch; at Finchley, its most southerly point, where it ends off at the northern slope of the ridge that bounds the valley of the Thames; and in Essex on the north and north-west of Brentwood, whence it spreads over a very large district, beyond our bounds.

Sections.

Good sections of the Boulder Clay are rare, but it can often be seen in temporary openings and in road-side sections and ponds. The gravel below is naturally more worked for road-material.

Very good sections of both divisions of the Glacial Drift were shown by the cuttings on the railway at Finchley, of which I took notes in the years 1864, 1865, unfortunately just too late for publication in the *Geological Survey Memoir* on Sheet 7. The later sections, on the line to Barnet, have been recorded by Mr. H. Walker, but little is now to be seen of any. At the best section, near Finchley church, there was a brown clay, without boulders, but with small calcareous concretions, between the Boulder Clay and the very pebbly gravel.

In the list of sections those only are named which, as far as I know, can still be seen.

Place of Section of Glacial Drift.	Beds found.
Buckinghamshire.	
Stoke Common (N. of Slough).—Pit at S. end	Gravel — coloured as Glacial, but not with certainty.
Stoke Common.—Pits N. of	Gravel and sand — coloured as Glacial, but not with certainty.
Hedgerley.—Pits on hills to N.	Gravel and sand — coloured as Glacial, but not with certainty.
Chalfont St. Peter.—Pit on hill to W.	Gravel — coloured as Glacial, but not with certainty.
Hertfordshire.	
Watford.—Pits W. of town	Gravel.
Watford.—Railway-cutting northward of town.	Gravel, lying irregularly on Chalk.
Watford.—Chalk-pit close to Bushey Railway Station	Brickearth and gravel.
Bricket Wood (at edge of map, N.N.E. of Watford).—Brickyard.	Boulder Clay, below which gravel and sand have been found.
Radlets (N.E. of Watford).—Pit on hill E. of railway.	Gravel and sand.
Middlesex.	
Harefield, N. of Uxbridge	Gravel, laying very irregularly on Chalk.
Finchley.—Brickyard southward of church	Clay and gravel.
Whetstone.—Gravel-pit ½ mile S. of	Boulder Clay and gravel.
Southgate.—Pit N. of (White's Barn)	Gravel.
Essex.	
Buckhurst Hill.—Gravel-pits	Gravel.
Theydon Mount.—Pit S.S.E. of church	Boulder Clay over pebbly gravel.
Epping.—Brickyard on N.	Boulder Clay.
Stondon Massey.—Pit	Gravel and sand.
Stondon Massey.—Pit N. of Halsford Bridge.	Sand (doubtfully classed as Glacial).
Hutton (E. of Brentwood).—Pit on S.	Pebbly gravel.
Mountnessing Street.—Pits on W.	Gravel.

Details of some sections will be found in the *Geological Survey Memoir* on Sheet 7.

4. Beds of Doubtful Age.

Plateau (or Hill) Gravel.

Under this name it is convenient to class certain gravel-patches that occur at a comparatively high level, capping some of our London Clay and Bagshot hills. Possibly, some of this may turn out to be of the same age as the Glacial gravels; but from the occurrence here and there of pieces of chert, like that found in the Lower Greensand of Surrey, &c., we are led to infer that the transport of material from the north did not hold at the time of the formation of this gravel, or at least to nothing like the extent that was the case during Glacial times, for these fragments of chert must have come from the south.

This gravel is mainly formed of sub-angular flints and flint-pebbles, with the occasional pieces of chert above mentioned, and some quartz-pebbles: in fact, it is not unlike much of our later gravel, which is connected, more or less, with the present valley-system, and it is indeed sometimes hard to distinguish the two.

Whilst, therefore, on the one hand, some of the highest masses that have been classed with the Valley-gravel (although they form the tops of existing hills, as at Richmond Park and Wimbledon Common) may, perhaps, really belong to this somewhat older series; on the other hand, so also may some of the higher gravels that have been classed with the Glacial Drift, as in Buckinghamshire, northward of Windsor.

The "plateau-gravel" does not occur in our district in broad tracts, like those that are found over the high ground of the Bagshot Beds on the south-west, but in more isolated patches, that have been separated by denudation. From the very wide spread that these hill-gravels have in some parts, one would be led to think that they are most likely of marine origin, and it has been inferred that they were deposited during emergence of the land at the close of the Glacial period, like certain gravels that occur locally on the Boulder Clay plateau of the Eastern Counties.

Patches of gravel occur far out in the Chalk tract, as on the top of the high Tertiary outlier at Well Hill, in Kent, where they have no relation to any existing valley, but are probably remnants of a former sheet, now almost destroyed by denudation.

Clay-with-flints.

The greater part of the higher ground of the Chalk-tracts, both on the north-west and south-east, has a covering of a more or less clayey nature; the upper part of this is often worked for bricks, but the lower is a stiff brown clay, with unworn flints and sometimes pebbles. This lies very irregularly on the Chalk, nearly everywhere, indeed, in "pipes" dissolved out in that rock by carbonated water flowing through it; and from the unworn character of the contained flints, the surfaces of some of which are as fresh as if they had come direct from the Chalk (save for their dark staining), we may infer that the deposit has been formed on the spot where it is now found, not from material transported from a distance, but through that dissolving away of the Chalk of which the pipes give evidence. By this process the carbonate of lime of the Chalk would be dissolved away, and the insoluble flints and earthy matters left behind, the last receiving, perhaps, an addition from any pre-existing clayey deposit that might occur over the Chalk.

Such an operation, of course, must have involved a large amount of time, and may have gone on at some depth from the surface, where water could get access to the Chalk; indeed, it may still be going on, so that a lower bed may actually be formed underneath a higher one. We may conclude, therefore that the "clay-with-flints" is not of definite age, but may have been forming at any time since the last emergence of the country from the sea (and its consequent subjection to atmospheric actions) to the present time. The corresponding "argile à silex" of France is classed by many French geologists as Miocene, or as Eocene, on the ground, that where present it is always next above the Chalk, never occurring on even the oldest Eocene beds; but if it is chiefly the result of the decomposition of Chalk in place, clearly it must always rest on that formation, whatever be its age.

Various theories of the formation of clay-with-flints have been brought forward by French geologists, especially of late years, and they have invoked diluvial action, thermal waters rising up from beneath, and also glacial action to account for deposits of this character;

but they seem for the most part not to be aware of the above theory, which was published in 1864 (see *Geological Survey Memoir* on Sheet 7), although some of them have now come to much the same conclusion.

From the irregularity of the surface of the Chalk beneath it, the thickness of the clay-with-flints is, of course, irregular, but it is rarely more than a few feet. The part next the Chalk is usually black, and its flints black-coated.

Brickearth (of the Chalk-tract).

The clay-with-flints is in great part covered by a more important bed, of a loamy nature, which, where in sufficient thickness, is worked for bricks. The origin of this brickearth is rather doubtful; in some places it seems to be little else than a mixture of re-arranged Lower Tertiary beds, with barely a trace of bedding; whilst in others it is a more or less finely-bedded sandy clay, or clayey sand; on the north it is possible that it may be allied to the deposits next underlying the Boulder Clay, the "Middle Glacial" of Mr. S. V. Wood, jun. It occurs chiefly in large hollows or pipes let into the Chalk, and is often so full of flints and pebbles as to be unworkable. In colour it varies from light-brown to grey and red-mottled, so that it might sometimes be taken, at first sight, for the mottled clay of the Reading Beds, from which, however, it is easily distinguished by careful examination, both the colour and the material being less pure than with the richly tinted plastic clay.

A fuller account of the Clay-with-flints, and the accompanying Brickearth, is given in the *Geological Survey Memoir* on Sheet 7, pp. 63–68.

CHAPTER 6.

POST-GLACIAL BEDS.

1. River Drifts.

It should be understood that the term "Post-Glacial" is here used in what may be called a local sense. For, whilst there can hardly be a doubt that the gravels and brickearths of the Thames Valley were deposited after the neighbouring Boulder Clay (here the newest member of the Glacial Drift), yet we naturally infer that further northward glacial conditions lasted longer; and indeed we have evidence of the existence of later deposits northward that as truly belong to the Glacial Drift as our southern Boulder Clay does. It follows therefore that our River Drifts may have been formed, in these southern parts, at the same time as some of the ice-formed beds in the colder tracts to the north, where moreover there is no such extent of Post-Glacial gravel.

Conditions under which they were formed.

The "River Drifts," to the consideration of which we have now come, are amongst the most interesting beds of the district; not only as occurring over large tracts and materially affecting the character of the surface (although generally of slight thickness), but also from their containing the bones of animals for the most part now extinct in our island, but associated with a molluscan fauna of recent type and with the earliest remains of human art,—the now well-known "flint-implements," the first traces of man yet found.

These beds of gravel, sand, and loam, formed after the great Ice Age, with its deposits of Boulder Clay, had (locally at least) passed away, and when the climate, though not so mild as now, had sensibly changed for the better, may be looked upon as the forerunner of present

conditions, the sign of the better times that were to succeed.

From their position at various levels along the valleys in which our streams run, from their character and composition, and from their fossil contents, which are of land and freshwater species, there can be no doubt that they were deposited by rivers, and by rivers following the present line of drainage. These rivers, however, from the coarseness of the material deposited, must have had greater power than their modern representatives, power that must have been gained by greater rainfall, and by greater liability to floods, both resulting from a greater elevation of the land and a colder (or more continental) climate than now holds.

At the time when the old Thames deposited the gravels that now occur along the flanks of its valley England was part of the European continent, and the Thames perhaps a tributary of the Rhine; but, rising from higher ground than now, receiving a greater quantity of water, and probably having a greater slope, it had a more torrential character than the present quiet stream, and therefore was endowed with greater erosive and carrying power. Across the land since worn away and now occupied by the "narrow seas" of the Straits of Dover, &c., must have come the animals that took possession of the country, and of whose existence at this period we have evidence in the bones and teeth that are found in the gravel and brickearth.

From the occurrence of these River Drifts at successive stages or terraces on the sides of the valley, we are led to infer that after the deposit of the first or highest gravel the river deepened its bed, cutting through that gravel, and depositing another mass at a lower level, in its turn to be cut through as the channel was further deepened. Naturally, the highest of these terraces, of which there are often three in the valley of the Thames, has suffered more from denudation than the others; sometimes, indeed, it occurs only in the form of outliers, completely cut off from the neighbouring masses, the underlying bed having been laid bare all round; and very generally it is separated from the terrace below by a narrow outcrop of London Clay, or other older formation.

Gravel and Sand.

By far the larger area of the Drift of the Thames Valley consists of the well-known gravel on which so great a part of London is built. The chief constituent of this is, as might be expected, the most indestructible material that occurs along the course of the river, and which indeed is perhaps the most enduring (whether against chemical or mechanical actions) that we possess, the flints of the Chalk. These, having been left behind during the denudation of their destructible containing-rock, have been more or less broken, and the fragments have been rolled about by transport in water until they have been reduced to the state known as "sub-angular," that is one in which, whilst preserving the general irregularly angular shape, all the more prominent edges and points have been rounded off.

Together with these sub-angular flints there are also many fragments of the same material in a very different state, perfectly waterworn and rounded, or, in other words, reduced to the form of pebbles. Now it is clear that these finished specimens of the result of long-continued attrition on pieces of flint could hardly have been formed by the same action that only succeeded in rounding off sharp edges, especially as we do not find the intermediate shapes that would occur were the difference merely one resulting from the difference of time during which the stones had been subjected to the wearing action of the river. On referring, however, to the accounts of the old Tertiary formations, it will be seen that those beds have already provided a stock of flint-pebbles ready to aid any future denudation in the manufacture of gravel, and it is to this source that we must trace the mixture of such with the sub-angular flints that have been got direct from the Chalk.

Besides flint, there are other forms of silica present: pebbles of quartz and quartzite from older rocks, which have gone through various phases of existence, and have successively formed part of various beds; removed from their parent rocks, rounded and deposited in the "pebble-beds" of the New Red Sandstone; disinterred after long ages, to contribute to the formation of some of the older Drifts, on the partial destruction of which they were transferred to their present resting place. More

rarely, too, there occur pieces of chert from the Lower Greensand, and fragments of Tertiary greywether-sandstone.

There are often many pieces of chalk where the gravel rests on that formation: indeed, there are cases of a bed of chalk-rubble at the bottom; but of the Jurassic limestones over which the river passes in the higher part of its course there are rarely any traces, on account, probably, of their dissolution by water, to the solvent action of which they were long exposed.

The gravel, which is rarely over 20 feet thick, is often rather ferruginous, and sometimes parts are cemented together by oxide of iron. Layers of sand often occur, and sometimes form almost the whole of the deposit, replacing the gravel. The spaces between the stones are of course for the most part filled in with sand.

Brickearth.

Above London the gravel is sometimes overlain by a brown loam, of no great thickness, which is largely worked for bricks, and is also much cultivated for market-gardens, its soil being very suitable for the growth of fruit and vegetables. This brickearth varies from a clayey sand to a sandy clay, and sometimes contains a few flints and pebbles, and it has been considered to be a deposit from flood-waters.

In the valley of the Thames below London a more interesting set of deposits occurs, at Ilford, Grays, Erith, and Crayford, where thicker beds of brickearth are worked. This brickearth is often laminated and interbedded with gravel and sand, and it contains land and fresh-water shells and mammalian bones, as also do some of the more sandy beds. The finely-bedded character of the clayey material points to tranquil conditions of deposit somewhat different to those of the gravels and sands, which so often show current-bedding.

Like fossiliferous beds occur within the Metropolitan area, and may be seen at Stoke Newington, though at Hackney I believe they are not now open to view. Fossils have also been found at Brentford, in a railway-section now hidden.

Fossils.

The chief interest of the River-Drift, from a zoological point of view, lies in the many remains of mammalia that it has yielded. Of these, some are of species still living in our island, such as the cat, fox, otter, red deer, roe-deer, pig, and field-mouse; whilst others are either known to have lived therein during the historic period, or are but slightly different from their present representatives, as the wolf and a species of ox and of horse. But besides these, there are the bones of large carnivorous animals; amongst others of a variety of lion, associated with remains of other mammals, such as hyenas and bears, of which luckily there are no descendants to trouble us at the present day. There have been found, too, remains of bison, of the musk-sheep, of the large-horned "Irish Elk" and of the beaver, and, most notable perhaps of all, we know that England was then tenanted by three kinds of elephant and of rhinoceros, as well as by a hippopotamus.

The shells of the deposits are all of land and freshwater kinds, belonging to the genera *Helix*, *Limnæa*, *Planorbis*, *Bithinia*, *Paludina*, &c., amongst univalves, and to *Cyclas*, *Pisidium*, *Unio*, *Anodon*, &c., amongst bivalves. Most of the species are the same as those living in our country now; but there are two exceptions, a freshwater mussel (*Unio littoralis*), which, though living in France, is extinct with us, and a smaller and sometimes abundant bivalve shell (*Corbicula*, or *Cyrena fluminalis*) extinct in Europe, but still living in the Nile.

Sections.

Openings in the old river-gravel are of frequent occurrence in London, in excavations for buildings, &c.; whilst in the neighbourhood the gravel is largely dug for road material. Where the brickearth is thin it is often worked off, leaving the underlying gravel at the surface.

The sections in the valley of the Thames below London, which are the largest and by far the most interesting, have for many years been favourite spots for geological excursions. From the extent of the workings, especially at Crayford and Erith, fresh exposures are

constantly laid open, and therefore they repay constant examination. At Erith masses of the older Tertiary beds have been found *above* the Valley Drift, probably the remains of an old landslip, and there are sometimes many broken shells of the Woolwich beds in the gravel and loam.

NORTH OF THE THAMES.

Place of Section of Valley Drift.	Beds shown.
Buckinghamshire.	
Slough.—Brickyards	Brickearth over gravel.
Stoke Poges, Upton, &c.—Pits	Gravel.
Middlesex.	
Hillingdon, Hayes } Pits	Gravel.
West Drayton, Southall } Brickyards	Brickearth over gravel.
Hanwell.—Pit W. of Asylum	Gravel.
Acton.—Brickyards eastward of (flint implements have been found in gravel at Acton)	Brickearth.
Shepperton.—Brickyards near Halliford	Brickearth.
Highbury.—Brickyards (a flint implement has been found here)	Brickearth and gravel.
Stoke Newington.—Brickyards on S.	Brickearth (with shells), gravel, and sand.
Old Ford, N. of Bow.—Pit	Gravel, sand, and brickearth.
Kingsbury (Brent Valley).—Pits	Gravel.
Tottenham (Lea Valley).—Brickyard on W.	Brickearth and gravel.
Tottenham, Edmonton, &c. (Lea Valley).—Pits	Gravel.
Ponders End (Lea Valley).—Brickyards	Brickearth over gravel.
Enfield Highway (Lea Valley).—Brickyard	Brickearth.
Southgate (Lea Valley).—Pit by Railway Station	Gravel.
Essex.	
Leyton.—Pits (Junction of Lea and Thames Valleys)	Gravel.
Plaistow, &c.—Pits	Gravel.
Ilford.—Brickyards	Brickearth, gravel, and sand, with shells and bones.
Aveley.—Pit	Gravel.
Grays.—Brickyards and chalk-pits	Brickearth, gravel, and sand, with shells and bones.
Theydon Bois (Roding Valley).—Pit on S.	Gravel.

Some of these sections (in Bucks and Middlesex) are described in the *Geological Survey Memoir* on Sheet 7.

SOUTH OF THE THAMES.

Place of Section of Valley Drift.	Beds shown.
Surrey.	
Egham.—Pit on E.	Gravel.
Croydon (and on N.).—Pits (Wandle Valley)	„
Wandsworth Common } Pits	„
Clapham Common }	
Peckham.—Brickyard on E.	Brickearth.
Kent.	
Ravensbourne Valley, Lewisham and N.W. of Southend.—Pits	Gravel.
Lee (side valley). — Burntash Lane Brickyard	Brickearth (bones have been found).
East Wickham. Brickyard on N.	Brickearth, with bones.
Erith.—Large brickyard on S.	Brickearth, gravel, and sand, with bones and shells.
Erith.—Brickyard at Northend	Brickearth and gravel.
Crayford.—Large brickyard on N.E.	Brickearth, gravel, and sand, with bones and shells.
Dartford Heath.—Brickyard and pits	Brickearth, sand, and gravel.
Bexley (Cray Valley).—Pit on W.	Gravel.
St. Paul's Cray (Cray Valley).—Brickyard (left side of valley)	Brickearth over gravel.
Dartford.—Brickyard on S., pits on S.E. (Darent Valley)	Brickearth, sand, and gravel.
Greenhithe.—Chalk-pits	Gravel.
Northfleet.—Pits for brickyard	Brickearth, gravel, and sand.

Those sections not in the Valley of the Thames have the names of their respective valleys in brackets.

2. Modern River-deposits.

We have now come to the last and newest deposits of the district, begun in pre-historic times, but continued until by human agency, in the embankment and canalisation of rivers, they have been suspended or checked. These alluvial deposits are confined to the very bottoms of the valleys in which streams run, and clearly owe their origin to the action of those streams, which have worn away material from their banks in some places, to deposit it in other parts along their course, forming marshy flats.

It is notable that for many miles above London there are but very narrow strips of alluvium or marshland along the sides of the Thames, the modern river seeming to have been confined to a comparatively narrow channel in the low gravel-flat through which it runs. Below London, however, it is very different, and the river is bordered on either side by broad marshes, the level of which is some feet below that of high water, but which are now never flooded on account of the river-wall that protects them. It would seem that the founders of our great city were led to choose its site where, in ascending the stream (broad at high tide, and comparatively narrow at low water) they first came to a dry gravel-plain of some extent, which, whilst free from flood and yet close to the water at all states of the tide, was nevertheless but little above the level of the river, that in its turn gave constant access to the sea, and so to other lands.

The deep trenches dug in the marshes on either side the Thames below Woolwich during the progress of the main-drainage works, laid open a bed that is rarely to be seen. It is a layer of peat, some feet in thickness, which underlies the silt or consolidated mud that forms the upper part of the alluvium. This peat contains not only leaves and twigs, but also trunks of trees, chiefly, I believe, of yew, but also of oak, pine, and others, and the stools or roots of these have also been found penetrating into the underlying gravel. This bed, therefore, is one of those "submerged forests," as they are called, that are found at so many places on our coast, at the mouths of rivers or streams. The explanation of their occurrence is that the trees must have grown where they are found, when the land was at a rather higher level than now, and on submergence they were covered by

the silt from the river that overflowed them. I would suggest, however, that the amount of submergence that has sometimes been inferred may be a little more than is needful, for the present low level of the peat-bed of the Thames may be partly owing to another cause, contraction of the beds from their continued freedom from inundation (and consequent drying), which process has actually resulted in leaving the surface of the marshland some feet below the level of high tide, whilst those mud shores that are still flooded keep a much higher level than the protected ground divided from them only by the river-wall.

The peat was well shown in the deep excavations for the Victoria Docks Extension, more than a mile long. Here I saw many large tree-trunks in it, one 30 feet long and of large girth. The most interesting find, however, was a canoe, or rather some 16 feet of one, hollowed out of a trunk, and which I was able, through the kindness of the engineers, to secure for the British Museum.

The old river-mud and its associated peaty beds often contain bones of ox, deer, &c., and shells of freshwater and land molluscs of the same species as those now living. Sections are rarely made in these beds, but the peat may be seen sometimes in the bed of the river at low water.

3. Made Ground.

In London, as in most large towns, there is a very general deposit of a purely artificial character, the result of the growth of the city, and of the changes that have taken place during a long time. In London this "made earth" is often of considerable thickness, and effectually masks the beds beneath, old stream-courses being more or less filled up and their peaty deposits hidden, and some small clay-slopes being, as it were, artificially covered with a sort of gravel. On the London Model there are some very small areas which, though coloured as gravel, really consist of a mass of this deposit hiding an old swamp or an outcrop of London Clay.

CHAPTER 7.

CAUSES THAT HAVE BROUGHT ABOUT THE PRESENT FEATURES OF THE DISTRICT.

The nature of all the formations and their usual features having been described in the foregoing pages, we can now consider the agencies that have effected those changes on the surface which have resulted in the present form of the ground. These subjects group themselves under two heads: firstly, the subterranean movements which have tended to shift beds from the more or less horizontal position that they originally had, and secondly, the natural forces that have tended to their destruction and removal.

1. Disturbances of the Beds and their Results.

The rocks in the neighbourhood of London are free from those foldings so often to be seen in districts composed of the older rocks, and the sudden displacements known as faults are both rare and small; nevertheless the whole tract has been subjected to a disturbance, which, though comparatively trifling in its amount of displacement, is of very wide extent, both in length and breadth. The disturbance in question is that which has caused the more or less parallel rolls that have resulted in bringing up the lower beds, in a gentle saddle-back, along the line of the Weald, with, on either side, the equally gentle troughs of the higher beds known as the Hampshire and London Basins. A glance at the sections published by the Geological Survey, which are drawn to the same scale horizontally and vertically, will best show the gentle character of this inward dip of the beds in the London Basin, and correct any previous notion of great disturbance that may have been formed; indeed, the sections of the model perhaps show lower angles of dip than are commonly supposed to occur, although these are somewhat exaggerated, from the vertical scale being greater than the horizontal.

The main trough is modified by smaller and more local lines of disturbance, such as those which bring up the Chalk to the surface in various places along the Valley of the Thames (at Windsor, from Deptford eastward, and between Purfleet and Grays), as well as between Bromley and Chiselhurst, or those which are less effective, causing merely inliers of some division of the Lower London Tertiaries, as at Eltham and Bromley (Kent).

There are also occasional faults (or fractures with displacement), but these are too small to be shown on a map, with the exception of one, which, running along the Thames Valley for some miles eastward from near New Cross, and sometimes with a downthrow on the north of 100 feet or more, has resulted in bringing the Blackheath pebble-bed against the Chalk, the same bed that occurs along the hill-top over Plumstead Common and Abbey Wood being also found beneath the marsh-land at its foot.

It is still, I fear, too commonly thought that the surface-features of the earth are directly due to the disturbing causes which have moved beds from their original positions, that the valleys are great cracks, and that the hills are areas of elevation. Now, although lines of disturbance may have often *guided* the forces that have actually carved out hills and valleys, yet such lines have in no way formed these features. Moreover, it will often be seen that the present surface-feature does not follow the underground arrangement of the beds, except, perhaps, in direction, for a hill may be found to be a geological trough, and a valley a geological saddle, and on examination this apparent parodox is easily explained, for it is where beds have been uplifted, and consequently dip outwards, that they are more favourably exposed to those agencies which constantly tend to their destruction, whilst where they dip inwards there is less tendency for their parts to separate and fall away. It is to these agencies that we must now turn to account for the present state of our district.

2. Denudation, its Nature and Effects.

On looking at a geological section, it will be seen that beds end off abruptly on hill slopes (in such a district as ours); but that their original limit of deposition can have been thus the least reflection will show to be

impossible; they must once have stretched farther, and their present limit must therefore be owing to the parts beyond having been carried away. We have evidence of this denudation, or wearing away of beds, in the occurrence of outliers, or patches separated from the main mass, and often many miles from it, the tract between having been bared of the beds in question.

The only agent that is now doing this work, the only one of which we can see any sign in past times, is *water*, in some form or other, and this is indeed the only agent capable of doing the vast work of denudation. Every wave that beats on the shore aids in the breaking up or the removal of sand, shingle, or rock; every stream, however small and sluggish, carries down earth in its course, nay, more, every drop of rain that falls on the ground aids in the moving of some particle of earth.

The question that remains, then, is in what form has water done its work in our district? At the first thought, the vastness of the sea, and the fact that its power can be seen on our coasts, naturally lead people to infer that this has been the great agent in doing the work of denudation; but when we examine the district we find no trace of any late submergence, all the newest beds being of freshwater origin, and when we examine the sea's action we find that it results in the planing down and levelling of land rather than in the cutting out of valleys.

Turning then our eyes to the other great form of water, streams and rivers, we find that these have a constant action in wearing away the rocks over which they pass, carrying down the loosened or dissolved matter in their course; and by measuring the quantity of solid matter carried down by a certain quantity of water, and calculating the amount of water flowing down the stream we get the data needful for estimating the total quantity brought down in any given time. By these means it has been shown that in our island far more denudation, or wearing away of land, is now being done by rain and rivers than by the sea. It becomes indeed a question of time to a great extent, and we are led to conclude that the ceaseless actions of streams, aided by rain and frost (the last being a powerful disintegrator of rocks), during a long period, has been the great means of carving out our present system of hill and valley.

The marvellous effects of denudation in clearing away a great thickness of solid earth is perhaps best seen by mentally reconstructing, as it were, the former state of certain spots; thus the greater part of the London Clay, with some of the Lower Bagshot Sand, has been carried away from the valley of the Thames at London, whilst lower down the river, as at Purfleet, where the Chalk is now at the surface, the whole mass of the Tertiary beds (from the Lower Bagshot Series to the Thanet Sand), amounting to a thickness of more than 500 feet, has been removed.

It has been said before that the Chalk here and elsewhere has been brought up by disturbance: this must of course be understood in the sense that through a disturbance having brought the Chalk to a comparatively high level, subsequent denudation has laid bare that rock.

Were it not for disturbing agencies, therefore, we should not have various beds brought up so as to be within reach of the denuding forces, the work of which would be more limited to the higher beds; and were it not for denudation we should not have the variety of surface that adds such charm to our scenery, through the exposure of lower beds by the partial wearing off of those above, and from the varying outline that has resulted during the process.

INDEX OF PLACES.

The Names in Italics are those of Places beyond the District described.

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RNWALL, DEVON, and WEST SOMERSET. By Sir H. T. De La Beche, F.R.S. &c. 8vo. 14*s.*
ESCRIPTIONS of the PALÆOZOIC FOSSILS in the above Counties. By Professor Phillips, F.R.S.
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