MEMOIRS OF THE GEOLOGICAL SURVEY.

ENGLAND AND WALES.

THE GEOLOGY
OF THE
LONDON DISTRICT.

(BEING THE AREA INCLUDED IN THE FOUR SHEETS OF THE SPECIAL MAP OF LONDON.)

BY HORACE B. WOODWARD, F.R.S.

SECOND EDITION, REVISED,

BY C. E. N. BROMEHEAD, B.A.,
WITH NOTES ON THE PALÆONTOLOGY,
BY C. P. CHATWIN.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

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PREFACE TO THE FIRST EDITION.

The great cost of the hand-coloured edition of the one-inch Geological Map of London and its Environs having made it desirable to issue a less expensive map, the present colour-printed edition, covering almost the same area, was published in four sheets in 1903. Though largely founded on the work of Mr. Whitaker and his colleagues, as depicted on the earlier map, the new sheets include the results of a six-inch survey of parts of the Thames Valley, made in 1902 by Mr. T. I. Pocock and Mr. J. Allen Howe.

Mr. Woodward, who had taken part in the original Drift Survey of the area, superintended the progress of the new work, but owing to the pressure of other duties, was unable to write the necessary descriptive memoir during his official connection with the Survey. He very kindly volunteered to do this after his retirement, and the present volume is the result.

"The Guide to the Geology of London and the Neighbourhood," prepared by Mr. Whitaker and published in 1875, dealt with the area contained in the older map of London and its Environs. This work reached its sixth edition in 1901 and is now out of print. The present memoir describes the slightly smaller area embraced in the new map. While avoiding local detail, the author discusses generally the characters of the geological formations, and summarises the most recent views on the various problems presented by them. For this purpose he has revisited many parts of the area, and has also taken the opportunity to collect records of new sections.

No one can write on the geology of the neighbourhood of London without being indebted to the work of the late Sir J. Prestwich and of Mr. Whitaker. In the early memoir on "The Geology of the London Basin," and in the two volumes on "The Geology of London," Mr. Whitaker not only recorded all the facts gathered during the progress of the Geological Survey, but dealt fully with the observations of other geologists, adding his own criticism on divergent views. During the twenty years which have elapsed since the publication of the Geology of London much has been added to our knowledge, especially of the Plateau Drifts and the deposits of the Thames Valley, by the labours of Mr. M. A. C. Hinton, Mr. T. V. Holmes, Mr. A. S. Kennard, Mr. H. W. Monckton, Mr. E. T. Newton, Dr. A. E. Salter, Mr. S. H. Warren, and Mr. B. B. Woodward. The Chalk, during the same period, has been more particularly the subject of investigation by Mr. G. E. Dibley and Mr. G. W. Young. Though no effort has been spared by Mr. Woodward to acknowledge the sources of information, it has proved to be impossible to do justice to the voluminous literature within the limits of so small a memoir.

Mr. Whitaker and Mr. Clement Reid have furnished corrections and suggestions during the progress of the work, and the names of the fossils have been brought into accordance with modern nomenclature in the Palæontological Department. Assistance has been rendered also by Mr. H. A. Allen, Mr. G. Barrow, Mr. G. Clinch, Mr. T. V. Holmes and Mr. J. A. Howe.

J. J. H. TEALL,
Director.

Geological Survey Office,
28, Jermyn Street, London.
19th October, 1909.

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PREFACE TO THE SECOND EDITION.

In preparing a second edition of Mr. H. B. Woodward's memoir on the Geology of the London District it was necessary, as far as possible, to bring the information up to date and at the same time to effect some condensation wherever that could be done without impairing the usefulness of the book. The task was entrusted to Mr. Bromehead, who has had considerable experience of field work in the London District. He has been assisted by Mr. Chatwin, who has revised the palæontological information.

The Special London Map (in four sheets) is still on sale, but will be superseded in a few years by the New Series one-inch Sheets, of which Windsor (269) and South London (Sheet 270) are already published, with descriptive memoirs.

The relief model of the geology of London, exhibited in the Museum of Practical Geology, has recently been renovated and revised in accordance with the six-inch survey. It is illustrated by a special collection of rocks, fossils and other specimens.

Assistance in the preparation of this edition has been given by Mr. Henry Dewey, Mr. J. A. Howe, Dr. R. L. Sherlock and Mr. R. W. Pocock.

JOHN S. FLETT,
Director.

Geological Survey Office,
28, Jermyn Street, London, S.W.1.
12th May, 1922.

Errata on the Special London Map.

Some errors and omissions in colouring were unfortunately introduced on the one-inch map, in four sheets, colour-printed in 1903. They are as follows :—

Sheet 1.—A small tract of Plateau Gravel should have been indicated at Elstree village.

Sheet 2.—North-east of Aveley, in the south-eastern corner of the map, areas coloured Woolwich and Reading Beds on the north-east of Belhus Park, and north of the high-road west of Somers Heath, should be London Clay.

At Hornchurch Station, south of the village, the small tract coloured as Valley Gravel should be London Clay.

Sheet 3.—Areas coloured as Woolwich and Reading Beds, except on the borders of the Thanet Sands and Chalk at Ewell and Sutton, should be London Clay.

Sheet 4.—In the tract north of Eltham and south of Eltham Common, the symbol i^2 should be i^3.

The Alluvium should have been coloured to the eastern stream along the valley between Darenth and the Powder Mills south of Dartford.

At Crohamhurst the red stipple has been omitted from the outlier of Blackheath Beds, which is therefore wrongly shown as Woolwich Beds.

The whole area shown on the four sheets is covered by the New Series colour-printed one-inch maps, Sheets 255, 256, 257, *269*, *270* and 271; the sheets whose numbers are given in *italics* are already published and the remainder will be issued shortly. Instances where newer information or more detailed survey has led to modifications in the mapping are noted in the text of this memoir.

CONTENTS.

THE GEOLOGY OF THE LONDON DISTRICT.

CHAPTER I.

INTRODUCTION.

The four maps which it is our purpose to explain in this Memoir represent the surface geology of the London District. In this respect, however, they are not intended to depict the soils which are often but a few inches thick, and for the most part of too variable a nature to be defined on any plan. The maps show the extent of the strata or geological formations which occur immediately beneath the soil. They represent in fact the subsoils, a term commonly applied to the more or less weathered portions of the strata near the surface. The subject of soils and subsoils in this area is fully considered in a separate Memoir.[1]

In the present area the strata consist of gravel, sand, loam or brickearth, clay, marl, limestone, and peat; and they are grouped according to age, position and mode of origin, under names that denote the different geological formations. Examples are found in the Thames Valley Gravels, the Bagshot Sand, the Thames Valley Brickearth, the London Clay, the Boulder Clay (a chalky clay or marl), the Chalk (limestone), and the Peat which occurs in the Alluvium of the marshlands. These terms indicate for the most part the leading lithological characters, but, as will be learnt from the detailed descriptions, all the formations are subject more or less to changes in composition.

The formations represented in the area are tabulated in sequence on Sheet 4; and their order of succession has been proved by observation in pits and quarries, and by the records of wells and borings.

The thick mass of the Chalk forms the foundation of the entire area. It is in places overlain by the Eocene series, which is represented in and around London by the Thanet Sand and higher divisions up to the Bracklesham and Barton Beds.[2] This series occupies a shallow trough formed by the uplift and bending of the Chalk so as to constitute what is known as the London Basin; thus it covers that formation from Dartford

[1] 'Soils and Subsoils from a Sanitary Point of View, with especial reference to London and its Neighbourhood' (*Mem. Geol. Surv.*), by H. B. Woodward. 2nd Ed., 1906. 3rd Ed. in preparation.

[2] These last occur at St. George's Hill, south of Weybridge, but they are grouped with the Bracklesham Beds on the map.

and Croydon on the south-east to Watford and Rickmansworth on the north-west.

At one time Eocene strata extended over the entire area, and their present limits are due to the effects of erosion. Within the basin, however, there is evidence of the impersistence of two of the divisions, the Thanet Sand and Blackheath Pebble Beds, which do not extend underground through the north-western portions of the Basin, being overlapped or overstepped respectively by the Woolwich and Reading Beds and by the London Clay. Otherwise the sequence is maintained, and the absence of any member is due to denudation. Thus the Bagshot Beds, which at one time covered the whole of the area, excepting possibly the south-eastern parts, have been so much eroded that they now occur only in outlying patches.

All these formations of Chalk and Eocene, like the many other series which enter into the main structure of our country, constitute what is sometimes termed 'bed-rock.' They have otherwise been designated the 'Solid' formations, in distinction from the 'Drift' or superficial accumulations, such as the Boulder Clay and Valley Gravels, which belong to the later periods of Geology, and rest irregularly and indifferently on any of the so-called Solid strata.

In ordinary geological maps of England and Wales, on a small scale, the Drift deposits are omitted, owing to the difficulty of representing them and at the same time of showing the main structure of the country.

In the New Series Geological Survey map on the scale of an inch to four miles, both Drift and Solid editions of the eastern and south-eastern portions of England have been published, and a comparison of the two maps of the country around London is instructive. The more striking differences are in parts included in our present Sheets 2 and 3, where, in place of the large areas of Valley gravel and brickearth, the map of the Solid geology shows for the most part only London Clay.

For both practical and scientific purposes the Drift edition is the appropriate geological map of the London District.

The nature of the soil is of consequence only to the farmer and market gardener, and to them the subsoil is of equal importance. It is with the subsoil, not the soil, except in the case of artificial accumulations of made ground, that the architect, the physician, and the house-hunter are concerned.

Apart from the economic products of the area, the chapters in geological history that can be deciphered from the strata in the London District are of much greater interest than at first might be supposed. The ordinary citizen who has delved in his back-garden finds as a rule either interminable stones or a stiff unproductive brown clay. Of these two subsoils the brown clay is known as the London Clay; the stones that occur in such abundance belong for the most part to the Thames Valley Gravel.

As will be seen, they furnish records of two distinct chapters in geological history. The London Clay was accumulated in an estuary and sea to which was carried the mud of an ancient river long before the present physical features were developed, and when the climate, as indicated by fossil remains of animals and plants, was sub-tropical in character. The Valley Gravel belongs to early stages in the history of the Thames, when climatic conditions were at times like those of the present day, but with evidence of more torrential action than we now witness. The fossils of the gravel and its associated brickearth are of great interest, and include remains of mammoth, rhinoceros, hippopotamus and other animals long extinct in the area; and with them are found ancient stone implements manufactured by man. These Valley formations underlie the greater part of London between Islington and Camberwell and between Brentford and the Lea[1] Valley.

We have not, however, to go far north before we meet with other formations, the fine sands on Hampstead Heath, known as the Bagshot Beds, and the chalky clay full of stones and boulders at Finchley, known as the Boulder Clay, a product of the Ice Age; while on the south-east between Lewisham and Woolwich and Erith there are great excavations in the Chalk, a comparatively deep-sea formation, covered by shallow-water marine and estuarine Eocene strata.

The several geological formations thus have each a story that can be deciphered, of great changes in physical conditions and in life history. Although the record of events is far from complete in our present area, yet we are enabled to picture the successive scenes of deposition and denudation, and the forms of life, which lead up to those of the Pleistocene period with its relics of palæolithic man; while onwards we come to the Recent or Holocene period, which, beginning in Neolithic times, has a fairly connected record through the Bronze and Iron ages to historic times and the present day.

The story of London is usually reckoned to commence less than nineteen hundred years ago, when the Britons, who had established a kind of fortified settlement on the rising ground now dominated by St. Paul's Cathedral, were displaced by the Romans (about A.D. 43). The reasons for the selection of the site and the influence of the geology on the subsequent growth of the Metropolis are discussed in the last chapter.

For a study of the geology open sections of the strata are necessary; in and around London these are always numerous on account of the ever increasing works of the builder, though most of the pits and excavations are of a temporary nature. One object of the present work is to give such descriptions as may enable the student to identify the different formations in fresh exposures, and to further our knowledge by recording

[1] The spelling 'Lee' is more correct, but 'Lea' has been adopted on the maps.

additional facts. Another object is to summarize as far as possible our knowledge with respect to the method of origin of the strata, and to indicate the causes which have brought about the present features of hill and valley. Here it is true we have to deal with some controverted questions, but the problems connected with the origin and life-history of the strata and with the scenery of the Thames Valley are well calculated to arouse keen interest and stimulate research.

No account of the geology of London would, however, be complete without reference to other formations which lie beneath the foundation of Chalk, and have been proved by means of deep wells and borings.

Following the plan of the historian it is well to begin with the oldest records, and in this case with what is known of the underground as apart from the surface geology.

The following is a list of the Geological Formations known to occur in the London district :—

List of Geological Formations exposed in the Area and Proved by Boring.

			Thickness in feet—up to
		Drift.	
Quaternary	Recent or Holocene	Alluvium - - - - -	70
	Pleistocene -	Valley Brickearth - - - -	30
		Valley Gravel - - - -	50
		Boulder Clay - - - -	35
		Newer Plateau Gravel (Glacial) - - - -	20
		Plateau Brickearth and Clay-with-flints - -	30
		Solid.	
Tertiary or Kainozoic.	Pliocene ?	Older Plateau Gravel - -	15
	Eocene -	Barton Beds[1] - - - -	50
		Bracklesham Beds - -	100
		Bagshot Beds - - - -	120
		Claygate Beds[1] - - - -	110
		London Clay - - - -	450
		Blackheath Pebble Beds -	60
		Woolwich and Reading Beds -	80
		Thanet Sand - - - -	80
Secondary or Mesozoic	Cretaceous-	Chalk - - - - - -	700
		Upper Greensand - - - -	40
		Gault - -	240
		Lower Greensand - - - -	?
	Jurassic -	*Great Oolite* - - - - -	87
Palæozoic -	*Devonian.*		

[1] Not shown on the map.

The names in *italics* indicate formations and groups not exposed at the surface in the London district.

For details and further information generally on the subject, the reader is referred to the memoir on 'The Geology of London and of part of the Thames Valley,' by W. Whitaker (*Mem. Geol. Surv.*), 2 vols., 1889.

Reference may also be made to his 'Guide to the Geology of London and the neighbourhood,' Ed. 6, 1901, and to the Proceedings of the Geologists' Association, the Essex Naturalist, and other publications of local societies, in which are many papers and Reports of Excursions relating to the London District. The more important papers will be referred to in the subsequent pages.

CHAPTER II.

UNDERGROUND GEOLOGY.

PALÆOZOIC ROCKS.

At present the existence of the Palæozoic floor has been definitely proved at ten localities in our district. In two borings only has the age of the rocks composing the floor been ascertained by fossil evidence. At Meux's Brewery, Tottenham Court Road, fossils of marine Devonian facies, *Edmondia*, *Chonetes*, *Orthis*, *Rhynchonella*, and *Spirifer verneuili*, Murch., were recognised in 1878.[1]

From a boring at Otto Monsted's Works, Southall, made in 1911–12, fragments of fossil fishes of Old Red Sandstone type, *Holoptychius* and *Bothriolepis*, were obtained by Mr. E. Proctor.[2]

From the other borings (*see* Table, p. 9) which have reached Palæozoic rocks, red, grey, purple, and mottled sandstones and marls have been recorded. The question of their age was the subject of much discussion, Devonian, Carboniferous, and Triassic ('New Red') all being suggested. It was thought that the existence of marine Devonian rocks at Meux's Brewery rendered it unlikely that rocks of Old Red Sandstone type would also occur. Now that this association is definitely known, it is generally agreed that the rocks should be assigned to the Devonian System in every case.

The association of the two types may be paralleled in the South of Ireland, Pembrokeshire, and North Devon,[3] districts with which the Palæozoic rocks of the London area appear to be connected structurally by the great Armorican axis.

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[1] *Quart. Journ. Geol. Soc.*, vol. xxxiv, 1878, pp. 901, 903, 904.
[2] *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, pp. 78–83 and Plate x.
[3] Evans, Dr. J. W., in discussion of Mr. Proctor's paper (*op. cit.*).

It will be seen from the table that the depth below Ordnance datum to the Palæozoic rocks varies but little from 1,000 feet. The form of the Palæozoic platform has recently been discussed by Sir A. Strahan,[1] who showed that the contour of 1,000 indicates a slight ridge running north-west to south-east, under London, from which the levels fall in all directions except to the north-west. If, however, allowances are made for subsequent earth-movements, the shape of the platform when newer rocks were laid down against or over it is found to be different; the northern half of our area is high ground falling away rapidly to the south and gradually to the north-west (Plate C). There is as yet insufficient evidence to determine the strike of the ancient rocks; at Ware, 9¼ miles north of our boundary, and again at Cliffe, 12 miles east of Dartford, Silurian rocks underlie the Cretaceous, while at Bobbing, 23 miles east-south-east of the same town 156 ft. of Jurassic strata intervenes. So far as is known, the intermediate area is occupied by the Devonian rocks.

Jurassic Rocks.

Great Oolite.

Rocks belonging to the Great Oolite series have been definitely recognised beneath London. At Richmond, 87½ ft. of shelly and oolitic limestones with a band of fissile sandstone, has been grouped with the Great Oolite. The series was entered at a depth of 1,151 ft. from the surface. At Streatham, at a depth of 1,081 ft., 38½ ft. of oolitic limestones, clays and sandy beds may be assigned to the Fuller's Earth Rock and the upper part of the Great Oolite. At Meux's Brewery, at a depth of 1,002 ft., 64 ft. of limestones, some beds oolitic, with a seam of sand and a few quartz pebbles has been grouped with this series. Coaly fragments have been found in the strata, but these, in Professor Judd's opinion, might have belonged to 'actual Jurassic coal seams.'[2]

Thus we find, at depths of 1,000 feet and more under London, strata, the representatives of which come to the surface about 100 miles distant on the west. There is evidence, however, that the Jurassic strata occur under London in the form of a denuded anticline, as on the west and north-west the Kimmeridge Clay, Portland and Purbeck beds are the nearest of the exposed Jurassic rocks. On the east beneath Chatham, the Oxford Clay has been reached, and on the south-east higher Jurassic divisions occur. Over most of the central area, as may be seen in the table, these rocks are absent.

Cretaceous Rocks.

Lower Greensand.

The Lower Greensand is of great importance as a source of water supply, but it is absent over the greater part of the area.

[1] *Quart. Journ. Geol. Soc.*, vol. lxix, 1913, pp. lxx–xci, contour map, Plate A.
[2] *Quart. Journ. Geol. Soc.*, vol. xl, 1884, pp. 748, 749.

Only in the south-west has it been proved. At Ottershaw Park, 3 miles south-west of Chertsey, 12 feet of coarse brown quartz sand was encountered, and yielded a plentiful supply of water.[1] The bed is absent at Southall, but has been found in two borings near Slough, 2½ miles west of the boundary of our map, so that its eastern limit presumably passes out of our area to the west near the middle of the western margin. In the newer Slough boring, at the Motor Depôt, a thickness of 130 ft. has been proved, consisting mainly of fine brown sands with a band of clay 12 ft. thick, 83 ft. from the top.

Selbornian.

Under this title are included the beds known as Upper Greensand and Gault. The Gault, which consists of dark grey clays with pyrites, surmounted by grey sandy marl, has been met with in every deep boring that has been carried beneath the Chalk in the London District. It is usually fossiliferous and has at its base a pebbly layer with coprolites. The Upper Greensand on the northern side of the London Basin comprises, in the lower part, beds of siliceo-calcareous rock or malmstone which owes its texture to the silica derived from sponge-spicules, and in the upper part dark green sand which becomes marly in places and merges upward into the Chalk Marl. The formation is not persistent in this district, as it is replaced in some tracts, as at Bushey in Hertfordshire, by the upper clayey beds of the Gault. On account of the variable lithology, the two formations have been included under the name 'Selbornian,' as suggested by Jukes-Browne.

Along the southern side of the London Basin the Upper Greensand consists of beds of malmstone, a glauconitic sandstone, more or less micaceous and calcareous. These are represented by the 'firestone' and 'hearthstone' that outcrop north of Godstone and Reigate, at the foot of the North Downs, a little south of the limits of our map.

In deep borings, beds of greensand, sandy marl and clay, like those of the northern outcrop, were proved at Kentish Town and Crossness; and beds of sandstone resembling the southern type were encountered at Meux's Brewery, Richmond and Streatham. In a boring at Purley, below the depth of 467 ft., a thickness of 35 to 47 ft. was assigned to Upper Greensand, the Gault Clay being entered only for 8 feet; at Shoreham, in Kent, the thickness of Greensand was only 10 ft., succeeded by 226 ft. of Gault. At Ottershaw the section showed 25 ft. of marl followed by 15 ft. of hearthstone and firestone passing down gradually into typical Gault. From the table it will be seen that under London itself the thickness of the Selbornian is from 150 to 200 ft. In the south-west it

[1] 'Geology of Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, pp. 5 and 112, 113.

reaches 278 at Ottershaw. The figures at Southall and White Heather appear anomalous, possibly owing to the difficulty of fixing the level of the base of the Chalk.

The following is a tabular statement of the deeper borings in the district. Details of eight of these are given in Whitaker's 'Geology of London,' Vol. II.; the more recent may be found in 'London Wells,' or in the Memoirs on the Water Supply of Kent, Surrey and Essex. (*See* page 9.)

CHAPTER III.

CRETACEOUS ROCKS.

CHALK.

This formation of soft white limestone with flints, in many respects the most important in our district, attains a thickness of about 700 ft., but largely on account of the erosion to which it had been subjected prior to and during the deposition of the Eocene strata, the thickness is subject to considerable variation. The greatest development appears to be at Bushey, near Watford, about 710 ft.; the thickness at a number of points is given in the table of borings (p. 9). At East Horsley, south-west of Leatherhead and beyond the limits of our area, it reaches 817 ft.

The area included in the London Maps comprises only a small part of the broad outcrop of the Chalk which forms the rim of the London Basin. The southern margin is to be found in the North Downs, in the scarp which extends from Guildford to Boxhill, Merstham and Otford; while the northern margin occurs in the Chiltern Hills, the Dunstable, Luton and Royston Downs —in both cases beyond the limits of our map. From these heights (600 to 800 ft.) the Chalk dips in Surrey and Kent northward and north-westward, and in Buckinghamshire, Hertfordshire Bedfordshire and Essex southward and south-eastward towards the metropolitan area.

The nearest point in our district to the North Downs escarpment is at Shoreham on the borders of the Darent Valley (the home in his later years of Joseph Prestwich) in the vicinity of which both Lower and Middle Chalk are exposed (*see* below). Here and along the undulating uplands to Downe (where Darwin long resided) and onwards to the Sanderstead, Purley and Banstead Downs, we find the characteristic features of the Chalk, smooth undulating downs, capped on some of the higher grounds by a variable thickness of Clay-with-flints and loam (*see* Chapter VI.).

THE ZONES OF THE CHALK AND THEIR FOSSILS.

Formerly the Chalk was divided, according to its prevalent and conspicuous characters, into Chalk Marl, Chalk-without-flints, and Chalk-with-flints. This grouping is useful from some

TABLE OF BORINGS WHICH HAVE PASSED THROUGH THE CHALK IN THE LONDON AREA.

—	Bushey.	Loughton.	Southall.	Park Royal, Willesden.	White Heather, Willesden.	Willesden Junction.	Chiswick.	Kentish Town.	Tottenham Court Road.	Mile End.	Beckton.	Crossness.	Ottershaw.	Richmond.	Streatham.
Above O.D.	180	90	95	105	130	110	25	162	85	23	12½	6½	142½	17	110
Superficial Beds	6	—	26	—	—	—	30	—	22	20½	26	39	—	10½	10
Tertiary	—	243	269	359½	256	340	258	324½	136½	180½	102	98	649	242	231½
Chalk	685	650	702	624	590	580	655	645	655½	654	647	684	646	671	623
Selbornian	9	207	138	169	252	80	177½	144	188	20	200	187	278	217½	217
Lower Greensand	—	?	—	—	—	—	—	—	—	—	—	—	12	10 ?	—
Jurassic	—	—	—	—	—	—	—	—	64	—	—	—	—	87½	38½
Devonian	—	—	97	27½	902	—	179½	188½	80	—	45	52	—	207½	138
TOTAL DEPTH	700	1,100	1,232	1,180	2,000	1,000	1,300	1,302	1,146	875	1,020	1,060	1,585	1,446	1,258

points of view, inasmuch as flints characterize the higher portions of the Chalk. It is now further divided into zones, which are bands of rock each characterized by the occurrence of certain species and assemblages of fossils. These zones indicate successive stages in the animal population of the sea on the bed of which the Chalk was originally deposited; and a zone is denoted by the name of one distinctive species, the range of which usually corresponds with the upper and lower limits of the zone. Lists of fossils from each zone will be found in several of the papers referred to below. The following table summarizes the present zonal divisions of the Chalk recognized in this area :—

Upper Chalk; with many flints.	(9) Zone of Actinocamax quadratus.
	(8) ,, ,, Marsupites testudinarius : about 60 ft., with sub-zone of Uintacrinus at base.
	(7) ,, ,, Micraster coranguinum : up to 200 ft.
	(6) ,, ,, Micraster cortestudinarium : 40–50 ft.
' Chalk Rock ' at base -	(5) ,, ,, Holaster planus : 40–60 ft., with sub-zone of Heteroceras reussianum at base.
Middle Chalk - - -	(4) Zone of Terebratulina : up to 160 ft.
Melbourn Rock at base -	(3) ,, ,, Rhynchonella cuvieri : up to 70 ft.
Belemnite Marl at top -	(2) Zone of Holaster subglobosus : up to 100 ft., with sub-zone of Actinocamax plenus at top.
Lower Chalk - - -	
Chalk Marl with Chloritic Marl at base.	(1) ,, ,, Schloenbachia varians : 80 to 120 ft.

The divisions into Upper, Middle, and Lower Chalk are not shown on the special London maps, but will be indicated by colour on the new maps of the Beaconsfield and Dartford areas (Sheets 255 and 271). It is only along the eastern part of the southern margin of our district that the Lower Chalk crops out, while the Middle Chalk comes to the surface there and in the north-west corner. Of the former a small area occurs south of Shoreham, the pale green Belemnite Marls being visible in the railway cuttings, and beneath them soft white chalk of the Subglobosus zone, wherein the small sparsely-ribbed brachiopod *Rhynchonella mantelliana* (J. de C. Sowerby) is commonly found; these exposures are, of course, inaccessible to the public.

The Middle Chalk borders this outcrop in the Darent Valley and extends as far north as Lullingstone. It has also been traced in two tributary valleys on the east, round Upper and Lower Austin Lodge and again as far north as Maplescombe, the hard Melbourn Rock at the base forming a noticeable feature; to the west of the Darent the Middle Chalk enters our map from the south in two valleys situated half a mile east of Downe and of the Kent–Surrey boundary respectively.[1]

In the north-west the Middle Chalk occupies the valley of the Chess above Chorley Wood.

Examples of the zone-fossil of the lower of the two divisions of the Middle Chalk are commonly found. This small, inflated, closely-ribbed brachiopod (*Rhynchonella cuvieri* d'Orbigny) is often accompanied by the tongue-shaped shells of the bivalve *Inoceramus labiatus* (Schlotheim), marked by close concentric furrows. The higher zone is named after a very small brachiopod, *Terebratulina*, a shell rarely more than $\frac{1}{4}$ inch in length, and ornamented with radiating ribs which often bifurcate and bear tiny granules. At this horizon one finds occasional examples of the heart-shaped sea-urchin *Micraster*, which occurs abundantly in the higher zones of the Chalk. The characters of this urchin as found in the Terebratulina zone may be regarded as primitive in comparison with those from higher horizons. Thus we note the absolute smoothness of the narrow tract between the double rows of pores bounding the five sunken areas that mark the upper surface of the test (or shell). In higher zones the appearance of tiny plates along this tract forms one of the features by which the horizon of a Micraster can be determined. In the Terebratulina zone *Micraster corbovis* Forbes is the species usually met with. The thinness of the test is a notable feature. In either of the zones of the Middle Chalk one finds tests of the sea-urchin *Conulus castaneus* (Brongniart), sub-pentagonal in outline, and *C. subrotundus* Mantell, a globular form, distinguished from *C. castaneus* by its more circular outline and its dome-shaped upper surface. There occur also certain fossils which are not so restricted in range and may be found in various zones of the Chalk; these are referred to later.

The whole of the remainder of the Chalk shown on the four sheets of our map belongs to the upper division, and the distribution of the zones has been studied by several workers.[2] The Zone of *Holaster planus* surrounds the outcrops of Middle Chalk just mentioned; at its base is a band, usually about 5 feet in thickness, recognizable by a peculiar assemblage of shell-remains, mostly preserved as casts. Of these the commonest are univalves, the top-like shells *Trochus schlueteri* Woods, *T. berocscirense* Woods and *Solariella gemmata* (J. de C. Sowerby) being typical representatives. Among the bivalves are the finely-ribbed, mussel-like *Septifer lineatus* (J. de C. Sowerby) and a form of *Inoceramus* peculiar to this horizon, the small *I. costellatus*

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[1] Dewey, H., 'Summary of Progress for 1914' (*Mem. Geol. Surv.*), 1915, pp. 27, 28.

[2] *See especially* Young, G. W., 'Chalk Area of N.E. Surrey,' *Proc. Geol. Assoc.*, vol. xix, 1906, pp. 188–219; 'Chalk Area of W. Surrey,' *ibid.*, vol. xx, 1908, pp. 422–455; Dibley, G. E., 'Zonal Features of the Chalk in Rochester, Gravesend and Croydon Areas,' *ibid.*, vol. xvi, 1900, pp. 484–499; vol. xxix, 1918, pp. 68–105.

Woods. Small ammonites of the species *Pachydiscus peramplus* (Mantell) and *Prionocyclus neptuni* (Geinitz), the loosely-coiled, flat-whorled *Scaphites geinitzi* (d'Orbigny), and the round-whorled spiral *Heteroceras reussianum* (d'Orbigny) are typical of the cephalopoda found in this bed. Remains of sponges are notably common. On account of its peculiar fauna the horizon is known as the sub-zone of *Heteroceras reussianum*, the index-fossil being recognized by the flanges which are developed at intervals on the ribs running across the whorls.[1]

In some areas the chalk of this sub-zone is extremely hard, and often conspicuous by reason of the presence of green-coated nodules of phosphatic chalk and grains of the mineral glauconite. When this type of lithology is developed the bed is known as the Chalk Rock; as such it has been recognized in a boring at Egham, in the extreme west of our district.[2]

The Zone-fossil *Holaster planus* (Mantell), a smooth-tested sea-urchin, with flattened base and gently sloping upper surface, is found in the Reussianum sub-zone as well as in the rest of the Planus chalk. Certain Micrasters have the same range. Throughout the Planus chalk *Micraster leskei* Desmoulins is found with its 'areas' perfectly smooth, and is identified by this character and by the presence of a smooth, raised, unjointed ring round the border of the mouth. *Micraster præcursor* Rowe, as found in this zone, exhibits a zig-zag line between the two rows of tiny plates along the 'areas'; these 'sutures' and the slight inflation of the plates are characteristic of this horizon. *Echinocorys scutatus* Leske, a sea-urchin with oval outline and flattened base, wherein both mouth and anal openings are situated, is also an abundant fossil.

The Zone of *Micraster cortestudinarium* is well exposed near Purley Station, and is rich in fossils; among them we may note the large, thin-shelled sea-urchin *Holaster placenta* (Mantell), *Micraster præcursor* Rowe and *M. cortestudinarium* Goldfuss. In both species of *Micraster* the plates in the 'areas' are so strongly inflated that they are 'subdivided' in many examples. A gibbous form of *Echinocorys scutatus* is typical of this zone. The profusion of polyzoa adherent to shells and sea-urchins is also a noticeable feature.

On account of its thickness the Zone of *M. coranguinum* occupies by far the greater part of the total Chalk outcrop. It contains a large number of flints, mostly in bands of large nodules. It occupies much of the north-western outcrop, and in the south-east the area round Dartford and Farningham; it is also found in the isolated areas shown at Lewisham, Charlton, Woolwich, Plumstead, Chislehurst and Erith in Kent, and at Purfleet and West Thurrock in Essex.

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[1] *See* Woods, H., 'Mollusca of the Chalk Rock,' *Quart. Journ. Geol. Soc.* vol. lii, 1896, pp. 68–98; vol. liii, 1897, pp. 377–404.

[2] 'Geology of London' (*Mem. Geol. Surv.*), vol. ii, 1889, p. 196.

Fossils are scarce at the base of the zone, but occasional specimens of *Echinocorys scutatus* Leske and *Micraster præcursor* Rowe are found. The 'areas' in the latter are more advanced in subdivision than is the case in the preceding zone. In the upper two-thirds of the zone the Micrasters reach a stage of development known as the high-zonal type, distinguished by the appearance of a sharp cut between the two rows of plates in the 'areas.' The *Micraster præcursor* and *M. cortestudinarium* of lower horizons are here replaced by the typical *M. coranguinum* Leske and the wider *M. coranguinum* var. *latior* Rowe. In this upper portion of the zone the frequent occurrence of the conical sea-urchin *Conulus albogalerus* Leske is characteristic. Similar to *Micraster* but distinguished in form by its pyramidal shape, the sides of its upper surface sloping steeply from the central apical disc, is *Epiaster gibbus* (Lamarck), found also at this horizon.

The Marsupites Zone frequently yields fragments of the fossil from which it takes its name, but is more often recognized by the Uintacrinus band at its base; it has been traced along the southern outcrop from Ewell to Croydon, Keston, Orpington and so on, and also at the top of the exposures at Charlton. The Uintacrinus band is marked by the occurrence in it of the small arm-joints and irregular, polygonal, deeply-grooved plates of the stemless crinoid of that name; *Micraster coranguinum* Leske, *Echinocorys scutatus* Leske, and *Conulus albogalerus* Leske also occur in this band. Above is the Marsupites chalk, wherein remains of the stemless crinoid *Marsupites testudinarius* (Schlotheim), chiefly the six-sided, radiately ridged plates, are found. These are associated with the species previously mentioned, of which *Echinocorys scutatus* is represented by the variety *pyramidatus* Portlock.

Many species of fossils have a wide range in the Chalk zones, although detailed study has shown that variations in form can be correlated with zonal occurrence. Skeletons of sponges are frequently found, the commonest being *Porosphæra globularis* (Phillips), a small, usually spherical fossil, with minute canal-apertures over its surface; and *Ventriculites*, funnel-shaped or cylindrical, sometimes with 'root' attached, and often conspicuous on account of the light-brown colour of the iron replacement. Isolated cylindrical corals of the genus *Parasmilia* are fairly frequent: the ornament on the fine longitudinal ridges gives indication of the zone.[1]

Spines of the sea-urchin *Cidaris*, usually rod-like, are recognized by the close fret-saw like ridges; only rarely are they found still attached to the highly ornamented, spherical test. The spines of *C. clavigera* Koenig are typically club-shaped. Found in the Upper Chalk, *Rhynchonella plicatilis* (J. Sowerby) is marked by a sharply-folded margin. *Terebratula semiglobosa*

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[1] *See* Lang, W. D., *Proc. Zool. Soc.*, 1909, p. 285.

(J. Sowerby), a still more common brachiopod, has a smooth inflated shell and gently-folded margin; its beak is pierced by a tiny foramen. Various species of oysters have wide ranges,[1] as have also the scallop-shells *Pecten* (*Chlamys*) *cretosus* Defrance, with its numerous, narrow, slightly spiny ribs and *P.* (*Neithea*) *quinquecostata* J. Sowerby, distinguished by its prominent main ribs. *Spondylus spinosus* (J. Sowerby), marked by regular, strong, rounded ribs, often found with thick spines still attached, is among the commonest bivalves of the Chalk. *Inoceramus lamarcki* Parkinson, a large inflated bivalve with prismatic structure and a surface marked by strong concentric folds, and its larger and flatter variety *cuvieri* J. Sowerby, have a wide range in the Middle and Upper Chalk. Vertebrates are represented chiefly by fishes, of which the sharp teeth of the shark *Lamna* and the crushing palatal teeth of *Ptychodus*, with their shiny rugose surface, are typical. Scales and fin-rays of the bony fishes, sometimes representing the complete skeleton, such as *Hoplopteryx*, are also preserved.

Of the various bands recognized by their lithological characters, the Chalk Rock is known over a great part of the country; in the south-eastern part of our area it is not always to be found, though the same horizon, as determined by fossils, can be traced, as stated above. The Melbourn Rock is also nodular. On the north-west side of London a local development of grey somewhat gritty chalk immediately above the Chalk Marl is known as 'Totternhoe Stone'; it likewise contains phosphatic nodules. As their names indicate, these three bands are all harder than the bulk of the Chalk. The 'Glauconitic' or 'Chloritic Marl' at the base of the formation forms a kind of passage from the Upper Greensand.

The total thickness of the Chalk in the boring at Ottershaw suggests that the Marsupites zone underlies the Tertiary strata there, as also at Richmond and Southall. The Quadratus Zone may be present at Egham, where the boring already mentioned shows 346 feet of chalk above the Chalk Rock. The still higher Zones of *Belemnitella mucronata* and *Ostrea lunata* do not occur anywhere in the London District.

On comparing Sheet 4 of the London Map with the newer Dartford Sheet (271) it will be seen that the Chalk outcrop between Plumstead and Erith is continuous on the latter, the faulted mass of Blackheath Beds shown on the former being omitted. This discrepancy is explained below (p. 37).

Conditions of Formation.

That the Chalk was deposited in moderately deep and clear water is inferred from the nature of the materials forming the mass of the rock, rather than from the more conspicuous organic

[1] For figures and descriptions of these and other Chalk bivalves *see* Woods, H., "Cretaceous Lamellibranchia of England," *Pal. Soc.*, 1899–1912.

remains. Indeed, it is held that some of the forms of life found in the Chalk must have drifted from shallower waters. Under the microscope foraminifera (*Globigerina*, etc.) ostracods, fragments of corals, crinoids, echinoids, bryozoa, brachiopods and molluscs, of a calcareous nature, may sometimes be detected, together with other organisms having siliceous structures such as certain sponges, diatoms and radiolaria (*Polycystina*). There are also minute oval bodies called Coccoliths, some of which appear to be organic, and there is much amorphous material that may be in part detrital, while portions may have been voided by fishes and other animals. The calcareous constituents formed a kind of ooze of fairly uniform composition over wide areas, akin to accumulations now taking place under the deep water of the Atlantic. In reference to this it is interesting to notice that in 1863 S. P. Woodward described a new and anomalous genus of echinoid from the Chalk of Kent under the name *Echinothuria floris*[1]—one example was obtained from Charlton. He then remarked that 'it seems to indicate the former existence of a family or tribe of creatures whose full history must ever remain unknown.' Ten years later C. Wyville Thomson in his 'Depths of the Sea' founded the family Echinothuridæ to contain the original genus, together with two recent forms brought to light by the deep-sea dredgings in the Atlantic.

The nodules which occur at several horizons in the Chalk may have been formed and partially rolled in tracts where the deposit had to some extent been consolidated, and they appear to indicate shallower conditions than the mass of the Chalk.[2]

In 1857 Godwin-Austen obtained from the Chalk at Haling pit, near Croydon, a waterworn boulder of granite and pebbles of other rocks, which in his opinion had been transported from a beach by a berg derived from coast-ice. Other erratic stones have since been found in the Chalk, and the problem of their origin may be variously explained. Drifted tree-trunks with gravel adhering to the roots may have been one cause, and it was suggested by H. G. Seeley[3] that pebbles may have been transported by some of the larger fishes and saurians, whose habits of swallowing stones are now well known.

Flint.

The origin of the nodules and bands of flint has ever been a source of wonder and curiosity. The nodules and some of the more regular bands are due to the concentration or segregation of siliceous matter from the soft calcareous ooze from which the bulk of the Chalk was formed. The siliceous matter in the

[1] Named after J. Wickham Flower, of Croydon; *Geologist*, vol. vi, 1863, p. 327.

[2] Jukes-Browne, A. J., 'Cretaceous Rocks of Britain' (*Mem. Geol. Surv.*), vol. iii, 1904, pp. 361, etc.

[3] 'Handbook of the London Geological Field Class,' 1891, p. 91. *See also* Stebbing, W. P. D., *Quart. Journ. Geol. Soc.*, vol. liii, 1897, p. 213.

first instance was derived from the sea-water by those organisms which have siliceous structures, certain sponges, diatoms and radiolaria. The decay of these organisms led to the diffusion of much siliceous matter in the soft calcareous ooze, and it appears to have become concentrated in certain fairly regular layers, from which it segregated into nodules or into thin bands probably in the soft calcareous mud during the process of consolidation. It formed around many kinds of nucleus—a tooth of fish or saurian, an echinoid or brachiopod—and some of the fossils became entirely replaced by flint. Sponges themselves more frequently than other forms of life were enveloped, because they contributed to the siliceous covering. Hence we often find thin-shelled flints enclosing sponges and with them bryozoa, foraminifera, &c.

There are also veins of flint which traverse the strata obliquely, and these must have been produced after the Chalk was consolidated and the flint bands and nodules (which they intersect) were formed.

The decay of flint gives rise to a white siliceous crust, and pebbles wholly made of such material are sometimes found in Tertiary and Drift deposits. What are called 'banded flints' occur both in the Chalk and in the form of pebbles derived from it. They appear to have been due to infiltration or the deposition of impure siliceous matter in cavities in the flints.[1]

The nature, formation and varieties of flint have been fully discussed by William Hill, whose paper gives many references to detailed work on these questions;[2] more recently these questions have been studied by Mr. W. A. Richardson in the light of new knowledge concerning the chemistry and physics of colloids.[3]

CHAPTER IV.

EOCENE ROCKS.

The Lower Eocene strata rest on the Chalk in apparent conformity, the flint-layers in that rock being approximately parallel, when seen in sections, with the bedding in the overlying formations. Nevertheless there is a great break between the Cretaceous and the Eocene. This is marked by the change in physical conditions, from the deep water of the Chalk to the comparatively shallow water of the Thanet Beds, by the absence in this country of any passage beds, by the occurrence of tiny fragments of flint in the Thanet Beds and of flint-pebbles in

[1] S. P. Woodward, *Geol. Mag.*, 1864, p. 145.
[2] 'Flint and Chert,' *Proc. Geol. Assoc.*, vol. xxii, 1911, pp. 61–94.
[3] *Geol. Mag.*, 1919, pp. 535–547; *see also* Brydone, R. M., *ibid.*, 1920, pp. 401–404.

the higher divisions of the Eocene, and by a great change in the organic remains.

It was held by Prestwich as far back as 1852 that the uplift of the Wealden anticline commenced in early Eocene times, and flint-pebbles were formed on the shores during the earliest stages of the period, and further formed or redistributed at successive stages. Other tracts of Chalk must similarly have been upraised, and although it is difficult to decide how much was eroded by marine action during the Eocene period, it is certain that considerable thicknesses of Chalk were removed from the London District before the deposition of the Eocene strata, probably in part by subaerial agencies. In 1911 Mr. Dewey discovered pebbles and fragments of Lower Greensand Chert in the pebble-bed which marks the base of the Barton Sands at several localities a few miles to the north of Woking (beyond our western limit).[1] This material has not been found in any of the older Eocene pebble beds; it may therefore be concluded that the Lower Greensand was first exposed to denudation in the Weald during Upper Eocene times.

The unconformity between the two systems is to some extent indicated by the varying thickness of the Chalk beneath the Eocene covering, and has been clearly demonstrated by detailed studies of the zones of the Chalk.[2] Thus the Marsupites zone which extends over a considerable area in the south-eastern part of our district is not known in the northern part. Moreover, there is no evidence in the district of the Zones of *Belemnitella mucronata* and *Ostrea lunata* elsewhere present in England. Still higher zones of Chalk occur in Denmark, Holland and Belgium. Further, it is clear that, before the plain of marine erosion on which the Tertiary strata rest had been cut, the Chalk had been thrown into gentle folds; in the western part of the area these folds appear to run approximately east and west,[3] but may perhaps swing round to the north under Central London.[4]

The term 'Lower London Tertiaries' has been used by Prestwich and Mr. Whitaker for the Thanet Sand, Woolwich and Reading Beds, and Blackheath Beds.

Thanet Beds.

The Thanet Beds, the oldest of our Eocene strata, are exposed only along the southern and eastern sides of the London District. On the four sheets of the London Map they are coloured pale brown with a yellow stipple, but on the newer maps (Sheets 270 and 271) a slate-blue tint, stipples being reserved for pebble-beds. The main outcrop runs from Ewell to Croydon, Farnborough, along the Cray Valley to Erith, and across the Thames

[1] 'Geology of Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, p. 53.

[2] 'Cretaceous Rocks of Britain' (*Mem. Geol. Surv.*), vol. iii, 1904, p. 172, and references in previous chapter.

[3] 'Geology of Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, p. 14.

[4] Baker, H. A , *Geol. Mag.*, 1918, pp. 296–305.

to Purfleet. South and east of this line there are extensive outliers, north and west an outcrop along the river cliff from Lewisham to Erith and inliers near Bromley. Underground the beds thin out to the north-west, the limit running approximately through Hendon, Ealing, Sunbury and Weybridge.

The Thanet Beds consist mainly of fine sand, passing down into a silt, and attain a thickness of nearly 70 feet in this district; in the most westerly outcrop near Ewell they do not exceed 15 feet. In colour they are buff or pale greenish-grey and speckly, but often they appear very pale and, at a distance, almost as white as chalk.

At the base there is a layer of green loam with green-coated flints known as the 'Bull Head Bed'; though worn or corroded flints occur here and there the majority are unworn. Where the Bull Head Bed happens to coincide with a layer of flints in the Chalk, the nodules may be green-coated above and unaltered below; at Stone, near Dartford, some of them appear to have been shattered and re-cemented by secondary flint.[1] The green colour is due to silicate of iron. The green sand at the base consists of quartz 45 per cent., flint 20, glauconite 15, together with felspar, magnetite, spinel, zircon, rutile, tourmaline, etc. In the higher beds the percentage of flint falls to about 5.[2]

The junction with the Chalk is usually even and seemingly conformable; occasionally the Thanet Beds rest in widely scooped hollows in the Chalk,[3] and near the present margin of the deposit may descend into 'pipes'; both phenomena are, however, due to solution of the Chalk in post-Eocene times.

The Thanet Sands are mainly of marine origin, though it is possible that the distinction between the fluviatile, estuarine and marine phases of the Reading and the Woolwich Beds (*see* below) is foreshadowed in the upper part of the sands.[4]

Few fossils have been found in these strata in the London District, and they are poorly preserved, being mostly in the form of casts. They include remains of fish, the bivalve shells *Cyprina* and *Pholadomya* and the univalve *Pyrula*. The beds can be assigned to the zones of *Pholadomya konincki* and *Cyprina morrisi* in the Lower Landenian of continental authors.[5]

The Thanet Sands are exposed in road-cuttings and pits at Beddington, in railway-cuttings between St. Mary's Cray and Farningham Road, at Dartford, and in extensive pits at Crayford, Erith and Charlton; they stand firmly in almost vertical faces. The beds are well seen at Purfleet, and in neighbouring parts of Essex; the sand is occasionally indurated into masses like greywether or sarsen stone.[6]

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[1] Priest, S., *Proc. Geol. Assoc.*, vol. xxvi, 1915, pp. 81–85.

[2] Gardiner, Miss M. I., 'The Greensand Bed at the Base of the Thanet Sand,' *Quart. Journ. Geol. Soc.*, vol. xliv, 1888, pp. 755–760.

[3] Stamp, L. D., and S. Priest, 'Geology of the Swanscombe Outlier,' *Proc Geol. Assoc.*, vol. xxxi, 1920, p. 188.

[4] Baker, H. A., *Geol. Mag.*, 1920, p. 420.

[5] Stamp, L. D., *op. cit.*, p. 190.

[6] Hinton, M. A. C., and A. S. Kennard, *Essex Nat.*, vol. xi, 1901, p. 342.

Allophane,[1] a hydrated silicate of alumina and lime, has been found in a nodular form at Charlton, Plumstead, and other localities in fissures of the Chalk at the junction with the Thanet Sand.

Woolwich and Reading Beds.

This formation is present everywhere beneath the London Clay in the district under consideration. It overlies the Thanet Beds in the southern and eastern tracts, but beyond the western limit of that formation, as given above, rests directly upon the Chalk.

The Woolwich and Reading Beds comprise a variable group of sands, pebble-beds and clays, with occasional hard calcareous bands, concretionary masses of siliceous greywether sandstone, and puddingstone. The sands are white, grey and occasionally crimson. The clays, for the most part brightly coloured, especially in the Reading facies, include red and mottled 'plastic clay' and green, grey and brown bands. 'Race' (concretions of carbonate of lime), selenite, iron pyrites, lignite, and seams of black lignitic clay occur in the formation. The pebble-beds are formed almost wholly of flint pebbles, and are met with at various horizons.

The term 'Woolwich and Reading Beds' was given by Prestwich to indicate different phases of deposition. The Woolwich Beds, which in East Kent are entirely marine, become estuarine and fluviatile in character at Woolwich and Dulwich, while in the neighbourhood of Reading the mass of the formation appears to be of freshwater origin, the product of an Eocene river, and to this set of strata the term Reading Beds is applied, although an estuarine bed usually occurs at the base. Many plant remains have been found at Reading, but others have been met with in the strata at Lewisham and Mottingham, so that the limit of the two phases is naturally very indefinite. Moreover, the Reading plant-bed may be slightly older than that in West Kent.

The estuarine bed at the base is persistent throughout the formation and is often referred to as the 'Bottom Bed' to distinguish it from the 'Basement Bed' of the London Clay. Like that below the Thanet Sand, it consists of greenish sand with unworn flints and flint pebbles, and an oyster bed with *Ostrea bellovacensis* Lamarck. The top of the underlying strata usually shows borings made by molluscs or other marine organisms. Where the Thanet Beds are present the Bottom Bed rests sometimes on an even surface of the sands, sometimes irregularly on them, the flints, which are always pebbles, being 'splashed into' the sands. At Swanscombe the Bottom Bed has yielded several fossils, mostly bivalves of a marine type;[2]

[1] Or more probably Halloysite.

[2] Stamp, L. D., and S. Priest, 'Geology of the Swanscombe Outlier,' *Proc. Geol. Assoc.*, vol. xxxi, 1920, p. 188.

Pectunculus terebratularis Lamarck, a large, thick, sub-orbicular shell, and the small, oval *Corbula regulbiensis* Morris are among the commonest. *Protocardia*, *Modiola*, a species of oyster (probably *Ostrea heteroclita* Deshayes), and sharks' teeth of the genus *Lamna* have also been found. The Bottom Bed represents the zone of *Cyprina scutellaria*.

In deposits of the Woolwich type there are definite shell-beds consisting of clay crowded with estuarine species. Among these are the trigonal bivalve *Cyrena cordata* Morris, the longer and more angular *C. cuneiformis* Férussac, and the oysters *Ostrea bellovacensis* Lamarck and *O. tenera* J. Sowerby. The univalves include the long-spired *Melania inquinata* Defrance, ornamented with blunt spines on the angular keel that runs along the whorls, *Potamides* (*Tympanotonus*) *funatum* (Mantell) and *Melanopsis buccinoidea* Férussac. Beds with freshwater shells contain mostly univalves, with occasional examples of the freshwater mussel *Unio*. *Viviparus lentus* (Solander), commonly known as *Paludina*, a short-spired, round-whorled, unornamented species, is probably the commonest of the univalves. Several species of *Neritina*, some with wavy colour-stripes still preserved, are recorded, as well as *Planorbis*, *Limnœa*, and *Pitharella*, while the tiny shells of *Hydrobia* occur in profusion.[1] Further interest attaches to the fossils of these beds by the discovery near Croydon of the remains of a large running-bird *Gastornis klaasseni* E.T. Newton, related probably to the goose-like birds, and bones of *Coryphodon croydonensis* E. T. Newton, a large, five-toed, herbivorous mammal. The fossils as a whole were considered by Prestwich to be indicative of a climate somewhat warmer than that of the Thanet Sand epoch.

The total thickness of the series varies from 40 to 90 ft., averaging about 70 ft. Along the southern outcrop there are good sections round Ewell and Sutton; that at Cheam Brickyard in 1913 was as follows:—

	Ft.
Clayey gravel (Pleistocene) - - - - - - - - -	2–5
Sand and loam, pink, grey, light green, buff, yellow and light mauve -	5–6
Grey-green clay, weathering buff - - - - - - - -	3
Mottled clay, crimson, magenta, yellow, grey and green - -	7
Sandy loam, green and glauconitic - - - - - - - - - }	7
Pebble bed with green-coated flints scattered through loam 3 ft. - }	
Grey clay with race and nodules - - - - - - -	3
Thanet Sand - - - - - - - - - - - seen to	7

The dip was 6° a little east of north.

At the famous Nonsuch Pottery sharks' teeth are frequent in the lower beds. Round Croydon many sections have shown the great variability of the formation; the shell-bed has yielded vertebrate fossils and is underlain by mottled clay of the Reading type. The most famous sections were at Lewisham (Loam Pit Hill) and Charlton[2] but are for the most part built over and

[1] For a list of fossils from the Woolwich freshwater bed, *see* 'Geology of South London' (*Mem. Geol. Surv.*), 1921, p. 22.

[2] *See* 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 148, 154.

obscured. The freshwater bed has been found in the bed of the Thames at Limehouse Reach, at Dulwich, Peckham, the north end of Elmstead Tunnel, Beckenham, Beddington and Brockley. At the last named locality a seam crowded with *Viviparus, Unio*, etc., is still (1921) visible in a brickyard beside the Brighton Railway 1 mile south of New Cross Station. The distribution of the plant beds is similar.

A number of sections at and near East Wickham show how the Blackheath pebble-beds cut into the Woolwich Beds in scoops of varying depths; sometimes the upper sandy beds of the latter are present up to a thickness of 15 feet, while in a neighbouring section both these and the shell-beds are cut out, leaving only a varying amount of the Bottom Bed present.[1] The same phenomenon is well seen in the Erith sand pits, where 14 feet of shell-beds found at the south-east are completely cut out at the west end;[2] in some parts of the pit the strata below the shell-bed consist of sand which can only be distinguished from Thanet by the presence of the Bottom Bed between the two.

On the eastern margin of the area, between Greenhithe and Green Street Green the Bottom Bed is ferruginous, and appears to have been worked as an iron-ore in Lord's Wood. The shell-bed is sometimes very prolific and besides the usual forms yields the freshwater univalve *Neritina*, some specimens retaining the original colour-stripes.

Under London, on the northern side of the Thames, the strata belong for the most part to the Reading type, and, as noted by Mr. Barrow, they consist in the upper part of mottled clay occasionally divided by a band of loam and sand, the united thickness in one place between Euston and Hampstead Road being as much as 58 ft.; underneath these occur about 20 ft. of green sands with pebbles and clays and then 18 ft. of sand; the lower 12½ ft. are referred to Thanet Sand.[3] It is difficult to decide from records of shafts and borings where the junction of Reading and Thanet Beds should be taken; nor is it always possible to decide in open sections, as at Ewell and Erith.

The green sands and clays in the Rotherhithe Tunnel included at the base a bed with *Ostrea tenera*, 4 ft. thick, while the shell-bed contained a seam of limestone and a lenticle of peat.

Mr. Barrow observed that the junction with the London Clay in the Tube Railways north of the Thames was clear and sharp; but occasionally the beds are faulted (*see* p. 39).

In certain areas the Woolwich and Reading Beds immediately underlie the river deposits. At Deptford the Chalk reaches

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[1] Leach, A. L. and B. C. Polkinghorne, 'Excursion to East Wickham and Bostall Heath,' *Proc. Geol. Assoc.*, vol. xix, 1906, pp. 341–347.

[2] Chandler, R. H., and A. L. Leach, 'Excursion to Erith,' *Proc. Geol. Assoc.* vol. xxiii, 1912, pp. 183–185.

[3] 'Summary of Progress for 1905' (*Mem. Geol. Surv.*), 1906, pp. 168–170.

this position with annular outcrops of Thanet and Woolwich Beds, indicating a dome-like structure. The Woolwich Beds run from the surface outcrop near Camberwell through Rotherhithe and the Isle of Dogs to Greenwich Marshes and thence into Essex under Plaistow Marsh and East Ham Level, having been proved at Beckton Gas Works.

In the valley of the Lea is another dome, somewhat elongated, bringing the Woolwich Beds up round Leyton; it extends from Lea Bridge to Stratford and includes the freshwater bed which has been detected in several excavations. The boundaries of these outcrops will be shown on the New Series Maps, Sheets 256 and 270.

The north-western outcrop (Sheet 1 of the map) extends from near Radlett (where the Midland Railway leaves the area of the map) south-westwards through Bushey to Moor Park, south of Rickmansworth, and thence southwards along both sides of the Colne Valley. The Reading Beds also form the surface in the low-lying areas of Pinner, Northwood, Ruislip and Ickenham. Local peculiarities are the large proportion of sand in the strata and the replacement of the usual Bottom Bed by a seam of pebbles 4 to 6 ft. thick. Blocks of sarsen and of Hertfordshire puddingstone are abundant in the drift of this district and have apparently been derived from the Reading Beds; the puddingstone has been observed *in situ* towards the top of the series near Radlett and elsewhere. Both rocks have been formed by the deposition of secondary silica, cementing a sand or a pebble bed respectively. The total thickness of the formation is about 40 ft. at Bushey and Watford, but further south, where the mottled clay becomes prominent, as much as 96 feet has been recorded at Hillingdon.

At Battlersgreen in the north the following section has been noted in several pits :—

			Ft.
Drift gravel (irregular capping).			
Reading Beds.	Brown clay passing down into red, mottled and pale clay - - - - - - - - - -	about	4
	White sand with layer of flint pebbles at base -	about	2
	Green sand - - - - - - - - -	about	1
	Bedded loam with a thin band of small flint pebbles near top, passing down into bedded loams and sands with occasional pebbles - - - -	at least	12

Round Bushey there were formerly many good exposures; the lower part of the series remains fairly constant, but the mottled clay at the top increases rapidly to the south and south-east from about 5 to 35 feet, with corresponding increase in the total thickness. At Oxhey and Northwood however the sand is predominant and the Bottom Bed is seen in Moor Park to consist of pebbles in a sandy matrix to a thickness of 6 ft. The Brick and Cement Works at Harefield reveal a complete section as follows :—

		Ft.
London Clay		20
Reading Beds.	Mottled plastic clay	23
	Brown sand, clayey in parts	8
	Grey sand and clay (impersistent)	1½
	Pebble-bed passing down into green sand with green-coated flints	2½
Chalk.		

On the west and north of the Colne several outliers of Reading Beds occur beneath the glacial gravels, as for instance at Croxley Green, but these cannot be shown on the map.

At Ickenham, Ruislip and Pinner the formation consists largely of mottled clay, and the same is true of the beds proved by borings under the cover of London Clay over the greater part of the area shown on Sheet 1.

It should be mentioned that in Sheet 3 there is an unfortunate error in the colouring. The numerous small outcrops, coloured as ' Woolwich and Reading Beds ' in valleys cut through the Thames river-gravels and in valleys between the gravel terraces, are all London Clay, and are shown as such on the New Series Maps of Windsor (269) and South London (270). The only outcrop of Woolwich and Reading Beds in Sheet 3 lies around Ewell and Sutton and has already been described.

Blackheath Beds.

This division is locally developed in the south-eastern and eastern parts of the London District.

It consists in the main of pebble-beds and sands, the pebbles being almost wholly formed of flint, rarely of sarsen, and the sand of quartz with some flint chips and heavy minerals. They are occasionally cemented by calcareous, ferruginous, or siliceous matter, forming a conglomerate.

Originally grouped for the most part with the Basement Bed of the London Clay by Prestwich, the pebble-beds and sands were separated in 1866 by Mr. Whitaker and designated the Oldhaven Beds from a locality between Herne Bay and Reculvers. Subsequently he applied the term Oldhaven and Blackheath Beds, the eastern type being sandy and the western pebbly, but for purposes of local designation in the London District the latter name only is used. The beds rest irregularly on the Woolwich and Reading Series, locally cutting through many layers even down to the Thanet Beds; while to the south the beds transgress on to the Chalk near Caterham and Worms Heath and also at Knockmill, as shown in the extreme south-east corner of the map, and thus have derived flint to form pebbles directly from that formation.

The fossils of the Blackheath Beds include estuarine, marine, and freshwater shells; and among the various forms relationship can be traced with species of the preceding Woolwich and

Reading series and the later-deposited London Clay. Some estuarine and freshwater species are survivors from the former, certain marine species are new-comers and range into the London Clay, while others returned with changed geographical conditions. On the grounds that an incoming fauna is a more important criterion of age than surviving species Dr. Stamp[1] correlates the Blackheath Beds with the Lower Ypresian. A typical shell of these beds is the common and variable bivalve *Pectunculus plumsteadiensis* J. Sowerby, less inflated and with a less prominent umbo than *P. terebratularis* Lamarck, from the Woolwich Beds; *Neritina globulus* Férussac, a thin-shelled, sub-globose univalve, with flattened spire and a sharp, semicircular mouth, is also common and characteristic. We may note also the globular *Natica labellata* Lamarck, with its well-developed spire, and the mussel-like bivalve *Modiola mitchelli* Morris.

The division is in the main a lithological one, a local accumulation of marine and estuarine shingle and sand, derived no doubt in part from pre-existing pebble-beds; the light-grey ovoid pebbles frequently referred to as 'quartzite' are in many, if not all cases, composed of sarsen stone;[2] they occur sparingly but may be found by careful search in almost every exposure.

The wooded hill of Crohamhurst, south-east of Croydon, and the fine scarp of the Addington Hills on the east are formed of the Blackheath pebble-beds which attain a thickness of about 50 ft., and with some underlying sands perhaps 20 ft. more. These in places overlap the Woolwich and Reading Beds and rest directly on the Thanet Sand. At Park Hill, Croydon, the pebble-bed, which is fossiliferous, occurs at the base with sand above and rests in a hollow cut partly in the upper clay and shell-bed and partly in the mottled clay of the Woolwich and Reading Beds. At Beckenham the pebble-bed yields many large specimens of oysters, some with the ligament preserved.

Fine sections of the pebble-beds have been opened up in the neighbourhood of Chislehurst by Camden Park, and in the Sundridge Park Rock-Pit and adjacent railway cutting. Here indurated layers of the pebble beds and sandstone occur at various horizons and yield many fossils, including both freshwater and marine forms.

Northwards the Blackheath Beds are exposed in various places from Blackheath to Erith and Crayford, the sections at East Wickham being specially notable. On the extreme eastern margin of the area, at Mounts Wood and Bean the whole series does not exceed 5 feet in thickness and may be absent here and there, though the pebble-beds come in again in force near Cobham.

From boring records it is difficult to distinguish between the Blackheath Beds and the Basement Bed of the London Clay, or

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[1] *Proc. Geol. Assoc.*, vol. xxxi, 1920, p. 192.

[2] Baker, H. A., 'Quartzite Pebbles of the Oldhaven Beds,' *Geol. Mag.*, 1920, pp. 62–70.

the sands and pebbles of the Woolwich and Reading Series. An approximate line for the western and northern limits of the Blackheath Beds may be drawn from Croydon and Thornton Heath to Lewisham and the neighbourhood of Stratford and thence north-eastwards roughly along the line of the Colchester Road.

London Clay.

On account both of its thickness and of the area occupied at the surface the London Clay is, as might be supposed, the most important formation of the district.

It consists of a stiff clay of dark grey or bluish-grey colour; when exposed at the surface, however, it is brown owing to the conversion of ferrous oxide to ferric oxide by weathering; a few feet down, where the process is not complete, the clay is frequently mottled.

The lowest part of the formation comprises a sandy bed with black flint pebbles and occasional layers of sandstone, and is known as the Basement Bed. Towards the top a varying thickness of alternating seams of clay and sand form a passage to the overlying Bagshot Sand. Recently it has been found desirable to separate these passage beds under the name of 'Claygate Beds,'[1] and in reading accounts of sections written previously to 1912 it must be remembered that this upper division is included under the term 'London Clay.'

Although the main mass is a stiff clay, it sometimes presents a silty appearance difficult to distinguish from alluvial clay that has no doubt been largely derived from the London Clay. In foundations for the Gaiety Restaurant this was the case, and had it not been for a floor of septaria it would have been difficult to decide that the London Clay had been reached.

These septaria or cement stones, which are a characteristic feature of the London Clay, occur in nodular layers at irregular intervals, and often enclose fossils. They are concretions of argillaceous limestone, and the cracks which arose on their consolidation are filled with calc-spar, forming septa. On decomposition at or near the surface we often find that the calcareous matter has formed small nodules or concretions of carbonate of lime called 'race,' themselves often septarian. A strong and continuous layer of septaria forms the foundation of the new County Hall.

There are only a few localities where the full thickness of the London Clay is shown, by the presence of the overlying Claygate Beds, to be present. At Harrow it is only about 220 ft.; at Hampstead the thickness is about 330 ft. on the south and 375 ft. on the north; at Highgate probably about 350 ft. In Essex the Claygate Beds have not yet been mapped, though many sections which would now be referred to that division have been described. A well-section at Brentwood seems to

[1] 'Summary of Progress for 1911' (*Mem. Geol. Surv.*), 1912, p. 31.

indicate a thickness of 391 ft. beneath Claygate and Bagshot Beds; another at South Weald 371½ ft. beneath Claygate Beds only.[1] On the south side we find about 400 to 450 ft. at Esher, 430 ft. at Wimbledon, less than 400 ft. at the Crystal Palace, and probably not much more than 300 ft. at Shooters Hill. Under London the formation has undergone much erosion, and the thickness met with at Tottenham Court Road (Meux's Brewery) was only 63 ft., at Leicester Square 148 ft., Pall Mall 120 ft. and in the City 85 to 130 ft.

Extensive lists of animal and plant remains from the London Clay have been published from time to time. They include many species of shells, crustaceans, fish, crocodiles, birds, and mammals. In some localities plants of a sub-tropical character, such as Magnolias and Ginkgo, have been found.

The Basement Bed affords evidence of near-shore conditions, and in it the slender, gently-curved tubes of *Ditrupa* are abundant. The main mass contains shells indicative of rather deeper water, such as *Nautilus* ; and with the return of shallow-water conditions we have the transition to the Bagshot Sands marked by the Claygate Beds.

Very little detailed work has been done, however, in dividing the formation into zones, according to the distribution of fossils. As early as 1854 Prestwich noted four zones, but they were to some extent topographical, as Sheppey and Highgate were classed as first and second zones respectively, Primrose Hill, Islington and other places were included in the third zone, while his fourth zone included the Basement Bed.

In the Basement Bed, the univalves *Aporrhais sowerbyi* (Mantell) with its obliquely-ribbed spire and well-expanded outer lip, the globular *Natica labellata* Lamarck, and the pear-shaped *Pyrula nodulifera* G. B. Sowerby, ornamented with a row of obtuse nodules on the angle of the whorl, are commonly found. The bivalves of the bed include the stout, orbicular, moderately-inflated *Dosiniopsis bellovacensis* (Deshayes) [= *Meretrix orbicularis* Edwards], *Panopea intermedia* (J. Sowerby), a gaping, oblong shell, *Pectunculus brevirostris* J. de C. Sowerby, a fairly large species, distinguished by its slight obliquity, the small form of *Protocardia plumstediana* (J. Sowerby *emend.*) [= *Cardium laytoni* Morris], an oblique, sub-trigonal shell, with surface occupied by numerous flattened ribs, which are more distinct on the angular side, and *Ostrea bellovacensis* Lamarck.

Fossils are not regularly distributed in the main mass of the London Clay; in certain exposures it is almost barren. Shells are the most usual among the fossils; specimens of *Nautilus* are occasionally conspicuous on account of their iridescence. Univalves occur in great variety; we find specimens of *Cassis*, the helmet-shell, *Phorus* (*Xenophora*), one of the group of carrier-shells, which become covered with bits of stone and other

[1] 'Water Supply of Essex' (*Mem. Geol. Surv.*), 1916, p. 105.

fragments, several species of *Pleurotoma*, *Voluta*, and *Natica*. The bivalves include species of oysters, wing-shells (*Pteria*, sometimes known as *Avicula*), the straight, tapering, thin-shelled *Pinna*, and *Teredo antenautæ* J. Sowerby, a burrowing shell that is often found in fossil wood. Fruits of *Nipadites* also occur.

In the higher beds fossils are more abundant, as at Kingston Hill, Highgate, Chingford, and Roehampton. Among the bivalves found are the mussel-like *Modiola simplex* J. de C. Sowerby and *M. elegans* J. Sowerby, the latter being smaller, more inflated, and ornamented with fine radial ribs, *Meretrix suessoniensis* Watelet (= *Cytherea tenuistriata* J. de C. Sowerby), an inflated, ovate shell, with fine concentric growth-lines, *Pectunculus decussatus* J. Sowerby, a small suborbicular shell, ornamented with concentric growth-lines as well as radial lines and finer transverse striæ, the small *Protocardia nitens* (J. Sowerby), marked by several lines of radiating ribs at one end and concentric markings over the rest of the shell, and the large *Cyprina planata* (J. de C. Sowerby), an inflated species with well-developed umbones. The univalves include *Voluta nodosa* J. de C. Sowerby, a shell with an elevated spire and blunt spines on the angle of the whorls, and *Pleurotoma teretrium* Edwards, with a high spire, long canal, a narrow depressed area by the line of junction of the otherwise convex whorls, but with variable ornamentation. Small, flat shells of the brachiopod *Lingula tenuis* J. Sowerby, thin, narrow, and long, are also found, and at some localities *Ditrupa plana* J. Sowerby again occurs. A list of some 40 species of fossils from the Bracknell district, to the west of our area, is given in the Windsor Memoir[1]; there the London Clay is succeeded immediately by typical Bagshot Sand, with a slight unconformity between the two beds instead of the gradual passage. At this locality Mr. A. Wrigley has drawn attention to two fossiliferous horizons at the top of the London Clay; the higher is a *Modiola*-bed, and below it is a *Cyprina*-bed.[2]

While the formation consists of mud brought down by a large river and deposited under estuarine and marine conditions in deeper water than the Woolwich Beds, the fossils indicate a subtropical climate; the conditions have been compared to those at the mouth of the Ganges at the present day.[3]

Despite the variety of organic remains and the interest attaching to them, fossils are rarely to be obtained in brickyards or shallow openings in the London Clay, except from some of the septaria. Compared with other great clay formations, like the Lias, Oxford and Kimmeridge Clays, the London Clay offers few attractions to the collector. Chemical changes are probably responsible for the rarity of fossils. The decomposition of iron pyrites leads to the production of sulphuric acid, and when this acts on calcareous organisms or nodules the formation of

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[1] 'Geology of Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, p. 31.
[2] *Proc. Geol. Assoc.*, vol. xxxiii, 1922, p. 79.
[3] Hooker, Sir J. D., 'Himalayan Journals,' vol. i, 1854, p. 1.

selenite results (*see also* p. 79). Good crystals of this mineral are not uncommon, but it is from deeper excavations that most of the fossils have been, and are to be, found in and around London.

When the Basement Bed is exposed fossils may usually be found. Round Bushey and Watford this band consists of brown sandy clay with many fossils in places, also flint pebbles and occasional masses of iron sandstone with *Ostrea bellovacensis* at the base, and may be as much as 12 ft. in thickness.

In an excavation for No. 9 Gas-Holder at Beckton, south-east of East Ham, in 1890, at depths of 21 to 30 ft. beneath alluvial deposits (*see* page 75), the following beds were proved :—

		Ft.	ins.
London Clay, Basement Bed.	Hard grey and brown calcareous sandstone, crowded in places with shells, elsewhere comparatively barren, and with occasional flint-pebbles (occurred only in southern part owing to depth of gravel in the north) - about	1	0
	Silt (fine grey sand), with decayed shells (1 ft. thick in northern part) - - - - -	10	0
	Clay and shells (poorly preserved) - - -	3	9
	Rock band and shells (poorly preserved) - -	2	0
Woolwich and Reading Beds.	Clay and shells - - - - - - - - - -	5	6
	Silt (boring continued in northern part) - -	3	9
	Hard sand (boring continued in northern part) -	0	6

The shells from the lower part were not sufficiently preserved for determination, but the hard sandstone at the top yielded about a dozen recognizable species.

The area of the London Clay is pleasantly undulating and picturesque, with hedgerows well timbered with oak, elm and ash.

On rising ground, with good natural drainage, the London Clay sites for building are often preferable to those on shallow gravel on lower grounds, where the porous strata are liable to be water-logged, but steep slopes should be avoided as the clay is very apt to slip, causing cracks in the buildings.

The greater part of the Tube Railways has been cut in the London Clay, which forms an ideal stratum for the purpose.

Owing to the impermeability of the clay, streams draining it are liable to sudden flooding in wet weather. In London this danger is provided for by relief-sewers, but as late as the beginning of the 19th century the lower course of the Westbourne was so badly flooded that communication between Chelsea and Westminster was only possible in boats; and Stow, the chronicler, records that in the early 17th century a youth of eighteen was drowned as a result of trying to jump the Walbrook at Bucklersbury after a storm.

Claygate Beds.

The Claygate Beds consist essentially of alternations of sand and clay forming a passage from the London Clay to the Bagshot

Sand; the clay predominates in the lower, the sand in the upper part. The passage beds were shown by a separate colour on Mylne's Geological Map of London in 1856, but Prestwich regarded them as part of the London Clay and on maps subsequent to Mylne they have been included with that formation.

Mr. Whitaker noted[1] their occurrence around London and considered them as true passage beds. He called attention to their presence at Wimbledon, Norbiton, Gipsy Hill and north of the Crystal Palace, and quotes Caleb Evans's[2] account of them at Hampstead and Highgate.

In the first edition of the present Memoir H. B. Woodward drew attention to the anomalies that result from inconsistency in drawing the boundary between London Clay and Bagshot Sands, and adds that 'in a future 6-inch survey the passage-beds will no doubt be separately mapped' (p. 36). That has now been done over the greater part of the area here considered, though Essex, where there is a large outcrop of these beds, has not yet been re-surveyed. The necessity for separating these passage-beds from the London Clay has recently been illustrated. The great reservoirs at Staines were excavated in Thames gravels down to the underlying London Clay, which formed an impervious bottom. Further reservoirs have been proposed near Littleton, south-east of Staines, but here trial borings revealed the fact that the beds, shown as London Clay on the Old Series Maps, contained seams of sand and would not retain water. These beds are described in the Windsor and Chertsey Memoir as 'Claygate Beds.' This name was given by Mr. Dewey because the passage beds are well developed and have long been worked for bricks and pottery at Claygate in Surrey.

At this type-section these beds have up to the present yielded no fossils; consequently, we are unable to correlate them with fossiliferous horizons elsewhere. Until more detailed work is done on the zonal distribution of fossils in the London Clay it will be impossible to say what horizons they represent. At Willesden Green[3] there are beds which on account of their lithological character are referable to the Claygate Beds; immediately beneath them is a layer of septaria which has yielded many shells and also abundant plant-remains. The shells include *Protocardia nitens* (J. Sowerby) and *Teredo antenautæ* J. Sowerby in abundance; the heart-shaped sea-urchin *Hemiaster branderianus* Forbes has also been found here. Additional records of fossils from this locality have been noted by Mr. Wrigley.[4] In similar beds at Shooters Hill[5] Mr. A. L. Leach records *Cyprina morrisi* (J. de C. Sowerby), *Pectunculus decussatus* J. Sowerby and other shells, found in ferruginous boxstones.

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[1] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 238–265

[2] 'Geology of Hampstead,' *Proc. Geol. Assoc.*, vol. iii, 1873, pp. 21, 22.

[3] 'Summary of Progress for 1914' (*Mem. Geol. Surv.*), 1915, p. 30.

[4] *Proc. Geol. Assoc.*, vol. xxxii, 1921, pp. 139–140.

[5] *Proc. Geol. Assoc.*, vol. xxiv, 1914, pp 115–117.

The 'boxstones' seem to be a constant feature; they are 'hard concretions of ferruginous loam, enclosed usually by harder and more ferruginous shells of limonite.' The septaria or cement-stones of the London Clay are absent, but pyrites nodules and crystals of selenite not uncommon.

At the type locality the following section was observed in Sims & Sons' brickyard in 1911 :—

		Ft.
Bagshot Sand.	Sand, yellow and current-bedded, with a thin seam of clay	3
	Ironstone, at times only ferruginous clay	1–2
Claygate Beds.	Pipe clay and white sand in alternate layers	1
	Pure white sand	¼
	White sand and grey pipe-clay in alternate bands, some beds of sand an inch thick	4
	Ironstone nodules enclosing white sand or clay	¼
	Pure white sand up to	½
	Clay, grey and lilac, alternating with white sand up to 5 ins. thick	3
	Sand and clay, drab or lilac	5
	Purplish-brown clay, evenly bedded in 2 to 4 in. seams with narrow veins of sand	30
London Clay.	Clay, blue or dark grey-green, enclosing nodules of pyrites, claystone concretions and septaria, often fossiliferous	20

The lilac tint is characteristic, and as it is not easily lost by weathering forms a useful guide in the field.

A good natural section may be seen in the cliff of the River Mole at Westend Common, showing 35 ft. of white or buff sand and drab or lilac clay in alternating bands up to one inch in thickness; fragments of leaves are common here, but badly preserved.

Claygate Beds underlie the gravel at Coombe and the southern part of Wimbledon Common.

In the north-west Claygate Beds occur at Harrow, but sections are scarce; the outlier at Willesden Green is mentioned above and many accounts of the beds at Hampstead and Highgate, notably those in the Archway cutting, have been published, for the most part many years ago: a summary of the chief points has been made by Mr. Whitaker.[1] The important paper by Caleb Evans quoted above includes a map of Hampstead showing the Claygate Beds, which form a continuous mass extending round Highgate, capped by the outliers of Bagshot Sand. The section proved in the Tube Railway shaft at Jack Straw's Castle, Hampstead, seems to show, under 4 ft. of soil and gravel, 16 ft. of Bagshot Sand and 110½ ft. of Claygate Beds on London Clay. Other small outliers have been detected at Horsenden Hill and at Hanger Hill, Ealing; these will all be shown on the forthcoming North London Map (Sheet 256) and the latter is indicated on the Special London Sheet 1 as 'Valley

[1] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 256–258.

Brickearth.' Claygate Beds are also preserved at Stanmore beneath the gravel, at Highwood Hill and elsewhere in North Middlesex.

In the south-east Claygate Beds occur on the Crystal Palace Hill, where sections formerly visible have been described by Mr. Whitaker.[1] Shooters Hill appears to lie in a slight synclinal fold, and the Claygate Beds may be 60 ft. thick. They have been described by Mr. A. L. Leach.[2]

In Essex the 6-inch survey has yet to be made, and the Claygate Beds have not been mapped. They occur wherever the Bagshot Sands are shown and on certain hills where those beds are no longer preserved.

West of the Roding they have been noticed near the Obelisk in Hawk Wood, at High Beech[3] and Loughton Camp,[4] and have been described in detail at Oakhill Quarry on the northern margin of the map.[5] The boxstones with casts of fossils are mentioned.

At South Weald 46 ft. of Claygate Beds were proved in a boring at the Essex County Asylum; another in High Street, Brentwood, on the margin of the map shows 41 ft. of Bagshot Sands, 92 ft. of Claygate Beds and 390 ft. of London Clay.[6] The Passage Beds are mentioned by Mr. Monckton[7] and also by H. B. Woodward, who estimates their general thickness round Brentwood as 50 ft.[8]

As mentioned above the Claygate Beds are present beneath the Thames gravels around Laleham and Littleton, on the axis of the London Basin syncline. To the west of our map, about the longitude of Windsor the beds die out, their place being taken by a slight unconformity or non-sequence.

Bagshot Series.

Bagshot, Bracklesham and Barton Beds.

The strata immediately succeeding the Claygate Beds comprise a series of sands, clays and pebble-beds, which have been grouped into Lower and Upper Bagshot Sand with an intermediate division of Bracklesham Beds.

It is now recognized that the Upper Bagshot Sand, which is developed to the west and south of Chertsey, at Bagshot Heath and other parts of Surrey, and in Berkshire and northern Hampshire, is to be correlated with the Barton Beds of southern Hampshire. In consequence the term Bagshot Beds is restricted to the lower division, and the Upper Bagshot Sand is now included with the Barton Beds.

[1] *Op. cit.*, p. 243.
[2] *Proc. Geol. Assoc.*, vol. xxiii, 1912, pp. 112–118; vol. xxiv, 1913, pp. 115–117.
[3] *Proc. Geol. Assoc.*, vol. xiv, 1896, pp. 337, 338.
[4] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, p. 258.
[5] Robarts, N. F., 'London Clay and Bagshot Beds in Epping Forest,' *Trans. Essex Field Club*, vol. iii, 1883, pp. 231–236.
[6] 'Water Supply of Essex' (*Mem. Geol. Surv.*), 1916, pp. 104, 105.
[7] *Proc. Geol. Assoc.*, vol. xi, 1889, pp. lxii–lxiii.
[8] *In* 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, p. 274.

On the maps of the London District only the two divisions, Bagshot and Bracklesham Beds, are shown. We have now to add an outlier of Barton Beds at St. George's Hill, Weybridge, and possibly another at St. Ann's Hill, Chertsey.

In dealing with our present area it will be convenient first to describe the general characters of each division, and then in referring to their distribution to treat them as one series, which may be conveniently termed the Bagshot Series. This is the more desirable, as doubt has been expressed about the correlation of the strata in some localities, and about their method of formation. Thus, clay marked on the map as Bracklesham Beds, between Weybridge and Chertsey, was grouped with the Bagshot Beds by W. H. Hudleston; and portions of the Bagshot Beds near Brentwood and Warley are considered by Mr. H. W. Monckton to be more nearly allied to the Bracklesham Beds, and in this view he received support from Irving.[1]

Bagshot Beds.

This formation is composed for the most part of fine white, buff-coloured and sometimes crimson sands, with occasional seams of white or grey pipe-clay and local beds of flint pebble-gravel: lignite is also met with.

It occupies some of the higher grounds, including the prominent hills of Harrow, Hampstead and Highgate; it extends over the picturesque heaths and wooded tracts south of Chertsey, Weybridge and Esher; and in the north-eastern part of our area it caps the hills at High Beech, Cabin Hill, south of Lambourne End, Havering-atte-Bower, Great Warley Street and Brentwood (on the eastern margin), and the hilly ground at South Weald and Kelvedon Hatch. The full thickness in the district probably does not exceed 120 ft., where overlain by Bracklesham Beds.

Prestwich regarded the beds as of marine origin, and referred to 'the shoaling of the sea after the deposition of the London Clay and the shifting and somewhat eroding currents of the shallower sea of the Lower Bagshot.'[2] That some parts of the area of deposition in the London Basin may have been estuarine or even fluviatile was maintained by Irving,[3] but evidence of this mode of origin has not been obtained within our district. Unfortunately little assistance in settling the question is afforded by palæontology: unrecognizable plant remains are the only fossils, though casts referable to three genera of marine gasteropods have been found in Essex beyond our Eastern margin.[4]

In the Bagshot Sand of Hampstead Heath Mr. A. B. Dick found about 94 per cent. of grains of quartz and felspar, one or two per cent. of flint fragments, and less than one per cent. of

[1] *Nature*, vol. xlii, 1890, June 26, p. 198, and July 3, p. 222.
[2] *Quart. Journ. Geol. Soc.*, vol. xlii, 1886, p. 171.
[3] *Geol. Mag.*, 1891, pp. 357–364.
[4] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 266–276.

zircon, rutile and tourmaline. In the sand at Weybridge, Hudleston noted that the bulk of the grains were quartz with a few chips of flint or chert, glauconite, and oxide of iron.

BRACKLESHAM BEDS.

This formation is divisible into three parts; the lower consists of clay, usually laminated and of a lilac or purplish tinge, though sometimes brown; in the middle is a highly glauconitic sandy bed, often of a deep pistachio green and fossiliferous; the upper consists of sand, loam and clay with an impersistent pebble-bed at the base.

The full thickness may be as much as 100 ft. at St. George's Hill, but is less further west. The figures are very variable, as the lower clays usually rest in basin-like hollows cut in the Bagshot Sand and the pebble-bed at the base of the Barton may cut out varying amounts of the upper part.

Fossils have not been definitely recorded from the area here dealt with, although casts of bivalves have been found; but there are several localities to the west and south-west where a considerable number of mollusca and a few fish teeth and bones of turtles occur.

The characteristic shells are the screw-shell *Turritella sulcifera* Deshayes, oysters (*Ostrea flabellula* Lamarck), and the large, thick, oval bivalve *Venericardia planicosta* Lamarck, marked with prominent radial ribs. The disc-like foraminifer *Nummulites lævigatus* (Brug.) is also typical of beds of this age. These forms indicate deposition in a shallow sea in a warm climate.

BARTON BEDS.

The Barton Beds consist essentially of yellow sands, usually with a pebble-bed at the base. They are not indicated on the map, but an important outlier, showing a thickness of at least 50 ft., occurs on St. George's Hill. The sands were recognised by H. B. Woodward and by Mr. Monckton as belonging to this division and have now been studied in detail.[1] They are shown on the new Windsor Map (Sheet No. 269). Outliers of the basal pebble-bed have been detected near our western margin, but it is apparently absent at St. George's Hill. It is well developed at Stanner's Hill, one mile west of Ottershaw, and contains pebbles of Greensand chert as well as flint; as this chert is not known from older Tertiary beds the occurence serves to indicate the date at which denudation of the Weald first uncovered the Lower Greensand.[2]

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[1] 'Geology of Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, pp. 51–58.
[2] *Op. cit.*, pp. 53, 55.

Local Particulars of Bagshot Series.

Beginning our local descriptions with the Bagshot Beds in Essex, we must note the following section which was exposed many years ago at Langtons, South Weald Park[1] :—

		Ft.
Plateau Drift.	Pebbly gravel, chiefly flint pebbles, with a few quartz pebbles and some unworn flints - - up to	6
Bagshot Beds.	Pebble-bed, wholly of flint pebbles, fine false-bedded sand interbedded with shingle in upper part; closely packed in lower part, where seams of ironstone and layers of pipe clay occur - - - about	15
Claygate Beds.	Loam, holding up water.	

The pebble-bed was first grouped with the Bagshot Beds by S. V. Wood, Jun., but he suggested at a later date that its age might be Diestian. This view, however, is negatived by the intercalation of sand of Bagshot character with the pebbles. The Eocene age of the deposit was accepted by Prestwich, who also describes the sections round Brentwood, more particularly in the railway cutting which lies just over our eastern border. It is possible that some of the beds of pebbles in Essex, shown on the map as Bagshot, belong to higher parts of the Eocene; more probably they are mixed relics of Tertiary beds rearranged at a much later date, though earlier than the Chalky Boulder Clay (*see* below).[2] In the outlier at High Beech some 10 ft. of Bagshot Sand, with the usual thin seams of pipe-clay, may be seen in small pits near the King's Oak Inn; the pebble-bed does not occur here, but the hill is capped with gravel.

In Highgate, occasional excavations have shown a bed of iron-sandstone 18 in. thick, with scattered flint-pebbles, intercalated in the Bagshot Sand. The bed was exposed at the Highgate end of Hornsey Lane, west of the Roman Catholic School; a large block of the conglomerate has been placed by the Highgate Road, near the top of West Hill.

At Hampstead Heath a large amount of sand of the Bagshot Beds has been excavated on both sides of the Heath Road; the sections are much obscured, but a pit some 20 ft. deep, showing the current-bedding and other features, may be seen in the grounds of Kenwood Farm.[3] The thickness of the Bagshot Beds at Hampstead has been estimated by Mr. Whitaker at from 60 to 80 ft.; but this must include part of the Claygate Beds. In a MS. note dated 1840 Prestwich described the beds as consisting of 20 to 30 ft. of fine white sands and coarser yellow sands with layers of small rolled flint pebbles and occasional iron-sandstone 6 ft. thick. This estimate agrees with the classification here adopted.

At Harrow the pebbly bed, which passes into a ferruginous grit, has again been observed.

In the south-western part of our area relics of Bagshot Sand occur beneath the Glacial Gravel at Wimbledon, Coombe Warren and Kingston Hill. At Wimbledon the beds dip gently west and much of the sand has been leached from under the gravel by springs thrown out by the Claygate Beds.[4] A small gravel pit on Copse Hill exposes the underlying yellow current-bedded sands of the Bagshot Beds. The sands are exposed in the Guildford road-cutting south of Esher, and they may be

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[1] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 273, 274; also *Proc. Geol. Assoc.*, vol. xi, 1889, p. 19.

[2] Monckton, H. W., and R. S. Herries, 'Bagshot Pebble Beds and Pebble Gravel,' *Proc. Geol. Assoc.*, vol. xi, 1889, pp. 13–23.

[3] *See* 'Hampstead Heath' by Members of the Hampstead Sci. Soc., 1913, pp. 59–62 and Plate I.

[4] 'Summary of Progress for 1912' (*Mem. Geol. Surv.*), 1913, p. 34.

seen in a large pit on Oxshott Heath (now a public common). In this pit the sands are buff-coloured, and contain streaks of grey and rather clayey sand; they are capped by Plateau Gravel. Two outliers of Bagshot Beds between Claygate and Chessington are also marked on the map. Another tract of basement Bagshot Beds, not shown on the map, has been proved in the brickyard north-east of Claygate Station, between South Hill House and Cooper's Hill.

The sections on the railway between Walton and Weybridge were described in detail by W. H. Hudleston,[1] but his 'Bagshot Beds' include much that is now called Claygate Beds. At the western end of the cutting, by Weybridge Station, a section still open shows 25 ft. of typical Bagshot Sands, belonging to the middle part of the group. In the Brooklands Motor Track there are many sections of the Bagshot Sand; at the north-west corner of Canes Wood, H. B. Woodward noted the following details :—

		Ft.
False-bedded ochreous sand, with irregular and impersistent clay-seams - - - - - -	about	20
Grey clayey sand with ochreous nodules - - - -		10
Pale clayey sand - - - - - - - -		5 to 10
Grey sand, ferruginous at base - - - - -		15
Grey and brown sandy clay, throwing out springs [? Claygate Beds] - - - - - -	seen to	8

On St. George's Hill the whole series, Bagshot, Bracklesham and Barton Beds, may be studied. Most of the sections in the Firgrove Brickyard, described by Woodward[2] have been obscured by the progress of building. The sandpit, however, is still (1919) untouched and shows the top part of the Bagshot Sand and the base of the Bracklesham Clays. The sands are seen to be clearly stratified in horizontal layers, often only a quarter of an inch thick, but individual layers are minutely current-bedded; many seams of pipe-clay are interstratified with the sands. In parts of the section the colouring is very brilliant, the sands being deep pink, yellow and silver-white, while the pipe-clay is crimson, grey or white, recalling the famous sands of the same age at Alum Bay. The Bracklesham Clays occupy a basin cut in the sands across the bedding; they are lilac-grey in colour, and somewhat laminated, developing a prismatic structure on weathering. Both the sands and the clays show staining by iron, but at the contact of the two materials the iron is segregated to form an ironstone. This ironstone was, at one time, extensively worked by means of shallow trenches, which follow the junction nearly all round the hill, and afford a useful guide in mapping. The ore was smelted and wrought at a mill, now known as Ham Mill on the Wey. Dr. Eric Gardner, of Weybridge, has traced the history of this industry and tells us that it was in existence more than one hundred years, from 1710 to 1812. On the original one-inch Geological Map of the district, of which the topography is dated 1815, the site of the works is still marked as 'Iron Mills.' A picked specimen of the ironstone was analysed at the Survey Laboratory and found to contain only 23 per cent. metallic iron.[3]

No other instance is definitely known of the use of a Tertiary ironstone in the London Basin. A photograph of this pit is given in the Windsor Memoir (Plate IV.). Another section on the south side of the hill shows the Bracklesham Clays resting horizontally on Bagshot Sands; but the overlying green beds are nowhere well exposed. The outcrop of the Barton Sands forms a narrow fringe round the greater part of the gravel-cap, as shown on the new map (Sheet 269). The sands

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[1] *Quart. Journ. Geol. Soc.*, vol. xlii, 1886, pp. 147–172; vol. xliii, 1887, pp. 443–456.

[2] *Proc. Geol. Assoc.*, vol. xxii, 1911, pp 237–240.

[3] Bromehead. C. N., *Proc. Geol. Assoc.*, vol. xxx, 1919, p. 127.

are yellow, but somewhat finer than the Bagshot; their structureless appearance presents a marked contrast to the current-bedding of that division. Some 40 ft. are exposed in an old road-cutting near the north-eastern angle of the 'British Camp.' The sands are also dug in the gravel pits on the summit of the hill, and were here recognised as of Barton age by H. B. Woodward (*op. cit.*).

West of the Wey the main mass of the Bagshot Sand is diversified by a number of outliers of Bracklesham Beds. On Woburn Hill, south-east of Chertsey, the following section was seen at the Hatch Brickworks in 1911:—

		Ft.
Bracklesham Beds.	Lilac and brown laminated brick-earth, strongly current-bedded, planes dipping south-east about	6
	Horizontally-bedded sands, thinning towards the south-east to a horizontal parting	0–1
	Brick-earth, similar to above, bedding planes dipping north-west	6
	Thin iron parting	—
	Pale lilac loam, very dense	1–1½
	Ironstone	½–1
Bagshot Sand	White sands - - - - - - - seen to	5

Here, again, the Bracklesham Beds rest in a basin cut in the Bagshot Sand with an ironstone at the junction. At Ongar Hill, where 30 ft. of lilac clays are exposed in a brickyard, the ironstone is replaced by a band of iron nodules. At Brox Church the pebble-bed at the base of the Barton Beds caps the hill; unfortunately, this outlier, the only one of that bed within our area, is indicated on the London map (Sheet 3) as two tiny patches of Plateau Gravel. Round Ottershaw there are several patches of the Bracklesham pebble-bed, which is also probably the bed which caps the St. Ann's Hill west of Chertsey, though Messrs. Gardner, Keeping and Monckton regarded it as the Barton bed.[1] At the bottom of this hill are several pits in the Bagshot Sand, which locally contains a thin pebble-bed; these are succeeded in turn by the lilac clays and the glauconitic sands of the Bracklesham Beds which have a combined thickness of about 30 ft.; this amount does not seem sufficient to allow of the pebble-bed at the top being referred to the Barton Series.

The particulars of the Bagshot, Bracklesham and Barton Beds in the south-western area are taken mainly from the Windsor Memoir, where they will be found set out in greater detail.

CHAPTER V.

STRUCTURAL GEOLOGY.

It has already been mentioned (p. 17) that the Chalk had been thrown into gentle folds before the deposition of the Tertiary strata; these folds have, however, little if any influence on the present structure, and it is to post-Eocene movements that the 'London Basin' owes its form. The term 'London Basin' has been used so constantly that it must be accepted, though many writers have pointed out that it is a misnomer. The structure would be better described as a shallow trough, with an axis running

[1] *Quart. Journ. Geol. Soc.*, vol. xliv, 1888, p. 609.

through our district about east 30° north to west 30° south, that is to say, approximately along the diagonal of the area shown on the maps.

This trough is steeper on the south-east side than the north-west, the gentle dips of the northern limb being largely replaced by faults. It is seldom easy to detect faults or small folds in the soft Tertiary beds, and it is only by studying the levels of the top of the Chalk as proved by borings that they become plain.

Two faults occur in our area. The more important had not been discovered when the special map was made; its course lies from near Deptford to Wimbledon and Raynes Park Stations, but it appears to die out towards Tolworth. At the Deptford end it is replaced by a parallel fault to the south-east passing through St. John's Station and Greenwich and across the River to Beckton Gas Works. The down-throw of both faults is to the north-west, that of the first being about 150 ft. at Raynes Park; the second has long been known, since it brings the Thanet Sand against the Chalk in the cutting at St. John's, part of its course being shown on the map (Sheet 4).

Three other faults are shown on this sheet, but should be deleted. That between Woolwich and Erith has been pointed out to many generations of students. There are several little outcrops of chalk at the surface to the south of it; at Crossness to the north the Chalk is 140 ft. below the surface. The change of level might be due either to a northerly dip or, if the beds were horizontal, to a fault; the latter explanation was chosen because a mass of pebbly material containing fossils occurs to the north of and at a lower level than the outcrops of Chalk. This material was taken to be Blackheath Beds *in situ* and is shown as such on the map. Well sections, and other evidence obtained since the original publication of the map in 1873, prove, however, that the Chalk dips steadily north with no break; an excavation near Abbey Wood Station showed that the pebbly material rests directly on the Chalk, and has slipped from the edge of the plateau above. The two 'faults' indicated near Ruxley are also nothing more than superficial landslips.

Although faults of significant size appear to be confined to the southern margin of the main trough, subsidiary folding occurs throughout the area, and is of practical importance, since it affects the surface topography and the water supply. Mr. Wills's map of the sub-Tertiary Chalk surface[1] covers a large part of our area. The complicated structure indicated by the contours can probably be explained as the result of the interaction of two sets of folds parallel and transverse to the main axis. Thus in the south-east a synclinal fold runs parallel to the trough through Mitcham, the Crystal Palace, and Shooters Hill; a small transverse anticline running through Thornton Heath and Streatham deflects this fold, while another, which

[1] 'Records of London Wells' (*Mem. Geol. Surv.*), 1913, Plate II.

brings up the Chalk to the surface at Chislehurst and Lewisham, neutralises it near Hither Green and further north-west produces the dome-structure at Deptford by intersecting the anticline between the Crystal Palace syncline and the main syncline.

In the east the disturbances along the Thames Valley are continued through the anticline of Purfleet and West Thurrock, where the Chalk has a northerly dip of about 10°, while a gentle southerly dip has been observed near Greenhithe. As suggested by Mr. Whitaker, this may be a continuation of an anticline which extends from Eltham to Crayford.

It may be noticed that the hills of London, where outliers of the higher Eocene beds are preserved, occur for the most part in structural basins, as, for instance, Hampstead and Highgate, the Crystal Palace and Shooters Hill. Dome-like structures can be recognised in the low ground of Deptford and Hackney Marshes.

The deepest part of the London Trough is in the south-west of our area, where the Upper Eocene beds are found: here, again, the structure is not simple. A subsidiary anticline occurs at St. George's Hill; on the south of the hill the southerly dip accounts for the presence of the Barton Sands, while on the north the dip in that direction brings the Bracklesham Beds of Woburn Hill to an unusually low altitude; on this account Hudleston suggested[1] that the clays there were in the (Lower) Bagshot, but Captain Lyons pointed out the structural explanation of the anomaly.[2]

The inliers of Reading Beds at Ruislip and Pinner indicate lines of anticlinal flexure, approximately parallel to the strike of the strata between Rickmansworth and Watford. Mr. Whitaker has figured some undulations in the Chalk and Reading Beds, which were exposed south of Bushey Station, and these may perhaps be continued in the area north-east of Letchmoreheath.

In Essex, between Chigwell, Havering, and Romford indications of faulting in the Chalk have been brought forward by Mr. W. H. Dalton[3], and attention was called to a possible syncline in the London Clay at Dagenham, where about 400 ft. of that formation was recorded in a boring,[4] but we are informed by Mr. Whitaker that the locality was Dagnam Park, about 4 miles north-east of Romford, the name Dagenham having been inserted by mistake in the printed record.[5] The error has now been corrected.[6]

Dislocations on a small scale are numerous. In the Chalk of northern Surrey Mr. G. W. Young notes slickensides showing in some cases vertical, in others horizontal shifting.[7] Many

[1] *Quart. Journ. Geol. Soc.*, vol. xliii, 1887, pp. 446–454.
[2] *Ibid.*, vol. xlv, 1889, pp. 636, 637.
[3] *Essex Nat.*, vol. v, 1891, p. 113.
[4] Holmes, T. V., *ibid.*, vol. vi, 1892, p. 145; vol. vii, 1893, p. 27.
[5] 'Geology of London' (*Mem. Geol. Surv.*), 1889, vol. ii, p. 18.
[6] 'Water Supply of Essex' (*Mem. Geol. Surv.*), 1916, p. 232.
[7] *Proc. Geol. Assoc.*, vol. xix, 1905, p. 189.

small faults in the Eocene strata are more nearly allied to landslips and die out in the lower beds; they have been observed at Nunhead, Lewisham, Blackheath, Croydon and elsewhere.[1] In the London Clay such slips, though frequent, cannot be seen in sections. In Wimbledon an excavation seen in 1912 showed 18 ft. of London Clay, apparently *in situ*, but beneath it was a garden soil yielding relics of the early 18th century. At Brockwell Hall Brickyard, where the Peabody Buildings now stand, Mr. Whitaker noted a section in which small faults, clearly seen in the bedded sands, are not traceable in the homogeneous London Clay above; in the same district a remarkable case of 'overfolding,' probably superficial in character, was revealed in 1921, when the cutting on the L.B.S.C. Railway south of New Cross was cleaned.[2]

A small reversed fault, bringing Reading Beds against London Clay, was met with in the Tube Railway between Oxford Circus and Regent's Park.[3]

CHAPTER VI.

PLIOCENE (AND LATER).

The folding described in the previous chapter, though it began during the deposition of the Eocene Beds, was in the main post-Eocene; it appears to have been practically completed during the Oligocene and Miocene periods, but it is highly probable that movement, better described as a tilt, caused a general submergence of this part of England in the late Miocene or early Pliocene[4] (Diestian) period.

About 8 miles south of St. George's Hill, Weybridge, there occur at Netley Heath, on the Chalk of the North Downs, certain patches of yellow sand 5 to 12 ft. thick, with a few flint-pebbles, and ferruginous sandy and occasionally glauconitic grit; here Mr. W. P. D. Stebbing discovered casts of fossils;[5] further finds have since been made[6] but the state of preservation does not permit specific identification. Some 12 genera occur, of which 11 are also found in the Lenham Beds which belong to the Diestian[7]. The strata occur at an altitude of 570 to 600 ft.

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[1] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 130, 158, 231, etc.

[2] Bromehead, C. N., *Proc. Geol. Assoc.*, vol. xxxiii, 1922, pp. 77, 78, Plate IV.

[3] 'Summary of Progress for 1905' (*Mem. Geol. Surv.*), 1906, p. 168.

[4] The term 'Pliocene' is used here and by the writers quoted in the sense of 'contemporary with the Lenham Beds'; Mr. R. B. Newton now considers that the Diestian division to which these beds belong is more correctly referred to the Upper Miocene. *See Journ. Conchol.*, vol. xv, 1916, pp. 56–149.

[5] *Proc. Geol. Assoc.*, vol. xvi, 1900, pp. 524–526.

[6] *Ibid.*, vol. xxviii, 1917, p. 50.

[7] Reid, C., 'Pliocene Deposits of Britain' (*Mem. Geol. Surv.*), 1890, pp. 42–58.

Somewhat similar sands occur at Headley Heath, about 6 miles south of Ewell, and 5 miles beyond the limits of our district; but there no fossils have as yet been found.

The fact, however, of the occurrence of these shelly beds at Netley Heath is most important as indicating a submergence probably of parts of our district, certainly of adjacent areas, during Pliocene times; and the depression may have amounted to 840 ft. or more, according to Clement Reid's estimate that the depth of water for the Lenham fossils was not less than 40 fathoms (*op. cit.*, p. 52).

We have no certain indication of the extension of the Lenham Beds, and it is possible that any further deposits that may originally have covered parts of our present district have been either destroyed or reconstructed and decalcified.

Before the identification of such relics can be discussed we must indicate briefly the physical changes to which the district has since been subjected. These changes have not only reconstructed the remains of Tertiary beds, but have introduced newer deposits which are frequently difficult to distinguish from each other and from the pre-existing materials.

That elevation of the area took place in Newer Pliocene times is generally admitted, and that this may have been accompanied by some relative depression along the line of the Thames Valley, giving direction to a late Pliocene river, the precursor of the Thames, appears probable.

With this upheaval of the land, the district was again subjected to the erosive action of rain and rivers; a process which has practically continued, with sundry changes of level and climate, to the present time.

The result has been a complex series of gravels and other accumulations, some directly connected with the Thames and its tributaries, others having no immediate relation with the present valley system. Mr. Whitaker remarked in 1890 that 'there was no problem more difficult in the geology of the south of England than the classification of various deposits of gravel,'[1] some of which may be of any age between Bagshot Beds and Boulder Clay. Since that date much attention has been paid to this complex subject, but few undisputed conclusions have been reached.

On the maps the superficial deposits are shown by seven distinct colours; the newest three divisions of Alluvium, Valley Brickearth and Valley Gravel form a fairly distinct series associated with the past or present river systems; they are described in Chapters VIII and IX. The Boulder Clay is a definite deposit with which are associated certain gravels, described here as Glacial, either underlying or apparently washed out of it. These gravels are characterised by the presence of certain constituents foreign to the Thames Basin, and brought in by glacial action; they are coloured pink on the maps and described in the indexes

[1] *Quart. Journ. Geol. Soc.*, vol. xlvi, 1890, p. 180.

as 'Plateau Gravel of various ages'; but the same division includes certain gravelly accumulations which do not contain the foreign material and are presumably older. The other two divisions, 'Clay-with-flints' and 'Plateau Brickearth,' are confined to the Chalk areas; they merge into one another and are of mixed character and indefinite age. The Boulder Clay and Glacial Gravels are discussed in the next chapter, but we are now concerned with the remaining parts of the 'Plateau Gravel,' the Plateau Brickearth and Clay-with-flints. These deposits are all destitute of contemporaneous organic remains and some may possibly represent decalcified relics of Diestian or later Pliocene strata. They occur at higher levels than those locally reached by the Glacial Gravels, usually round about 400 ft.

THE OLDER GRAVELS.

North of the Thames these ancient gravels are best seen, within our area, on Stanmore Hill, at Oxhey Wood, Totteridge and around Chipping Barnet. At Stanmore Hill Mr. R. W. Pocock finds that 'Reading pebbles form by far the greater part of the hard material, and many of these appear to have been weathered before being involved in this deposit. Vein-quartz is fairly common . . . and occurs as small pebbles, only one specimen above an inch long having been found. Other pebbles are very rare. A few of the flints have been derived directly from the Chalk, and prolonged search yielded one or two fragments of cherty rock (possibly from the Lower Greensand), one well-rounded pebble of sarsen and one fairly large block of a pebbly variety of the same.'[1] At Barnet both the quartz pebbles and the chert are more abundant. Mr. Pocock notes the important fact, that, though patches of this high level gravel occur to the north-west, the chert is practically limited in that direction by a line running from a short distance north of Barnet to Little Berkhampstead.[2] This suggests that the chert was derived from the Wealden area rather than from that north of the Chilterns.[3] The reverse appears to be true of the quartz pebbles, which are extremely abundant in the Lower Greensand at Leighton Buzzard and elsewhere in the northern outcrop.[4]

At Little Heath, $5\frac{1}{2}$ miles north of our north-west corner, Mr. C. J. Gilbert claims to have discovered a shore-deposit of these gravels.[5] He considered the gravels to be of Pliocene age and marine origin, on the latter point having the support of McKenny Hughes.[6]

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[1] 'Summary of Progress for 1913' (*Mem. Geol. Surv.*), 1914, p. 33.
[2] 'Summary of Progress for 1914' (*Mem. Geol. Surv.*), 1915, p. 33.
[3] *Quart. Journ. Geol. Soc.*, vol. lxxv, 1920, pp. 49, 50.
[4] Barrow, G., *ibid.*, p. 45.
[5] *Ibid.*, pp. 32–43.
[6] *Quart. Journ. Geol. Soc.*, vol. xxiv, 1868, pp. 233–237.

It is hardly possible that the chert and the quartz pebbles should have reached their present position from opposite directions. It has, however, been mentioned that the Barton Pebble Bed contains chert and that it transgresses the under-lying divisions (p. 33). It seems reasonable to suppose that this bed originally extended north of the Thames and, if so, contributed at its destruction to the formation of the gravels. The present limit of the chert, running through what appear to be relics of a single deposit, would correspond approximately with the margin of the Barton sea. The former extension of Upper Eocene beds over this area is also suggested by the occurrence of *Venericardia planicosta*, a Bracklesham fossil shell, in the Boulder Clay at Finchley (p. 45).

Whether these beds are of Pliocene or later age cannot be definitely proved in the absence of fossils; it may be mentioned that the late Clement Reid, whose knowledge of the Pliocene Beds was unrivalled, searched the district for traces of such beds and failed to find them.[1] He was inclined to regard the Stanmore gravels as of Bagshot age, comparing them with undoubted Eocene gravels in the Hampshire Basin and with the pebble bed at Highgate which forms the base of the Bagshot Sand (p. 34)[2]; but the Highgate Bed occurs also at Hampstead at the base of the Bagshot, while small patches of the high level gravel (not shown on the map) are found there resting on that division.

Owing to the large percentage of Eocene flint pebbles, Mr. Whitaker calls these deposits the 'Pebble Gravel' and heads his description of them 'Pre-Glacial (?)'.[3] That they are prior to the advance of an ice-sheet into our area is certain, but opinion is still so much divided that we can as yet say nothing more definite. In the forthcoming Memoir on the country around Beaconsfield (Sheet 255) the term 'Pebble Gravel' is used. Prestwich's term 'Westleton Beds' included such varied deposits that it has been generally abandoned.

In Essex no re-survey has as yet been made, and it is difficult to distinguish the ancient gravels from those associated with the Boulder Clay on the one hand and from Bagshot pebble beds on the other. The latter have to some extent been re-arranged by surface-slipping and no hard and fast line can be drawn between those which are practically *in situ* and those which should be regarded as a new deposit. Where pebbles of Bunter quartzite and other foreign rocks have been introduced, we have good reason for calling the deposit Glacial, but in many old accounts the term 'quartzite' probably implies sarsen.

A gravel which should certainly be included in the High Level Series occurs at Lambourne End, and at High Beech, where it attains an altitude of 362 ft. and consists of loam with pebbles mostly of flint, and a few of quartz.

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[1] *Quart. Journ. Geol. Soc.*, vol. lxxv, 1920, p. 47.
[2] 'Summary of Progress for 1899' (*Mem. Geol. Surv.*), 1900, p. 140.
[3] 'Guide to the Geology of London' (*Mem. Geol. Surv.*), Ed. 6, 1901, p. 64.

To the north and east of South Weald, in the neighbourhood of Brentwood, the Boulder Clay rests in places on the Bagshot Sands and pebble bed.

The upper part of the pebble-bed, from 3 to 6 ft., consists of re-arranged material with a few quartz pebbles and unworn flints, moved doubtless when ice overspread the land. To that agent, perhaps, the vertical position of the pebbles may be attributed.[1] These features are well seen on the Warley plateau, on the eastern margin of the map.

More recent downwashes of the Bagshot pebble-beds occur south-east of Great Warley Street, and in places between Brentwood and Brook Street.

Mixed pebbly flint gravel, with a few pebbles of quartzite, as well as quartz and angular flints, occurs on the border of Dagnam Park, north of Harold Wood, and this is evidently associated with the Boulder Clay.

No Eolithic or Palæolithic Implements have been found in any of these Pebble Gravels on the northern side of the Thames.

Clay-with-flints and Plateau Brickearth.

On the Chalk tracts of Hertfordshire, Buckinghamshire and the North Downs there occurs an irregular accumulation to which the term Clay-with-flints has been applied. Associated with it there is much brickearth.

The Clay-with-flints rests generally on a piped surface of the Chalk, and occurs as a lining of reddish brown clay, with unworn flints, often blackened with manganese and iron salts. This portion was largely formed by dissolution of the Chalk liberating the flints, and any insoluble matter in the Chalk. The percentage of earthy matter in the Chalk is, however, very small, and it is admitted that the accumulation represented on the map is a mixed one.[2]

Intermingled with the Clay-with-flints are undoubted relics of Eocene beds; black flint-pebbles and sand, greywethers, coloured clay, and in some cases considerable tracts of mottled brickearth occur, as well as stones from the Glacial Drift. In mass the accumulation is largely the relic of denudation, locally much modified during successive events of the Pleistocene period.[3]

It is a noteworthy fact that in the Clay-with-flints of the uplands south of Croydon there have been recognised not only flint-pebbles derived from Eocene strata, but chert from the

[1] Woodward, H. B., in 'Geology of London' (*Mem. Geol. Surv.*), 1889, p. 273, and *Proc. Geol. Assoc.*, vol. xi, 1889, p. lxxiii; vol. xviii, 1904, p. 486. Monckton, H. W., and R. S. Herries, *ibid.*, vol. xi, 1889, p. 18; vol. xii, 1892, p. 109.

[2] Whitaker, W., 'Guide to Geology of London' (*Mem. Geol. Surv.*), Ed. 6, 1901, p. 72; Jukes-Browne, A. J., *Quart. Journ. Geol. Soc.*, vol. lxii, 1906, p. 132.

[3] Sherlock, R. L., and A. H. Noble, 'Glacial Origin of the Clay-with-flints of Bucks.' *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912, pp. 199–212.

Hythe Beds, and ferruginous sandstone possibly from the Folkestone Beds of the Lower Greensand.[1]

Plateau or Eolithic implements have been found near Shoreham, Eynsford and other places where Clay-with-flints is shown on the map.

Good examples of the deep hollows or 'pipes' filled with gravel and Clay-with-flints are met with in the cuttings of the Metropolitan Railway beyond Rickmansworth, and elsewhere. In these pipes the chalk walls are usually lined with Clay-with-flints, while the middle part is filled with an accumulation of material derived from the strata which locally overlie the Chalk; examples of pipes filled with Blackheath Beds at Worms Heath, four miles south of Addington, have recently been described by Mr. Whitaker.[2]

CHAPTER VII.

PLEISTOCENE.

Glacial Deposits.

The Glacial Deposits shown on the map include the Boulder Clay, found about Finchley and in Essex, and the gravels coloured pink other than those just described. These gravels are in part older and in part newer than the Boulder Clay; those at Finchley underlie this deposit and have been termed 'Middle Glacial' as they are newer than the Lower Glacial Drift of Norfolk. They were probably formed by flood-water, due to the melting of the ice before it reached our area from the north; owing to an increase of cold or some other change the ice-cap then advanced into the Thames Valley, and the Boulder Clay was laid down beneath it. With the return of more clement conditions the ice again melted and newer gravels were formed in the same way as before. Unless, therefore, Boulder Clay is preserved beneath or above the gravels, it is difficult to say whether a particular mass is earlier or later than the maximum glaciation. Both series are characterised by the occurrence in fair abundance of liver-coloured quartzite pebbles derived from the Bunter, by many erratic rocks, some of Scandinavian origin, by fossils derived from Jurassic and other formations, as well as by quartz, chert, flints, ironstone, blocks of sarsen stone and puddingstone, of more or less local origin. Contemporary fossils have not been found within the district, nor are any implements recorded from beneath the Boulder Clay.

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[1] *Quart. Journ. Geol. Soc.*, vol. xlvii, 1891, pp. 127–54; and *Proc. & Trans. Croydon Micros. & Nat. Hist. Club*, 1896–7, 1897, p. 219.

[2] *Quart. Journ. Geol. Soc.*, vol. lxxv, 1920, pp. 7–31.

There is no evidence to suggest that the great ice sheet ever crossed the present Thames Valley, but glacial gravels, probably newer than the Boulder Clay, occur on Kingston Hill and Wimbledon Common; besides the northern material they contain a large proportion, increasing from north to south, of 'Southern Drift.' It seems a fair inference that these deposits mark the bottom of the valley at the end of the Glacial Period, since there alone would the waters from north and south mingle.

THE BOULDER CLAY.

The Boulder Clay or Northern Drift is recognised as a direct product of land-ice formed during the Glacial Period.

It is for the most part a tough bluish-grey clay with many pellets and pebbles of hard chalk, rolled and unrolled flints, together with fragments of rocks and fossils derived from many different formations, notably from the Jurassic and Cretaceous. Lenticular beds of sand and gravel occasionally occur in the clay. Both rocks and fossils exhibit glacial striæ, and they are especially noticeable on the pebbles of hard chalk.

The Jurassic materials include oolitic limestone and sundry ammonites; also *Lima gigantea* from the Lower Lias; *Belemnites abbreviatus* and *Gryphœa dilatata* from the Corallian and the Oxford Clay; *Orbiculoidea latissima* and *Lucina minuscula* (a conspicuous white bivalve shell) from the Kimmeridge Clay. Pieces of Red Chalk and occasional Eocene materials, notably *Venericardia planicosta* (a Bracklesham fossil) have been obtained.

At the surface the Boulder Clay becomes decalcified, and appears as a brown stony loam 3 or 4 ft. thick, which merges into the unweathered Boulder Clay, or occupies pipe-like cavities in it.

In thickness the Clay is very irregular, but in our present district is not known to exceed 35 ft.

It occurs on the uplands in the north-eastern tracts around Navestock and Lambourne, at Havering-atte-Bower and Chigwell Row, as well as at Stapleford Tawney, on the northern side of the Roding Valley. It thus overspreads certain tracts of Bagshot Beds. Sometimes it rests directly on London Clay, and elsewhere is based on Plateau gravel and sand.

To the south-west of Brentwood[1] (which lies to the east of South Weald), the Boulder Clay descends into the Thames Valley, and was exposed in the railway-cutting at Hornchurch, between Upminster and Romford, beneath the Thames Valley Gravel, where its presence was made known by Mr. T. V. Holmes.[2]

It occurs to the west of Enfield and in outlying patches towards East Barnet, and a large tract extends from near Whetstone to Finchley and the summit of Muswell Hill.

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[1] *See* Prestwich, *Quart. Journ. Geol. Soc.*, vol. xlvi, 1890, p. 164.
[2] *Quart. Journ. Geol. Soc.*, vol. xlviii, 1892, p. 365.

Westwards in our district it has not been met with, but it occurs at Bricket Wood, north of Watford.

A small outlying mass of Boulder Clay, much weathered at the surface, and about 6 ft. thick, was exposed (1908) at Oakleigh Park, Whetstone; and beneath the clay a thickness of 8 ft. of pebbly flint gravel was exposed; the junction between the two was fairly even.

To the south of Church End, Finchley, the Boulder Clay has been exposed on both sides of the main road in recent excavations for building sites, and in a trench west of the Manor House; it occurs over parts of the St. Pancras, Islington, and Marylebone Cemeteries, where sections may usually be seen; a good account of the exposures opened up when the railway-cutting at Finchley Station was made has been published by Henry Walker.[1]

Much of the local material in the Boulder Clay was derived from the subsoil that was temporarily frozen to the base of the ice sheet, but material was transported from a distance at higher levels in the ice, being shifted by thrusts and shear-planes in the moving mass. In this way chalk detritus was scored by fractured flint or different broken rocks, and other stones were glaciated.

Blocks of igneous rock from Scandinavia were probably derived, in transit, from earlier accumulations of Boulder Clay, belonging to the Lower Glacial Drift of East Anglia. Mr. G. Potter has found rhomb-porphyry at Fortis Green, west of Muswell Hill.[2]

That during the formation of the Boulder Clay the land stood at a higher level than now, in reference to the sea, cannot be doubted, when we consider the deep channels of erosion met with in the Eastern Counties, in the Cam Valley, in Essex, at Glemsford in Suffolk, as described by Mr. Whitaker, and at Hitchin, as described by Mr. William Hill. At Glemsford the drift extended to more than 350 ft. below O.D.

It may be noted, however, that in 'Nature' (7th July 1904, p. 218) Mr. G. W. Lamplugh called attention to observations in Alaska by G. K. Gilbert, who concludes that glacial ice may continue to exert influence on the rock bed if it has descended from the land into water and is not buoyed up, so 'that the depth to which glacial troughs have been excavated is not demonstrative of a relatively low base-level at the time of their excavation.'

The discovery of a mass of Boulder Clay, 15 ft. thick, beneath the 100-ft. terrace-gravel in the Thames Valley at Hornchurch has been of great importance in showing that the fossiliferous gravels and brickearth of the Thames Valley are newer than this great glaciation. The Boulder Clay here occupied a hollow in the London Clay, and was overspread by the Valley Gravel, but the reading of this section has recently been disputed (p. 52).

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[1] *Proc. Geol. Assoc.*, vol. ii, 1872, pp. 289–298.

[2] *Quart. Journ. Geol. Soc.*, vol. lxv, 1909, p. 263; *see also* Woodward, H. B., and J. G. Goodchild, *Proc. Geol. Assoc.*, vol. x, 1887, p. 145.

Since Mr. Holmes made known his discovery, he has observed another patch of Boulder Clay beneath the gravel on the eastern side of Romford, in a cutting of the Romford and Upminster Railway.[1]

During the 6-inch geological survey of the area by Mr. T. I. Pocock, a number of additional patches of Boulder Clay were mapped on either side of the Ingrebourne River, to the south of Maylands and Havering-atte-Bower.

The evidence so far appears to suggest that a tongue of Boulder Clay was accumulated in a hollow along what is now the Ingrebourne Valley. As Mr. Pocock has observed, 'Several outliers of stony clay have been traced in this neighbourhood, some of which still contain a little chalk, and others are probably decalcified remnants of the Chalky Boulder Clay.' One of these outliers was found on Tyler's Common, to the west of Great Warley Street.

The Glacial Gravels.

The Glacial Gravels occupy a large area to the north and west of the Colne, crossing that river in the neighbourhood of Watford and Harefield. Dr. Sherlock finds that these deposits differ from the older 'pebbly clays and sands' in four particulars :—

(1) There is hardly any clay, the waters which laid them down being more or less torrential.

(2) The flints are usually subangular, unworn chalk flints being very rare.

(3) They contain a small proportion of far-travelled stones brought into the district by the ice.

(4) They lie more horizontally.

By these criteria it is comparatively easy to distinguish the glacial from the older Plateau gravels described in the previous chapter; but, on the other hand, it is almost impossible to draw a definite line between the Glacial and the newer River Gravels. In the main valley, as, for instance, near Richmond, erosion had lowered the river-level some 80 ft. between the deposition of the Glacial and the earliest River Terrace Gravels (*see* p. 63); but as we trace the tributary streams to their sources this figure gradually decreases to zero, and the distinction lies between gravels in the state in which they were left by the fluvio-glacial waters and those which have been resorted by the rivers at approximately the same level. Many of the patches of Glacial Gravel shown on the map should have an indefinite margin, towards the river, coloured as River Gravel. The point would be of small importance were it not for the fact that palæolithic implements frequently occur at such sites; among the best known is Croxleygreen, near Rickmansworth (p. 68), which should be assigned to the Boyn Hill Terrace, but, on account of

[1] *Quart. Journ. Geol. Soc.*, vol. l, 1894, p. 443.

the difficulty of drawing a boundary line, appears on the map as 'Plateau Gravel.' The thickness of the deposit here is 20 to 25 ft., and blocks of quartz and quartzite up to 10 by 8 by 6 in. occur.[1] Further down the valley, at Iver Heath and Hillingdon, a feature can usually be seen between the Glacial Gravels and those of the Boyn Hill Terrace, and the two deposits can be separated as on the map.

On the east of the Colne the Glacial Gravels approach the older 'High Level' deposits and reach almost the same height but can be distinguished by the presence of Bunter quartzites. At Moor Park, Clement Reid noted a gravel at 359 ft. (surface level) consisting of some 70 per cent. Eocene material, but yielding also quartzites and Palæozoic grits, while the Oxhey Wood gravel and its outliers descend to little above the 300-ft. contour and contain no far-travelled stones. Further north by Battlersgreen and Aldenham, the Glacial Gravel is 15 to 20 ft. thick; the western margin of this spread, towards the Colne, is probably river-gravel.

At Hendon, as pointed out by Hicks,[2] the gravel contains an intercalated and irregular mass of brown clay like London Clay, and the same feature was observed by Mr. Whitaker at Finchley.[3] There, beneath the Boulder Clay, he noted 17 ft. of brown clay, blue-mottled and with much 'race,' somewhat like London Clay; it rested on about 9 ft. of sand and gravel, largely composed of flint pebbles, beneath which was London Clay.

These beds of brown clay appear to be re-constructed masses or boulders of London Clay, and it was noticed at Hendon that in places the brown clay extended through the under-lying gravel down to the London Clay floor from which it had not wholly been severed.

The outlying patches at Dollis Hill and elsewhere are probably fluvio-glacial gravels laid down after the formation of the Boulder Clay and the retreat of the ice; they contain a smaller amount of the readily destructible Jurassic material than the main mass at Finchley. The gravels of Southgate and Belmont are, on the other hand, early glacial, but north-west of Enfield the Boulder Clay appears to rest on the ancient 'High Level' deposits.

In Essex gravels containing liver-coloured quartzite pebbles occur in Epping Forest up to 370 ft. above O.D.[4] The higher gravel of Barking Side, north of Ilford, shown on the map as River Gravel, has been grouped by Mr. Monckton with the deposits immediately succeeding the Boulder Clay.[5]

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[1] *See also* Hopkinson, J., *Proc. Geol. Assoc.*, vol. xx, 1907, p. 96, and Kidner, H., *ibid.*, vol xxi, 1909, p. 244

[2] *Quart. Journ. Geol. Soc.*, vol. xlvii, 1891, p. 575; *Proc. Geol. Assoc.*, vol. xii, 1892, p. 334; vol. xiv, 1896, p. 327.

[3] Geology of London, vol. i, 1889, pp. 309–311.

[4] Salter, A. E., *Proc. Geol. Assoc.*, vol. xiv, 1896, p. 394.

[5] *Essex Nat.*, vol. vii, 1893, p. 116.

Perhaps of somewhat similar age is the brickearth at the Upminster Pottery and brickyard, to the east of Martin's and north of Upminster Hall; a deposit which occupies a small area from 144 to about 150 ft. above O.D. It is about 20 ft. thick in the centre and occupies a hollow in Chalky Boulder Clay. Small patches of gravel are associated with the Boulder Clay of the north-east corner of our area.

South of the Thames undoubted glacial gravels containing Bunter pebbles are found only in one district; there are now three patches, in Richmond Park, on Kingston Hill and on Wimbledon Common, separated by the valleys of the Beverley Brook and Pen Ponds; but these must once have formed a continuous sheet. The finest section is at Coombe Warren, Kingston Hill, where the Urban District Council's pit has a face a quarter of a mile long and 8 to 20 ft. high. The total thickness is about 25 ft. The gravel consists mainly of southern material, including subangular blocks of resinous chert, pebbles of spongy chert, ironstone, sarsens, Chalk flints, some of them fresh and of great size, Tertiary pebbles and thick seams of sand which appear to be almost entirely Bagshot. Besides these, there is some 10 per cent. of northern material, such as quartz, quartzite, igneous rocks, Carboniferous cherts, veinstones etc.; the quartzite pebbles are sometimes as much as 9 in. long. The deposit is strongly current-bedded and, in the upper 6 ft., much contorted.

This pit is near the present southern limit of the gravel; at the northern end a small pit in Sidmouth Wood, Richmond Park, shows a markedly different composition; the same components are all present, but northern material forms more than half of the total.

On Wimbledon Common the gravel is more shingly, that is to say, there is less fine material, but this may have been leached out of the gravel by the copious springs, leaving only the pebbles; these are smaller and more angular than at Coombe, and the proportion of northern material does not exceed 10 per cent.

CHAPTER VIII.

PLEISTOCENE (*continued*).

River Deposits.

The Lower Thames Valley as we now see it is a broad tract of gravel and brickearth, traversed by the main river and intersected by numerous tributary streams which flow from north and south.

The deposits all bear evidence of having been distributed by fluviatile action, but under conditions different from those which exist at the present day. As Prestwich pointed out in 1863,[1] it is necessary to infer river-action of greater intensity, and floods of a more or less torrential character; such conditions may reasonably be attributed to a greater elevation of the land, and, to some extent, to a more rigorous climate.

The River Gravel, obtained for the most part ready-made from the older gravels that cap the hills on either side of the Thames, is formed chiefly of pebbles and subangular flints, with many pebbles of quartz and quartzite. Some materials, including flint-casts of Chalk fossils, may, of course, have been derived directly from Eocene pebble-beds or from the Chalk. There is a greater variety of stones in the gravel of the tributary streams on the north than on the south, owing to the fact that the Plateau gravels are there of local composition, while on the north occur extensive tracts of mixed Glacial Gravel as well as older Plateau Gravel.

Interbedded with the Gravel there is much sand, and in some cases the bulk of the deposit is sand. Peaty seams are occasionally met with. The gravel attains a thickness of 30 or 40 ft., and even more, but is not usually so thick.

To the Glacial Gravels may be attributed most of the erratic stones, such as the Bunter quartzites, occasional Jurassic fossils, and fragments of older stratified and igneous rocks. Limestone pebbles, such as occur in abundance in the Upper Thames Valley, are not met with, as they would have been ground to powder before reaching the present district.

Blocks of greywether or sarsen stone have been encountered here and there in the gravel—at Bayswater, Kensington, and at Grays, just beyond West Thurrock. These were probably derived from the Woolwich and Reading Beds, and may have been dislodged during Glacial times, as examples are met with in the newer Plateau deposits on the Chalk tracts near Rickmansworth. Specimens figured by Mr. T. V. Holmes from Grays Thurrock are very similar to those obtained at Croxley-green.[2]

The Brickearth or loam, a mixture of sand and clay, was, no doubt, formed largely from the destruction of London Clay and Bagshot Sand, and in part from other Eocene clays and sands. It is of variable character, and passes from a light sandy loam to a clay that seems to be little else than reconstructed London Clay. It appears to have been deposited for the most part in tranquil waters, and has been described as an inundation-mud. In some cases it has been held that the material may have been wind-drifted like some of the loess of northern Europe; and Clement Reid has suggested that desert or steppe conditions prevailed during the later parts of the Pleistocene period.[3] In

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[1] *Phil. Trans.*, 1864, pp. 250, 297, etc.
[2] *Essex Nat.*, vol. xiii, 1904, p. 197; Woodward, H. B., *Geol. Mag.*, 1891, p. 119; 1900, p. 543
[3] *Nat. Science*, vol. iii, 1893, p. 367; 'Origin of the British Flora,' 1899, p. 44.

thickness the brickearth varies from a few feet to 20 ft. or more.

Hydrated oxide of manganese is not uncommon in the Thames Valley gravels, where it is found, usually in association with ferric oxide, coating grains of sand and pebbles and forming black or blue-black seams.[1]

Fossils.

In a general sense the great mass of the Valley Gravel and brickearth belongs to the later Pleistocene period, when man occupied the district in association with a fauna, many of the members of which are extinct or no longer inhabitants of this country.

Brentwood, Uphall, and Ilford, West Thurrock and Grays (just beyond the limits of the map), Crayford and the Swanscombe area are the more noted localities where mammalian remains have been found in abundance, a fact which may be attributed for the most part to the extensive excavations made to obtain brickearth and gravel.

It is not possible in this work to give lists of fossils which characterise any one horizon or terrace exclusively, but certain general remarks may be made. The fauna of the oldest (Boyn or 100-ft.) terrace indicates a fairly warm climate; in the middle (Taplow or 50-ft.) many of the same forms survive, but others indicative of a colder climate appear, such as the reindeer and the musk-sheep (*Ovibos moschatus* Zimm.); so far as is known, the latter is confined to this horizon. In the lowest (Flood-plain) terrace the reindeer attains its acme, and the period represented has been termed by some writers 'the age of the reindeer.'[2]

The elephants, whose remains are among those most frequently found, do not afford much help; in the Thames and Somme Valleys *Elephas antiquus*, a warm-climate form, generally characterises the Boyn Terrace, being succeeded by the mammoth, but in Belgium the latter occurs in the earliest and in South France the former survives till the latest of the Palæolithic deposits.[3]

Beds containing remains of arctic plants have been found at several localities in, and especially near the base of, the Flood-plain gravels,[4] accompanied by mollusca and other fossils from which also a cold climate may be inferred. The physical characters of certain valley deposits also point to a cold period immediately following the deposition of the Taplow gravels

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[1] Hudleston, W. H., and F. G. H. Price, *Proc. Geol. Assoc.*, vol. iii, 1872, pp. 52–55; Hinton, M. A. C., *Sci. Gossip*, N.S. vol. vi, 1899, p. 146; Johnson, J. P., *Essex Nat.*, vol. xii, 1901, p. 133. *See also* Mackie, W., *Geol. Mag.*, 1902, p. 558.

[2] *e.g.* Wood, S. V., Junr., *Quart. Journ. Geol. Soc.*, vol. xxxviii, 1882, pp. 712–732, and many continental authors.

[3] 'Guide to the Antiquities of the Stone Age,' British Museum, 2nd Edition, 1911, pp. 43, 44.

[4] Abbott, W. J. L., *Proc. Geol. Assoc.*, vol. xii, 1892, pp. 346–356. Warren S. H, *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912, pp. 213–251.

(below). On the existence of such a cold stage all lines of argument converge and all authorities agree, but the brief outline of the palæontology given above is sufficient to draw attention to a curious anomaly. It has been assumed in the previous chapter that the Chalky Boulder Clay is older than the oldest (Boyn Terrace) river gravels; but the fossils of that terrace indicate a genial climate and seem to connect it with the Pliocene epoch: for instance, the giant beaver (*Trogontherium cuvieri*) found near Swanscombe is well known from the pre-Glacial 'Cromer Forest Bed.'[1] At the same locality a mollusc (*Theodoxus crenulatus* Klein, better known as *Neritina grateloupiana*) is found in abundance and is otherwise known only from the Upper Miocene of Germany. It is urged by some of those to whom we are much indebted for detailed work on the Pleistocene mollusca that the fossils indicate no break such as might be caused by an Ice Age between the Cromerian and the Boyn Terrace stages, but do show such a break in late Pleistocene times, after the beds with arctic plants just mentioned were formed. Accordingly the Chalky Boulder Clay must be newer, not older, than the river terraces. Since, however, only two species of mollusca, found in the Cromerian and in the river gravels, died out as a result of the late Pleistocene cold period, and 43 are still living in Britain,[2] this argument from their survival-values is not strong; and the possibility that some of the Swanscombe mammals and other forms are derived from the destruction of older deposits, and not contemporaneous, must not be overlooked. Were the Chalky Boulder Clay newer than the river terraces the section at Hornchurch, where T. V. Holmes described the river-gravels as resting on a shelf cut in that boulder clay, must have been wrongly interpreted; it was, however, accepted, while still visible, by many experienced geologists.[3] The advocates of a late Pleistocene date for the Chalky Boulder Clay have yet to produce a plausible explanation of the presence in all the river terraces of Bunter pebbles, igneous rocks, etc., usually considered to have been brought into the area by the ice. On the whole, we consider that the traditional view of the sequence of events must still be maintained.

Among the more interesting fossils found in the river gravels and brickearth and not yet mentioned are the bison and urus, wolf, beaver, great Irish elk (moose), hippopotamus (very frequent in the Flood-plain deposits), two species of rhinoceros, saiga antelope, brown and grizzly bears, a monkey and an interesting series of lemmings and voles which has been specially studied by Mr. M. A. C. Hinton.[4]

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[1] Newton, E. T., *Geol. Mag.*, 1902, pp. 385–388.

[2] Kennard, A. S., and B. B. Woodward, 'Post Pliocene Non-marine Mollusca of Ireland,' *Proc. Geol. Assoc.*, vol. xxviii, 1917, pp. 109–190 and table.

[3] Holmes, T. V., *Quart. Journ. Geol. Soc.*, vol. xlviii, 1892, pp. 365–372; vol. l, 1894, pp. 443–452 and discussions.

[4] *Proc. Geol. Assoc.*, vol. xvii, 1902, pp 414, 415; vol. xx, 1908, pp. 39–58; vol. xxi, 1910, pp. 489–507.

More or less complete skeletons of mammoth have been obtained at Ealing, Endsleigh Street (London), Ilford and West Thurrock.

Bones of goose (*Anser*) have been obtained at Ilford and Crayford. Remains of frogs and toads and of the grass snake (*Tropidonotus natrix*) have been found near Grays.

Remains of the freshwater fishes—dace, pike, roach, rudd, and ruff—have been recorded from Grays; the pike also from Ilford.

Stratigraphy.

It has been suggested that the different types of flint implements might supplement the evidence of fossils for the establishment of definite horizons in the river gravels; a fairly definite sequence of these types has been established on the continent, and much work has been done towards establishing this sequence in England; but before a zonal classification of geological deposits is accepted, it must be shown that it agrees with the stratigraphical sequence where normally developed. Unfortunately, the stratigraphy of the river deposits is, from their nature, difficult to decipher with certainty. For our present purpose it will be best to describe the stratigraphy first, then to give a brief resume of the time-sequence of the flint implements, and finally to discuss the extent of the agreement between the two.

Nomenclature.—The Thames gravels and associated brickearths along the main valley were originally divided by Prestwich into high-level and low-level deposits. At a later date Mr. Whitaker recognised three terraces which can be separately mapped over the greater part of our area, though they are much less distinctly separated in some parts than in others. These terraces are shown by different colours and symbols on the new maps in course of publication, but are not distinguished on the four Special London Sheets; they were described by Mr. T. I. Pocock as Upper, Middle and Lower Terraces.[1] Unfortunately, a fourth higher terrace was at one time thought to exist, and consequently a numerical system was used; but some writers numbered the terraces from above, others from below; accordingly the upper terrace has been called the first and the third and, by those who recognised four in all, the second. Another method of naming the terraces was by the height above Ordnance datum at which they occur. Mr. Pocock (*op. cit.*) shows that the upper and middle terraces of the Thames maintain an almost uniform level from Staines to Grays, that is to say, throughout our area, corresponding approximately to the 100-ft. and the 50-ft. contours respectively. The terraces have often been spoken of as the 100-ft. and the 50-ft. But the only true basis for such a

[1] 'Summary of Progress for 1902' (*Mem. Geol. Surv.*), 1903, Appendix viii, pp. 199–209.

terminology is the level of the shelf or terrace in the 'solid' rock on which the gravels rest as a floor; this figure is not always readily obtainable and, in a single spread, increases with the distance from the river; when the terraces are traced further up the Thames or up the tributary valleys confusion is inevitable.

When the systematic re-survey of the London District on the 6-inch scale was undertaken in 1910, beginning from the neighbourhood of Maidenhead, it was decided to adopt a new nomenclature which should involve no presuppositions. Gravel terraces occur in that district at Boyn Hill some 70 ft. and at Taplow some 20 ft. above the local river level. At both localities flint implements occur, and at Taplow Station[1] pit a fine series of mammalian fossils was found.[2]

These were chosen as type localities and the names Boyn Hill or Boyn Terrace and Taplow Terrace were adopted, and will be found on the 6-inch maps and in the New Series One-inch Sheets 255, 256, 269, 270; the lowest gravels lying in the valley bottom were called Flood-plain gravels. One result of the re-survey has been to indicate the existence of three, and only three, main divisions of the river deposits, and in consequence we can safely speak of the Upper (Boyn, or 100-ft.), Middle (Taplow or 50-ft.) and the Low (Flood-plain) Terraces.

The Upper Terrace.—On the north side of the Thames the Upper Terrace is found south of Iver and Hillingdon in the west. Its lower limit is here about at the 100-ft. contour, and is also the upper limit of the Middle Terrace, the division being marked by a sudden drop in the level of the London Clay beneath; a similar feature occurs between the Middle and Lower Terraces further south and here and there causes an outcrop of the London Clay, but the line with which we are now concerned is frequently obscured by the subsequent descent of the upper gravel and by the overlap of the later Brickearth; excavations have revealed the 'buried' cliff near Osterly Park.[3] The upper limit is clearly seen at Iver and at Hillingdon Heath, where it runs up to about 160 ft., but the deposit there may belong more to the Colne than the Thames; in the former valley and that of its tributary, the Gade, the Upper Terrace rises as high as 280 ft., but becomes merged in the Glacial Gravels. The Brent, on the other hand, is a newer stream and has cut through the Upper Terrace of the Thames, which is also interrupted by the low ground round Shepherd's Bush. The gravel of Castlebar Hill, Ealing, is probably an outlier of this terrace, but that on Hanger Hill (shown on Sheet 1 of the map surrounded by Brickearth), appears to be Glacial gravel capping an outlier of Claygate Beds. Further east this terrace has been wholly removed by denudation except at the outliers of Islington and Highbury. The gravels of the

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[1] Formerly called Maidenhead: not the present Maidenhead Station on the Berkshire side of the river.

[2] Owen, R., *Quart. Journ. Geol. Soc.*, vol. xii, 1856, pp. 124–130; Dawkins, W. B., *ibid.*, vol. xxv, 1869, p. 198.

[3] Brown, J. Allen, *Proc. Geol. Assoc.*, vol. x, 1888, p. 362.

Lea appear to be almost entirely Middle and Lower Terrace, within our area, but east of that river there are wide spreads of Upper Terrace gravel; the first forms the highest ground at Wanstead, and falls from 120 ft. in the north to 90 ft. in the south; this patch must be regarded as Thames gravel, since a deposit of the Lea in that locality would fall from east to west. Beyond the Roding, a great area of gravel of this terrace is found round Barking Side, and small patches continue through Romford, Hornchurch (p. 46) and Upminster; some of the gravels north of West Thurrock may also belong to this terrace.

On the south side of the Thames the large spread of Upper Terrace gravel on Walton Common appears to belong jointly to the Wey and Mole; corresponding gravels belonging exclusively to the Wey occur in the neighbourhood of Addlestone and Woodham. Owing to the southern encroachment of the Thames between Windsor and Richmond (p. 63) it is only east of the latter locality that we find the Upper Terrace of the Thames; little outliers may be noticed on the northern margin of Richmond Park and north of Roehampton. The valley of the Wandle cuts through the line, which is continued past Wandsworth and Clapham Commons, the gravels of which may be referred partly to the Wandle and partly to the main stream; further south the gravel extending from East Croydon to Thornton Heath belongs to the Upper Terrace of the Wandle.

Traces of Upper Terrace gravel have been detected south of Camberwell and in Lewisham, but no large expanse is found till we reach the Dartford area; Dartford Heath is formed by this deposit, which attains the great thickness of 50 ft., the base-level being about 88 ft. above Ordnance datum; this gravel contains many 'foreign' rocks derived from the Boulder Clay, including the peculiar Rhaxella chert from the Corallian formation.[1] It has been described fully by Messrs. Chandler and Leach, whose papers will be further referred to when we come to deal with the flint implements.[2]

The gravel of Dartford Brent was no doubt continuous with that of the Heath, but is now separated from it by the valley of the Darent. Important sections in the Horns Cross gravel have been described by Mr. S. Priest,[3] and on the extreme eastern margin of the map is a part of the Swanscombe deposit, famous both for the fossils already alluded to and for the implements to be discussed below.

It will be seen from the above that, as Mr. T. I. Pocock pointed out, the fall seawards of these gravels is, for the main valley, practically negligible throughout our area, not exceeding 15 ft. in a distance of 37 miles. The deposits are usually, where

[1] A siliceous rock having the appearance of a fine-grained oolite, in which the minute structure of the sponge *Rhaxella* can be recognised. Newton, E. T., *Proc. Geol. Assoc.*, vol. xx, 1907, p. 127.

[2] *See especially Proc. Geol. Assoc.*, vol. xxiii, 1912, p. 102, and vol. xxiv, 1913, pp. 337–344.

[3] *Proc. Geol. Assoc.*, vol. xxvi, 1915, pp. 78–85.

undisturbed, well stratified, layers of sand and of loam occurring with the gravel, though the latter is frequently very coarse, especially towards the base.

The Middle Terrace.—After the deposition of the Upper Terrace the river again began to deepen its bed, lowering the level some 30 ft. before deposition was renewed, and the Middle Terrace formed. This terrace occupies a larger area than the upper and its gravels are accompanied by important deposits of brickearth.

In the Colne Valley it occurs at Denham and at Mill End, where it contains implements. In the main valley it forms a wide spread extending from West Drayton and Staines to Brentford and Hampton; its lower margin, concealed by the banking of Low Terrace deposits near Staines, was revealed when the reservoirs were built;[1] it is separated from them by outcrops of London Clay at Hanworth Park, Hampton, Twickenham, and between Isleworth and Brentford. Over the northern part of this spread brickearth occurs, sometimes as much as 20 ft. thick; the deposit has been largely utilised and is almost worked out. A good section of the gravels, some 20 ft. in height and yielding implements, may be seen near Hanwell Railway Bridge. East of the Brent this terrace is found at Ealing and Acton, the lower margin practically coinciding with the upper limit of the Low Terrace Brickearth. Another large area stretches from Paddington and Kensington to the Lea Valley. The lower limit runs from Holland Park past the Albert Hall to Knightsbridge, across the Green Park, along Jermyn Street, and thence to the river bank at Charing Cross. The valley of the Fleet cuts through the gravel, but the City is built on Middle Terrace deposits, both gravel and brickearth, the latter having been worked in Roman times. This gravel area has had a great influence on the location and growth of London (p. 89). Many important sections have been laid open at various times, notably at the site of the Law Courts[2] and at Endsleigh Street, the latter famous for its fossils[3]; mammoth, horse and red deer were found in the gravel, while at the base was a loam bed containing seeds; these were identified by Clement Reid, and all belong to species now living in Middlesex; the period of cold climate can, therefore, hardly have begun. The Middle Terrace gravels of the Lea form a band whose lower margin is about 1 mile west of the river; the sections at Stoke Newington and Clapton[4] are famous. East of the Lea, deposits of this age extend from Wanstead Flats to the margin of our area; they include several patches of brickearth overlying the gravel, notably that at Ilford, which has yielded many fossils, including mammals and other vertebrates and molluscs.[5]

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[1] 'Geology of Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, p. 75.
[2] Hudleston, W. H., *Proc. Geol. Assoc.*, vol. iii, 1874, pp. 43–64.
[3] *Quart. Journ. Geol. Soc.*, vol. xlviii, 1892, pp. 453.
[4] Smith, W. G., 'Man the Primeval Savage,' 1894, pp. 189–294.
[5] *See* Hinton, M. A. C., *Proc. Geol. Assoc.*, vol. xvi, 1900, pp. 271–281; Kennard, A. S., and B. B. Woodward, *ibid.*, pp. 282–286.

On the south side of the Thames we find Middle Terrace deposits of the Wey and Mole, consisting mainly of sand from the Bagshot Beds; these may be traced to Surbiton and also occupy much ground (more than is shown on the map Sheet 3) in the valley extending from Kingston to the Wandle at Merton; the meaning of this distribution is discussed below (p. 64). Narrow bands of Middle Terrace gravel of the Thames are found at Mortlake and Putney, but further east the river has cut away all the deposits, and low level gravels or alluvium abut against a 'cliff' of Tertiary Beds and Chalk as far as Erith. The southern tributaries, however, have important gravels of the Middle Terrace. Those of the Wandle form the surface around Mitcham and as far south as Beddington; they have yielded fossils and implements. It appears probable that the gravels in the valleys of the Ravensbourne, Cray, Darent and other tributaries belong in the main to the Middle Terrace period; in several cases the streams now rise far below the point to which the gravels can be traced up valleys that are now dry.

Between Erith and Crayford is a stretch of brickearth in which many pits have been opened and of which many descriptions have been written;[1] it appears to belong to the end of the Middle Terrace period, that is to say, the Mousterian stage of palæolithic culture (p. 69), but the gravels of this area seem to be continuous from the 50-ft. level to the bottom of the buried channel, and consequently no line can be drawn between the Middle and Low Terraces; the confusion may be due to changes in the course of the main river (p. 64).

The Low Terraces.—The deposits at lower levels than the Middle Terrace are not as simple as some writers have taken them to be; they descend below the present level of the river and east of London far below sea-level; consequently open sections are seldom seen. The evidence available suggests that there may be two periods of deposition, the gravels of which are not clearly to be differentiated by their level. From Brentford eastward it is sometimes possible to trace an upper and a lower Flood-plain gravel, and in the same area we find evidence from borings and excavations of a deep channel of the river descending in the east of our district as much as 100 ft. below Ordnance Datum. Probably the two phenomena are connected, and the sequence of events appears to have been as follows: after the deposition of the Middle Terrace gravel and brickearth a period of corrasion ensued, and the river lowered its base level some 20 ft.; deposition of the upper Flood-plain gravels and brick-earth ensued, a cold climate being indicated at the base of the gravel. Later a fresh elevation of the land enabled the river to cut the 'buried channel'; this channel is narrow and gorge-like, and cannot be traced above Brentford; its gradient is steep, compared with that of the Upper and Middle Terraces, about

[1] *e.g.*, 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 432–439; Chandler, R. H., *Proc. Geol. Assoc.*, vol. xxv, 1914. pp. 61–71; vol. xxvii, 1916, pp. 72–76 and references there given.

80 ft. in 20 miles. Before the river was able to widen or grade its valley deposition of gravel began, and the deep channel was filled up practically to the level of the Upper Flood-plain.' Hence gravels laid down before or after the cutting of the deep channel cannot be distinguished except where a series of borings has revealed the form of the cross-section of the base, and the term 'Low Terrace' or Flood-plain gravels must cover both.

Between Staines and Brentford a band of Low Terrace gravels with patches of overlying brickearth is found between the lower margin of the Middle Terrace and the river except at Hampton, where that line touches the river. These beds are probably for the most part older than the buried channel; remains of reindeer are very common, together with many species found also in the Middle Terrace (*e.g.*, the hyena, bison, wild boar); the reindeer and saiga antelope appear to be new arrivals. Most of them have been recorded from Twickenham,[1] the last named there only; a few plant remains were also found.

Another important area of Low Terrace deposits extends from Brentford to Westminster and runs up as far north as Wormwood Scrubbs between the higher ground of Acton and Holland Park. Many mammals and molluscs, including among the latter the extinct fresh-water mussel *Unio littoralis*, have been found a little north of Kew Bridge. The 'island' of gravel and sand on which Westminster was founded—Thorney Island —belongs to the Flood-plain, as do all the eyots on which the ancient hamlets around London, such as Chelsea, Battersea and Bermondsey, were built. At the Admiralty Buildings Mr. Lewis Abbott found a large number of fossils, both mammals and molluscs, as well as the plant-bed with arctic birch; he noted that in the basal bed, 'large boulders forming a layer, had been driven *into* the London Clay and all their tops planed off and striated.'[2]

It is from deposits of this age in the Lea Valley that most of our knowledge of the period is derived; they extend along the west bank of the river throughout our area, and several large pits have been opened in the gravel. In certain of them at Ponder's End and Angel Road Mr. Hazzledine Warren discovered a peaty bed containing plants, mollusca, etc., indicative of a cold climate about equivalent to that of Lapland to-day.[3] The date of the deposit appears to be very late in the palæolithic sequence, considerably later than that of the Admiralty bed. It may be that the 'Buried Channel' stage intervenes, and that these two arctic beds belong to the Lower and Upper Flood-plain gravels respectively, but 'without further evidence one could not,' as Mr. Warren remarks, 'suggest two separate arctic stages so near together as that of the Admiralty Buildings and Ponder's

[1] Leeson, J. R., and G. B. Laffan, *Quart. Journ. Geol. Soc.*, vol. l, 1894, pp. 453–462.

[2] *Proc. Geol. Assoc.*, vol. xii, 1892, pp. 346–356.

[3] 'Late Glacial Stage in the Lea Valley,' *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912, pp. 213–228, seven appendices and 3 plates.

End ' (*op. cit.*, p. 222, *footnote*). The maximum thickness at Ponder's End is 22 ft., including a few feet of the brickearth overlying the gravel.

East of the Lea the division between the Middle and the Low Terraces exists, but is frequently ' buried ' and difficult to follow exactly; on the south of the river it hardly exists.

On the south side of the Thames the low gravels are well developed; west of the Wey we find a large area, partly within the map, between Egham and Thorpe, and an eyot of gravel on which Chertsey is built. The great spread near the mouths of the Mole, between Walton and Ditton, may be connected with the change in the course of that river (p. 64). Ham Common again is formed of Low Terrace gravel, the Thames having now migrated to the west from its old cliff between Kingston and Richmond. Similarly, from Richmond to Greenwich we find areas of low-level gravel included between the rising ground of the London Clay and the successive northerly loops of the present course of the river. Probably this deposit is as a whole newer than the buried channel, since that feature can be traced through it, and the beds with late implements and that with *Pseudunio auricularius* (Spengler) occur.

From Greenwich to Erith the Holocene alluvium abuts against the Chalk and Tertiary rocks. In the bay between Erith and Greenhithe at the mouths of the Cray and Darent some of the gravel is, no doubt, of the same age as one or both parts of the ' Low Terrace '; but it is continuous with deposits which must clearly belong to the Middle Terrace. Mr. R. H. Chandler has shown that this gravel can be traced from beneath the Crayford brickearth to about 100 ft. below Ordnance datum.[1]

The Coombe Deposits and Trail.—Besides the bedded gravels and brickearths which have been laid down at various periods by the rivers, there are deposits which, although occurring in the valleys, show little sign of arrangement by running water. In many of the smaller valleys, more particularly in Kent, we find the bottom filled with an accumulation of mixed material to which the name ' Coombe Deposits ' may be given.[2] These masses have been formed by the descent of material from the sides of the valleys and take their character from that of the deposits available at any spot: thus, in the valley starting near Bean and opening into the Thames at Greenhithe (Sheet 4) the Coombe Deposits include gravel from the High Terrace deposits, a sandy loam formed of Tertiary material and best described as brickearth—it has, indeed, been used on a small scale for brickmaking—and chalk rubble. The last resembles the deposit known as ' Coombe Rock,' the origin of which has been discussed by Clement Reid,[3] and the whole assemblage has probably been

[1] *Proc. Geol. Assoc.*, vol. xxv, 1914, pp. 61–71, and fig. 3.
[2] ' Summary of Progress for 1920 ' (*Mem. Geol. Surv.*), 1921, p. 9.
[3] *Quart. Journ. Geol. Soc.*, vol. xliii, 1887, pp. 364–373.

formed in the same way; the period of formation appears to be that of the down-cutting between the Middle and the Low Terraces and of the cold period at the base of the latter.

A good example may be seen at East Wickham, where the valley has been described as an 'adult coombe.' It is filled to a maximum known depth of 30 ft. with brickearths, gravels and chalk rubble (Coombe Rock) which have yielded mammalian fossils including the musk-ox (*Ovibos moschatus*).[1] At Wallhouse Farm, between Erith and the mouth of the Darent, a chalk rubble has been noted beneath low-lying gravel;[2] where such a rubble is overlain by Pleistocene deposits its upper surface is frequently re-cemented by lime, a phenomenon which sometimes serves to distinguish Eocene deposits *in situ*, beneath which this 'calcrete' is never found, from similar material subsequently moved and re-arranged. The deposits in the valley leading to Greenhithe have already been mentioned; they can be seen to a depth of 20 ft. and may be much thicker; neither fossils nor implements have been found here, but at Northfleet, a few miles to the east, remains of mammoth and implements of Mousterian type are abundant on the surface of the solid chalk beneath Coombe Rock.[3] Coombe Deposits may also be seen in the Chalk area of Purfleet and West Thurrock.

It is probable that much of the gravel found in the dry valleys of the Chalk area is of the nature of a Coombe deposit, as it shows little or no sign of stratification by flowing water; the process of formation may be slowly continuing at the present day. In the upper parts of the Darent Valley, as noted by Prestwich,[4] there are accumulations of white chalk rubble which merge downwards into undisturbed Chalk. The rubble contains broken flints and occasional Eocene flint-pebbles, and appears to be of older date than a local red rubble which has been derived by downwash from the Clay-with-flints. In the gravels of the Ravensbourne valley near Hayes Common and West Wickham remains of reindeer, mammoth, horse, and rhinoceros have been found, and at Green Street Green in the upper part of the Cray Valley the musk-ox occurs as well.

With the Coombe Deposits we may describe what is known as 'Trail,' a term introduced by the Rev. O. Fisher in 1866 to include tumbled and frequently contorted material which forms the surface layer over wide areas; it appears to have been formed by movement down a slope of semi-fluid masses comparable with 'the flowing soils of northern lands which arise from the snow and frozen earth partially thawing in summer and sliding downhill with their burden of rubbish.' Here and there such flows have dragged up the underlying strata into waves or festoons which may be overfolded in the direction of movement; in these

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[1] 'Geology of London' (*Mem. Geol. Surv.*), vol. i, 1889, pp. 431, 432; *Proc. Geol. Assoc.*, vol. xix, 1906, pp. 341–347.
[2] *Proc. Geol. Assoc.*, vol. xxv, 1914, p. 66.
[3] Smith, R. A., and H. Dewey, *Archæologia*, vol. lxiv, 1913, p. 195.
[4] *Quart. Journ. Geol. Soc.*, vol. xlvii, 1891, pp. 126–163.

cases, where parts of the contorted material are in continuity with that which is undisturbed, the term 'underplight' has been used by Spurrell.[1] Though the formation of Trail may to a small extent have taken place throughout a long period and even continue at the present day, there are two lines of evidence which suggest that it belongs mainly to a single definite epoch. The phenomenon may frequently be observed in beds of all ages up to the Low Terrace gravels, into which the Trail appears to merge; and mammals and other fossils indicative of late Pleistocene age have frequently been found, as, for instance, hippopotamus at Wembley Park[2] and mammoth at New Malden in Trail consisting mainly of London Clay; again the character of the deposit strongly suggests a cold climate. The combined evidence points to a period immediately after the Middle Terrace;[3] in other words, the Trail is equivalent to the Coombe Deposits but is material which has not actually reached a position of rest at the bottom of a valley.

A good example of Trail was described by Hudleston on St. George's Hill, where laminated lilac clay of the Bracklesham series may be seen to be nipped up and contorted (the underplight), the hollows being occupied by disturbed masses of gravel, with green sands and loams derived from higher parts of the Bracklesham Beds. He remarked 'it is not difficult to imagine that, when the climate was colder, the steep northern slope of St. George's Hill was occupied by a kind of *névé*, or a sliding mass of indurated snow. This, adhering to the greensand beds, caused large masses of them to slide downwards involving also a portion of the original plateau; hence the occasional jambs of flint gravel.'[4]

To the same group of phenomena belongs the descent of the Upper Terrace gravels, at their margin, to rest on the surface of the Middle Terrace, between West Drayton and Ealing. Here and there Mousterian working-sites have been discovered on the surface of the old Middle Terrace preserved by the overlying Trail from the terrace above (p. 68), affording another indication of the date of the movement. Throughout the London Clay area Trail is constantly found, and frequently small deposits of gravel, which may yield fossils or implements, are completely buried. Mr. G. E. Dibley tells us that he has detected gravel terraces at many points along the western bank of the Pool River, but owing to the layer of clay that has slipped from the higher ground they can be seen only when excavations are made. There are notable instances of Trail in the brickearth and gravel that extend eastwards from Ilford to Purfleet and Grays. In the tract near the latter town the superficial disturbances, very suggestive of glacial action, have been attributed by Mr. T. V.

[1] 'History of the Rivers and Denudation of W. Kent,' Greenwich, 1886.
[2] *Quart. Journ. Geol. Soc.*, vol. xlviii, 1892, p. 468.
[3] Dewey, H., *Proc. Prehist. Soc. E. Anglia*, vol. ii, 1915, pp. 114, 115.
[4] *Quart. Journ. Geol. Soc.*, vol. xlii, 1886, pp. 169, 170.

Holmes to the effects of river-ice.[1] The Trail near Crayford has been described and discussed by Mr. Chandler[2]; that in the Darent Valley by Prestwich.[3]

The Buried Channel.—The date of the Buried Channel is not far distant from that of the Trail and Coombe deposits, though whether it is slightly earlier, contemporary, or slightly later is difficult to determine. Possibly the melting of the snows that had accumulated during the arctic period contributed to its formation, which was evidently rapid, since it is narrow, straight, comparatively steeply graded, and can be traced only a short distance up the main stream or the tributaries. As already mentioned, it first becomes noticeable near Brentford and thence follows a fairly straight course through Fulham and Battersea, where depths of 35 ft. are known, to Nine Elms, where as much as 72 ft. of river deposits have been proved, giving the level of the bottom as 60 ft. below Ordnance Datum. Through the remaining part of London it appears to keep near the Tertiary outcrop which forms the southern bank of the Thames valley. The Bakerloo Tunnel beneath the river showed 80 ft. of superficial deposits at one spot, but records in the immediate neighbourhood show that this depth is not due to the Buried Channel, but to the encountering of an old shaft sunk in the river-bed many years ago for a proposed 'pneumatic railway'; this shaft collapsed and became filled up with river ballast.

Traces of the Buried Channel have been found in the valley of the Lea, Mr. T. V. Holmes recording that at one spot the section opened for the construction of the reservoirs near Walthamstow showed the surface of the London Clay to be 57 ft. below the river level.[4] Other records in the main valley are 50 ft. at Greenwich, 60 at Albert Dock, 70 at Beckton, while at Erith an unbottomed depth of 70 ft. has been recorded in the valley of a little tributary stream.[5]

River Development and Topographical Evolution.

From the nature and distribution of the deposits described above, it is possible to deduce certain changes that have taken place in the courses of the Thames and its tributaries. The evolution of the Thames has been a favourite subject for speculation amongst geologists and geographers for nearly a century, but a discussion of the widely differing hypotheses put forward would necessarily take us far beyond the limits of our map and the scope of this memoir.

An attempt has been made to trace the pre-Glacial course of the Thames through a part of our area.[6] It is thought to have passed through Rickmansworth and Watford, but at the period

[1] *Proc. Geol. Assoc.*, vol. xii, 1891, p. 197.
[2] *Ibid.*, vol. xxv, 1914, pp. 66, 67, and Plate 10.
[3] *Quart. Journ. Geol. Soc.*, vol. xlvii, 1891, pp. 153, 154.
[4] *Essex Nat.*, vol. xii, 1902, p. 226.
[5] *Proc. Geol. Assoc.*, vol. xxiii, 1912, p 186, and vol. xxv, 1914, p. 64.
[6] Sherlock, R. L., and A. H. Noble, *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912, pp. 199–212.

of the Glacial Gravels it seems to have been much further south. We have seen that at Richmond Park and Wimbledon materials from north and south mingle after their descent from the Chilterns and North Downs respectively; here, therefore, we must have the valley-bottom at the period of formation, some 150 to 180 ft. above the present water level. This valley was occupied by a river flowing, roughly, from west to east like the present Thames, but whether its sources lay within the Chalk rim, on the Jurassic outcrops, or in the Welsh mountains, as various writers have suggested, cannot be discussed now. That the tributaries of this river corresponded with those of the present Thames may be inferred, since, on the south side at any rate, the distribution of the Plateau gravels points to the existence of gaps in the Chalk escarpment near Guildford, Dorking, Croydon and Shoreham.

The main river now deepened its valley by some 80 ft. and then deposited the Upper Terrace Gravels. Henceforward it is possible to trace the positions of the main and tributary streams to various periods and to indicate with some confidence the changes that have taken place. Wherever river-deposits occur, we have a relic of the floodplain on which the river meandered at that time, and wherever such relics are bounded by higher ground we have a limit to that plain. Thus, in Upper Terrace times the northern limit of the Thames plain ran from Iver to near Acton Station, and again from near Wanstead to Romford and Hornchurch, while the southern bank is preserved from Richmond through Roehampton and Clapham to Camberwell. Near Dartford there must have been a loop to the south through Erith, Crayford, Dartford Heath and Wilmington, and thence north of east to Stone Castle. On the same principle, we see that the larger tributaries have, for the most part, kept to the same general courses, but the Lea has shifted its course steadily eastward and now hugs the eastern bank of its valley, and the same is true to some extent of the Wey and the Mole. The Wandle, whose upper waters originally occupied the Purley valley, laid down vast masses of gravel when it reached the Tertiary plains at Croydon; these gravels deflected the course of the stream further and further west, till it now flows due west as far as Wallington and then turns north again along the western margin of the gravel spread.

Certain important changes in the courses of the rivers can, however, be detected. Between Maidenhead and Richmond the Thames takes a great loop to the south, partly interrupted by the Chalk inlier of Windsor; the greater part of this loop is included in Sheet 3 of the map, of which it occupies nearly half. From the neighbourhood of Maidenhead, where it leaves the main Chalk area, the river seems, in Upper Terrace times, to have flowed nearly due east, the limits of the valley being marked on either side at Ealing and Richmond respectively; on its northern bank the Colne entered, bearing with it large masses of gravel derived from the great spread of glacial deposits.

These gravels had the effect of pushing the main stream gradually southwards, the Colne being broken up into a number of 'distributaries,' as in a delta. In Middle Terrace times the most southerly point reached by the Thames was Hampton, but subsequently it almost reached Weybridge, the most southerly point of its course at the present day being the backwater near Shepperton Lock. This southerly encroachment by the main river has materially altered the courses of the southern tributaries, which must obviously have been longer, when the Thames was further north, than now. It seems likely that the Wey followed a north-easterly course to join the Thames near Ealing; the deposits of that terrace there contain masses of sand resembling Bagshot Sand, and a lenticle of highly glauconitic material, apparently derived from the upper part of the Bracklesham Beds, has been found by Mr. F. N. Haward. While this former course of the Wey has been eroded away and is consequently hypothetical, a part of the valley of the Mole has been preserved to the south of the Richmond and Wimbledon plateau. On the southern bank of the dry valley between Kingston and Merton relics of a high river-terrace occur, and the bottom is occupied by large spreads of sand and gravel which appear to belong to the Middle Terrace; over much of the area, however, these deposits are concealed by a layer of clay washed down from the hills practically indistinguishable from London Clay *in situ*; excavations have revealed the existence of the river deposits at a number of localities where they are not shown on the map. It is certain that this valley was formed by a river draining a tract of Bagshot Sand, flowing west to east to join the Wandle; it laid down deposits belonging to the Upper and Middle Terraces and encroached on its left or north bank. After the Middle Terrace period this river ceased to flow. It seems a reasonable inference that it was the Mole, and that by its southward encroachment the Thames broke laterally into the valley between Middle and Low Terrace times. That part of the valley which is now unoccupied is drained in part by the Hogsmill, which may have been a southern tributary, and in part by the Beverley Brook. The latter probably had its original source in the Glacial gravels of the Wimbledon Plateau.

Another example of 'capture by lateral encroachment' occurs near the western margin of our map; the gravel-filled valley parallel to and south of the railway through Chertsey is now dry; it represents the former course of the Chertsey Bourne, which has been diverted into the Thames flat a little further west. This instance of diversion is remarkably clear and has been described in detail elsewhere.[1]

There have evidently been considerable changes in the course of the Thames near our eastern margin. At the period of the Upper Terrace the river came as far south as Dartford Heath;

[1] 'Summary of Progress for 1911' (*Mem. Geol. Surv.*), 1912, pp. 74—77; *Proc. Geol. Assoc.*, vol. xxiv, 1913, pp. 331–314; 'Geology of the Country around Windsor and Chertsey' (*Mem. Geol. Surv.*), 1915, pp. 88–90.

during part, at any rate, of that of the Middle Terrace, it seems to have flowed to the north of the Purfleet and Grays Chalk ridge, subsequently returning to the south side. The deposition of the Crayford Brickearth and the absence of any break between the Middle and Low Terraces may be connected in some way with these changes, and the present valley below Purfleet and Dartford is, compared with that above, somewhat gorge-like in character.

No important changes in the physiography since the time of the Low Terrace cold period can be detected. The variations in the character of the Coombe deposits show that the distribution of outliers of gravel and of Tertiary strata was already much the same as to-day, and the same inference may be drawn from the occurrence of palæolithic implements on the Chalk plateau, since they are found most abundantly near the present outcrops of the Bullhead Bed and the gravelly margins of the Clay-with-flints.[1]

The existence of numerous dry valleys in the Chalk area has been taken to indicate a change in the climatic conditions. Many of the valleys occupied by streams can be followed far above the springs at which those streams normally originate; in some we find 'bournes,' that is, streams which flow only at intervals, when the natural water-level rises temporarily, causing springs to be given out at various points further up the valleys. Descriptions and statistics of these bournes are given in the memoirs on Water Supply.[2] The point where a dry valley becomes a wet one varies, therefore, according to the season, and if the annual rainfall was formerly greater than now, a greater length of the Chalk valleys would have been subject to erosion by streams; but on a porous stratum, such as the Chalk, valleys cannot be initiated in this way. Clement Reid has suggested that certain Chalk valleys may have been formed by the action of summer rains after cold winters on the frozen and consequently impervious surface of the Chalk.[3] Other writers have accounted for these coombes by a cause which is active at the present day, the removal of chalk in solution by percolating waters. Rain water, running off the clay which frequently caps the high ground, enters the Chalk by means of swallow holes and tends to follow the natural joints in the rock; some of the chalk is removed along these lines and in this way a 'master-joint' is formed, carrying an underground stream like those known to occur in the Chalk. The constant widening and deepening of this line of weakness at length produces a deeply sunk valley, in which a stream appears at the point where the base-line cuts the water-table.[4] A study of the ground plan of the valleys,

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[1] Dewey, H., 'Surface-changes since the Palæolithic Period in Kent and Surrey,' *Proc. Prehist. Soc. E. Anglia*, vol. ii, 1915, pp. 107–116.

[2] 'Water Supply of Kent' (*Mem. Geol. Surv.*), 1908, pp. 54–63; 'Water Supply of Surrey' (*Mem. Geol. Surv.*), 1912, pp. 61–71; 'Records of London Wells' (*Mem. Geol. Surv.*), 1913, pp. 25–29.

[3] *Quart. Journ. Geol. Soc.*, vol. xliii, 1887, pp. 369–371.

[4] *See, for instance*, Young, G. W., *Proc. Geol. Assoc.*, vol. xix, 1905, pp. 191–193; Spicer, Rev. E. C., *Geog. Journ.*, vol. xxxii, 1908, pp. 288–291; Chandler, R. H., *Geol. Mag.*, 1909, pp. 538, 539.

which follow a major and a minor direction at right angles to each other, tends to confirm this theory.

Flint Implements.

We have kept the subject of the associated flint implements to the last division of our account of the River Deposits, because of the large number of unsolved problems involved. The occurrence in the gravels of the Thames of stone implements made by man has been known for more than two centuries: about the year 1690 a 'British weapon' was found together with an elephant tooth at Black Mary's Hole near Gray's Inn Lane, and is now in the British Museum. During the 19th century large numbers of implements were collected, but for the most part it is only of recent years that they have become the subject of a science rather than of a hobby. This science was developed on the continent, where a series of types of culture has been named from important localities and arranged in a chronological order; the accompanying table gives these divisions with the forms of implements most characteristic of each; it is taken mainly from Mr. R. A. Smith's short paper on 'The Classification of Palæolithic Stone Implements'[1]; the subject, as a whole, should be studied in his British Museum Guide[2] and in Professor Sollas's fascinating work.[3]

Classification of Ancient Stone Implements.

Upper Palæolithic.	Cave Period.	Magdalenian (La Madeleine)	Long blades and minute tools, borers, &c.
		Solutrian (Solutré).	(II) Points with shoulder on one side (*pointes-à-cran*). (I) Lozenge- and leaf-shaped blades, finely chipped.
		Aurignacian (Aurignac).	Planing tools with steep sides, pointed blades with one edge battered.
		Mousterian (Le Moustier).	Scrapers (*racloirs*) made of flakes worked on one face.
Lower Palæolithic.	River Drift Period.	Acheulian (St. Acheul).	Amygdaloid implements, finely flaked and often twisted.
		Chellean (Chelles).	Hand-axes (*coups-de-poing*) often pear-shaped or flat oval, coarsely flaked.
		Strepyan (Strépy).	Nodules, flaked, generally at the point.
Eolithic	Plateau Drift.		Nodules, rudely chipped on parts of the edges only to form single or double scrapers, borers, etc.

[1] *Proc. Geol. Assoc.*, vol. xxiii, 1912, pp. 137–147.
[2] 'Guide to Antiquities of the Stone Age', British Museum, 2nd Ed., 1911.
[3] 'Ancient Hunters,' London, 2nd Ed., 1915.

The earliest division in the table, the Eolithic, has long been the subject of controversy. It can hardly be doubted that the earliest implements and weapons selected for use by man were stones naturally worn or broken; and that in process of time such specimens would be rudely chipped on the edges to suit particular purposes. Many flints to which the name 'eolith' has been applied have been collected on the Kent plateau and elsewhere, but not all competent judges acknowledge their human workmanship. They are found accompanied by recognised palæoliths on the surface and, without admixture of later forms, in gravels associated with the Clay-with-flints. The literature of the subject is voluminous; that which favours the human origin has been inspired by the work of the late Mr. Benjamin Harrison; a useful summary of his results, with illustrations of specimens, will be found in F. J. Bennett's book 'Ightham, the story of a Kentish Village.'[1] Some of his examples are convincing, but a series can be selected showing a gradual transition to forms which, on their merits, few would claim as showing any sign of workmanship, and it is difficult to discover any adequate criterion. Among the opponents of eoliths much work has been done to show how natural agencies may produce similar chipping, notably by Mr. F. N. Haward and by Mr. Hazzledine Warren; the latter has recently described a 'natural eolith factory' at Grays, where flints at the base of the Thanet Sand have been subjected to natural pressure and have in some cases developed chipping resembling that of eoliths, or more rarely of palæoliths. That it should be difficult to distinguish between flints fractured by nature and those which early man has adapted, by slight trimming, to his use is to be expected, and it will probably remain open to individuals to hold either opinion. It should be added that some writers consider 'eoliths' to be flints casually adapted for temporary use by men of all periods, as opposed to finished implements showing the characteristics of various cultures[2]; and, further, that the cylindrical nodules trimmed to a point belonging to the Strépy stage are more suggestive of a first link in the chain of evolution of implements than are the eoliths.

The task of applying the remaining divisions to the Thames valley has been taken up by many careful observers.[3] Since implements of several types are abundant it is clear that, provided their chronological sequence is firmly established, they will serve as zone-fossils for the Pleistocene, indicating the comparative date of any particular river-deposit; for this purpose the system of 'sequence dates' used by Mr. Warren (*op. cit.*)

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[1] Garden City Press, Letchworth, 2nd Ed., 1917.

[2] Kendall, Rev. H. G. O., 'Eoliths—their Origin and Age,' *Proc. Prehist. Soc. E. Anglia.* vol. iii, 1921, pp. 333–352.

[3] *See* Hinton, M. A. C., and A. S. Kennard, 'Relative Ages of the Stone Implements of the Lower Thames Valley,' *Proc. Geol. Assoc.*, vol. xix, 1905, pp. 76–100; and Warren, S. H., 'Late Geological Stage in the Lea Valley,' *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912. p. 223.

is specially convenient.[1] The prolific gravels and loams of the High Terrace in the Swanscombe area were investigated by Messrs. Smith and Dewey: the most important pit, Barnfield, lies just beyond our eastern margin near Greenhithe; implements of Strepyan, Chellean, and Lower Acheulian groups were there found in definite vertical succession.[2] The Middle Terrace has yielded late Acheulian types, while from its surface, overwhelmed by Coombe Rock or Trail, numerous Mousterian implements have been obtained from localities as far apart as Northfleet (4½ miles east of Dartford) and West Drayton. A long list of occurrences which bear out the correlation of the Upper and Middle Terraces with the Strepyan, Chellean and Lower Acheulian and with the Upper Acheulian and Mousterian culture-stages respectively could be compiled, but, with our limited space, it is better to point out certain anomalies.

Near Piccadilly Circus and elsewhere in Central London beautiful implements of Chellean type in fresh unabraded condition have been found at the base of a deposit attributable on stratigraphical and palæontological grounds to the Middle Terrace: specimens may be seen in the London and the British Museum. It seems impossible to reconcile this occurrence with the geology or, indeed, with the archæological discoveries elsewhere, and we must wait for future work to provide a consistent account of human culture and its relation to physical history in the Thames Valley. The importance of recording accurately the position of any implements found, and of submitting them to some authority competent to decide their culture-stage, cannot be over-emphasised.

In the Colne Valley there are two noted localities—Croxleygreen and Mill End; the former is shown on our map as situated on 'Plateau Gravel' which has in part been resorted in Upper Terrace times; the latter appears to be the Middle Terrace; yet the Croxleygreen implements are mainly early Acheulian,[3] those from Mill End Chellean,[4] so that here, again, there is a problem awaiting solution.

Along the upper margin of the Middle Terrace, between West Drayton and Acton, many fresh implements of Mousterian date have been found; they mostly lie on the surface of the gravel, beneath a cover of Upper Terrace material that has slipped from the higher ground; at Acton a 'working-floor' was discovered by Allen Brown, whose many writings on this district should be consulted[5]: rolled Chellean forms are frequent in the gravels.

The implements from the base of the Middle Terrace in Central London have been mentioned above; in South London

[1] *Geol. Mag.*, 1902, pp. 98–99.
[2] *Archæologia*, vol. lxiv, 1913, pp. 177–204; vol. lxv, 1914, pp. 187–212.
[3] Beevor, Sir H., *Proc. Geol. Assoc.*, vol. xxi, 1907, p. 245.
[4] *Archæologia*, vol. lxvi, 1915, pp. 195–224.
[5] *e.g.*, *Proc. Soc. Antiq. Lond.*, 2nd series, vol. xi, 1887, pp. 211–216; 'Palæolithic Man in N.W. Middlesex,' 1887: *Proc. Geol. Assoc.*, vol. x, 1888, pp. 361–372, and vol. xiv, 1896, pp. 118–120.

Chellean forms are occasionally found in the relics of the Upper Terrace between Wandsworth and Camberwell. At Stoke Newington important discoveries were made some thirty years ago by Worthington Smith in the Middle Terrace: a palæolithic floor has been traced over a large area in this district; the floor is of Mousterian date, but older implements occur below, and in the Trail which covers and so preserves the floor, various forms derived from a distance are mixed together.[1] Other discoveries in the Lea Valley have been made by Mr. Hazzledine Warren, whose paper on the Ponder's End deposit (*op. cit.*) contains a valuable attempt at correlation of the palæolithic periods and the deposits, giving the 'sequence dates.' East of the Lea a certain number of implements have been recorded from various gravels and brickearths on the north side of the Thames.[2]

On the south side the Crayford brickearth pits contained the first recorded 'floor' or workshop, described by Spurrell,[3] who also discovered the Northfleet deposit;[4] the implements and flakes, as well as a few isolated specimens found recently, are of Mousterian age.

At Wansunt, at the north-west corner of Dartford Heath, a large number of examples have been obtained referable to Chellean, older and newer Acheulian and early Mousterian. Messrs. Leach and Chandler consider that the true Upper Terrace gravels yield the earlier forms, those of St. Acheul II. and Le Moustier being confined to certain stream-channels subsequently cut through the deposit;[5] excavations by the British Museum and Geological Survey suggest that the newer gravels are due to the lateral encroachment of the main stream when flowing at a slightly lower level than that at which the main mass of gravels was deposited.[6] At the Globe Pit, near Greenhithe Church, late Acheulian and Mousterian implements have been found in the brickearth and Coombe Rock.[7] Implements belonging to the various divisions of the Lower Palæolithic have been found in the valleys of several of the southern tributaries.

Of the relationship between the Upper Palæolithic cultures and the geological sequence we have little knowledge, most of the implements assignable to that division being surface finds; they are formed from flakes in contradistinction from those of the Chellean and Acheulian, among which core forms greatly

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[1] *Journ. Anthrop. Inst.*, vol. viii, 1879, pp. 275–279; vol. xiii, 1884, pp. 35–84 and Pl. viii–xxiii; 'Man the Primeval Savage," 1894, also 'Guide to Antiquities of Stone Age," British Museum, 2nd Ed., 1911, pp. 21, 22.

[2] *See Essex Nat.* passim.

[3] *Quart. Journ. Geol. Soc.*, vol. xxxvi, 1880, pp. 544–548.

[4] *Archæologia Cantiana*, 1883.

[5] *Proc. Geol. Assoc.*, vol. xxiii, 1912, pp. 102–111; vol. xxiv, 1913, pp. 337–344.

[6] *Archæologia*, vol. lxv, 1914, pp. 199–212.

[7] *Ibid.*, vol. lxiv, 1913, pp. 192–196.

predominate, though flake-implements are not unknown.[1] The most important finds *in situ* have been in the valleys of the Cray and the Colne. At Footscray, Mr. R. H. Chandler found a 'scraper-core' and several long narrow 'worked angle-flakes' identical with forms from Les Eyzies, in Dordogne, regarded as transitional between the Solutrian and Magdalenian periods; they were lying on the surface of a low-level gravel of the Cray beneath a cover of alluvium and were in fresh and unabraded condition. This gravel must, therefore, be older, how much it is impossible to say, while the alluvium cannot be much newer than the period indicated. Mr. Chandler was also able to trace other similar flints that had previously been found in the same position.[2]

Flakes and scrapers 'nearly all of the long duck-bill type' and 'identical with those found in the French cave of La Madeleine' had previously been recorded by Messrs. Kennard and Hinton from Uxbridge: these again rested on the low-level gravel of the Colne beneath a cover of alluvium.[3] Implements from the Admiralty Buildings site (above) appear to belong to some part of the Cave Period.

It is unfortunate that among the deposits subsequent to the Middle Terrace, where the stratigrapher is most in need of assistance, the archæologist has, as yet, but little to give him.

CHAPTER IX.

HOLOCENE, OR RECENT.

Alluvium.

This term is applied to the latest deposits which form the flat meadow and marsh lands that border the river and its tributary streams.

They comprise lands now liable to flood when the river overflows its banks; and prior to the artificial protective works there were extensive marshes and stagnant pools, where peat could accumulate in areas to the east of London.

The more conspicuous tracts of Alluvium are along the Colne Valley, from Watford to Uxbridge and Staines Moor, and along the Thames from the famous meadow of Runnymede, between Egham and Staines, to Chertsey and Walton-upon-Thames. Below Walton-upon-Thames very little Alluvium is shown on the map, in the main valley, until the mouth of the Lea is reached.

There are belts of Alluvium along the Wey above Weybridge, along the Mole between Hersham and East Molesey, and the

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[1] Dewey, H., 'Palæolithic Flake Implements from High-level Terraces of the Thames,' *Geol. Mag.*, 1919, pp. 49–59.

[2] *Proc. Prehist. Soc. E. Anglia*, vol. ii, 1915, pp. 80–98.

[3] *Proc. Geol. Assoc.*, vol. xviii, 1903, p. 188; vol. 1905, p. 76.

Wandle below Hackbridge, south of Mitcham. Alluvial meadows border the Thames between Kew and Richmond, notably in front of Syon House.

There is a spread of Alluvium between Barnes and Hammersmith Bridge, a tract into which the Beverley Brook runs; and there is Alluvium at Westminster, Pimlico, in parts of Lambeth, Southwark and Bermondsey, at Rotherhithe and the Isle of Dogs, now a region of docks. Thence north of the Thames are the extensive marshes of Plaistow, with Canning Town and Beckton, and numerous docks, the Barking Level, and the Rainham, Aveley and West Thurrock Marshes.

Along the Lea Valley there are broad tracts of marsh land from Enfield to Hackney and Blackwall; and along the Roding Valley there is a continuous strip of Alluvium.

On the south side are the marshes of Greenwich, Plumstead, Erith and Dartford; the Cray and the Darent unite below Crayford and Dartford, and the last-named town is largely built on the Alluvium.

With regard to the levels of the Alluvium, we find along the Colne valley from near Watford to the Moor above Staines, a distance of about 20 miles, that there is a fall from 180 to 50 ft., or more than 6 ft. per mile. In the valleys of the Lea and Roding, the fall, within the district, is respectively 3 and 7 ft. per mile. In the Darent Valley from Shoreham Castle to the mouth of the river, a distance of about 10 miles, there is a fall from 167 to 5 ft., or about 16 ft. per mile. In these cases the fall is not uniform. Along the main river from above Staines to Walton-upon-Thames the descent is from 50 to 30 ft. above O.D. in about 7 miles, or 3 ft. per mile. At Barnes, 11 miles further (in a direct line), the Alluvium is about 14 ft. above O.D.; while from Rotherhithe to the eastern part of our district near West Thurrock, much of the Alluvium is but 4 or 5 ft. above O.D.

Prior to the embanking of the Thames there was much swampy ground at Chiswick, Chelsea and Fulham, also in the lower grounds at Wandsworth, Battersea, Lambeth, Southwark, Bermondsey, Rotherhithe, Deptford and Greenwich.

Small islands of a gravelly or muddy nature, known as aits or eyots,[1] occur along the Thames at various spots between Egham and Staines, between Shepperton and Weybridge, at Sunbury, between West Molesey and Hampton Court, at Surbiton (Raven's ait), Teddington, Petersham, Twickenham (Eel Pie Island), Isleworth, Brentford (Corporation Island), and Chiswick. Formerly there were islets at Putney, Chelsea (Chesil or Shingle Island),[2] Battersea (St. Peter's Island), Westminster (Isle of Thorns or Thorney, where the Abbey now stands), and Bermondsey. Chertsey is situated on an island of gravel in the Alluvium. The Isle of Dogs was a more or less isolated bank of mud, subject in old times to inundation at high tide. Frog

[1] Indicated by the Anglo-Saxon suffix *ey* or *ea* in the names of places.
[2] Chelsea may be derived from *cealc hythe* = chalk quay.

Island is now a tract of Alluvium between Hornchurch and Rainham Marshes, and may have been a marshy island.

The Alluvium consists of alternations of silt or mud, clay, shell-marl, peat, sand, and (usually at the base) gravel. In places along the Brent Valley, near Greenford, it is largely made up of re-deposited London Clay with seams of gravel in it. Vivianite (phosphate of iron) is occasionally met with in the alluvial deposits. The 'marsh-clay,' described by Mr. Whitaker as 'an impure and often sandy clay, more or less charged with vegetable matter,' may be said to include both freshwater and tidal alluvium.

The present course of the Thames bears no necessary relation to the full depth of Alluvium; masses of Lower Eocene strata have been dislodged from the bed in dredging operations below the Tower Bridge, and it is probable that the Chalk is not far below the mud of the river-bed in some of the reaches between Woolwich and Greenhithe. Spurrell, however, remarked that 'notwithstanding that the waterway of the Thames is very irregular, it is clear that it has kept its present line of flow the same, within narrow limits, since it first became estuarine.'[1]

The depths of Alluvium, apart from underlying gravel, in London bordering the Thames from Battersea to Deptford are from 7 to 16 ft.; the depth at Shadwell is 16, at Walbrook 25, and in the Isle of Dogs from 8 to about 20 ft. Eastwards there is 35 ft. or more at East Greenwich and Charlton, from 26 to 31 in the marshes of Plumstead and Erith, 22 at Crossness, and up to 50 ft. further down the estuary.

On the northern side of the river at Plaistow and East Ham the depth is from 18 to 30 ft., at Dagenham (locally) 16, and at Aveley Marsh 30 ft. Further on beyond our region as much as 54 ft. of mud, clay and peat were proved at Tilbury. In the records of borings two or three layers of peat are sometimes met with, alternating with silt or mud and clay, and often a peaty bed is noted at the base, sometimes with remains of trees.

That the alluvial deposits are newer than the Cave Period has already been mentioned; but since the implements of Les Eyzies type found on the gravel surface beneath them are unworn, the alluvium at those localities must have been laid down shortly after that stage; on the other hand, much of the alluvial mud found below London is of post-Roman date. The Holocene or Recent division thus covers the Neolithic or Newer Stone Age, the Bronze Age, regarded as extending from 1800 to 600 B.C., and the Iron Age which merges into historic times.

Of neolithic times, Clement Reid remarks that 'at first the land stood at an elevation of some 60 or 70 ft. above its present level, so that many of the river valleys were cut to that depth below the sea, and much of the English Coast was fringed with a broad strip of alluvium, which probably almost connected our island with Belgium and France. The climate during this epoch

[1] *Proc. Geol. Assoc.*, vol. xi, 1889, p. 212.

was temperate, for in the lowest "submerged forests" the oak is the most abundant tree. Then gradual and intermittent submergence flooded the lower parts of the valleys, and caused them to be silted up by the deposits of the rivers that no longer had sufficient fall to scour their beds. In some of the peaty deposits, or old vegetable soils that mark stages of rest in their process of submergence, we find polished stone weapons, and relics of cultivated plants and of domesticated animals. Since the close of the Neolithic Period changes in physical geography have been slight.'[1]

With due allowance for the changes in level and the artificial modifications, it is held that the physical features in neolithic times were much like those at the present day; and that settlements were made by neolithic men, who were herdsmen and tillers, on the chalk uplands and on the less elevated tracts of sand and gravel of Eocene and later date. Clearances of woodland were begun before the time of the Roman occupation.

Among the stone implements and weapons are axes or celts, scrapers, arrow-heads, etc. They include some of the roughly chipped 'mesoliths' of early date, the finely chipped or ground and polished neolithic celts, and certain pygmy implements which are considered to belong to the Neolithic or early Bronze period.[2] Many celts have been dredged from the Thames; other implements and weapons have been found in various localities in the soil, but not often in the valley-deposits. The late George Clinch has drawn attention to the evidence of a factory of neolithic implements at Millfield, Keston, and to many pit-dwellings or hut circles of Neolithic age in various parts of Surrey and Kent. Many relics of the Bronze Age have been found in the Thames, and in the Wey near Weybridge. Dug-out canoes of oak, belonging to that period, have been found in excavations for the Albert Docks at North Woolwich, at Walthamstow, and on the bank of the Wey south of Brooklands.

Indications of pile dwellings, probably of the Iron Age, have been described as occurring at the mouth of the Fleet and of the Wandle, in the Lea Valley, in Southwark, and at Kew.[3]

The following are the principal Holocene mammalia which have been recorded from the district; those marked † being extinct, and those marked ‡ no longer living in Britain :—

‡ Alces machlis *Ogilby* - - -	Elk or Moose.
Bos taurus, *var.* longifrons *Owen*	Keltic short-horn (probable ancestor of Welsh and Highland cattle).
† —— —— primigenius *Boj.* -	Urus (probably extinct before Roman occupation).

[1] 'Origin of the British Flora,' 1899, p. 46; *see also* Memorandum on Coast Erosion, by C. Reid, *Rep. R. Comm. on Coast Erosion*, Appendix XII. (A), 1907, p. 163.

[2] Johnson, W., and W. Wright, 'Neolithic Man in N.E. Surrey,' 1903; 'Guide to Antiquities of the Stone Age,' British Museum, 2nd Ed., 1911.

[3] *See, for instance*, Gomme, Sir L., *Geog. Journal*, vol. xxxi, 1908, p. 490.

Canis familiaris *Linn.* - -	Dog.
‡ —— lupus *Linn.* - - -	Wolf (living in Britain until near close of 17th century, and in England until beginning of 14th century).
—— vulpes *Linn.* - - -	Fox.
Capra hircus *Linn.* - - -	Goat.
Capreolus caprea *Gray* - -	Roe Deer.
‡ Castor fiber *Linn.* - - -	Beaver (extinct in Britain in 11th or 12th century).
Cervus elaphus *Linn.*- - -	Red Deer.
† —— giganteus (*Blum.*) - -	Irish Elk.
Equus caballus *Linn.* - - -	Horse.
Felis catus *Linn.* - - -	Wild Cat.
Lepus timidus *Linn.* -	Hare.
Lutra vulgaris *Erxl.* - -	Otter.
Meles taxus *Bodd.* - - -	Badger (living in Ken Woods, Hampstead).
Mustela martes *Linn.* - -	Marten.
—— putorius *Linn.* - - -	Polecat.
Ovis aries *Linn.* - - -	Sheep.
‡ Rangifer tarandus (*Linn.*) - -	Reindeer (living in Caithness until 1159).
‡ Sus scrofa *Linn.* - - -	Wild Boar (extinct in Britain about 1620).
Tursiops tursio (*Bonn.*) - -	Dolphin.
‡ Ursus arctos *Linn.* - - -	Brown Bear (living in Britain until Saxon or Danish times).

The domesticated animals include, since Neolithic times, the Keltic short-horned ox, pig, goat, sheep, and dog; and, since the Bronze period, also the horse, not to mention other species introduced.

The mollusca of the alluvial deposits have been dealt with by Mr. A. S. Kennard and Mr. B. B. Woodward, who have recorded the species from Walthamstow and Dagenham as belonging to early deposits of the Holocene period; and from Staines, Uxbridge, Westminster and Tooley Street where the deposits are considered to be of much later date. It is noted that *Helix aspersa* Müll. occurs at London Wall in deposits of the Roman period: it was also found at Walthamstow and Staines.

With reference to the Dagenham deposit it is remarked that 'there is a total absence of all brackish-water forms, and this, in conjunction with the depth, clearly shows that the deposit was laid down in early Holocene times, when England stretched far out into what is now the North Sea, and the tidal waters were probably miles away.'[1]

Subsequently, the area sank gradually but intermittently, as evidenced by the occurrence of peat-beds, the highest layer being considered to be of Bronze age, and to have been dry land in Roman times. The deposits of tidal clay were spread out, at intervals, when the Thames had become subject, as it now is, to the influx of the tides. In that clay the bivalve shells

[1] Kennard, A. S., and B. B. Woodward, *Proc. Malac. Soc.*, vol. viii, 1908, p. 96.

Scrobicularia plana Da Costa and *Tellina* (*Macoma*) *balthica* Linné occur at Crossness and elsewhere lower down the valley.[1]

It is doubtful whether any of the mollusca found in the Holocene deposits are extinct at the present day; *Pisidium supinum* A. Schmidt and *Planorbis strœmii* West, long regarded as such, have now been discovered living in Britain.

The plant-remains found in deposits of neolithic age indicate temperate conditions and include the alder, ash, beech, birch, holly, ivy, maple, oak, pear, pine or Scotch fir, poplar, willow and yew.[2]

The Alluvium in the Colne Valley consists of loam, shell-marl, and gravel. By the Staines Reservoir remains of elk, fallow deer and other animals were obtained, and identified by Mr. E. T. Newton.[3]

In the Lea valley clay, loam, peat and shell-marl occur in irregular beds, 12 ft. or more in thickness, with evidence of local erosion and deposition, so that deposits of different ages occur at the same level. At Ponder's End Mr. Warren found fragments of pottery and flint chips at the base of the Alluvium, and considers that the deposit may be of early Bronze Age; further up the river, at Chingford Reservoirs he records Romano-British pottery.[4] The modern alluvial mud is well seen between Blackwall and West Ham.

Remains of beaver have been found in considerable numbers at Walthamstow, as pointed out by Henry Woodward, who expressed his opinion that the animal had been an important geological agent in that region of the old Forest of Waltham. Thus 'every stream is converted by the Beavers into a series of falls with beaver-dams, and large, deep, clear, still pools of water. It is evident that, if ever a big flood came down such rivers, these beaver-dams would be quite calculated to cause an overflow and an inundation of the Forest for miles around. Many of the forest-trees could not stand this excessive damp, and would give way to *Sphagnum* or bog-moss; and large tracts thus flooded would be converted into peaty, marshy fen-land.'

The fallow deer has also been found in the Alluvial deposits of Walthamstow.

Many sections of Alluvium along the main valley have been described, notably at North Woolwich, and Crossness, where numerous plants were obtained, and remains of beaver and other animals.

At Beckton excavations for the Gas Works yielded neolithic implements, mammals, including dolphin and a whale, and mollusca; a bed of peat, impersistent but sometimes as much as 7 ft. thick, contained much wood, including bog-oak.

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[1] Spurrell, F. C. J., *Proc. Geol. Assoc.*, vol. xi, 1891, p. 214.
[2] Reid, C., 'Origin of British Flora,' 1899, pp. 55, 64, etc.
[3] 'Summary of Progress for 1902' (*Mem. Geol. Surv.*), 1903, p. 207.
[4] *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912, p. 226; and *Proc. Geol. Assoc.*, vol. xxii, 1911, p. 170.

At Bermondsey brown sandy loam with land-shells (Marsh Clay) is overlain by carbonaceous silt with freshwater shells and remains of Roman pottery. The Marsh Clay here gives evidence of 'a land surface liable to flooding, each flood adding to the thickness of the deposit.' It was formed by a tributary of the Thames; by subsequent sinking the influence of the main stream was felt and the carbonaceous silt was deposited.[1]

The Thames and its Tributaries.

Owing to the windings, the course of the Thames through our area is about 62 miles in length, the distance in a straight line being 36 miles; the lower 42 miles, below Teddington, is tidal; the ancient name of that hamlet is Totyngton, so that the usual derivation from Tide-end-town must be discarded. At London Bridge the tides ebb seven hours and flow five hours, the average range being 16 or 17 ft., though at times it has been as much as 27. At Twickenham it is only 8 ft., low-water being about 5 ft. above O.D. The fall thence to London Bridge is less than 1 ft. per mile; Trinity High Water mark, the old standard height, is 12½ above O.D., a fact which must be borne in mind in using Mylne's excellent contour and geological map of London, published in 1856. The low-water depth of the river at Crayfordness is about 22 ft., decreasing to 16 or 18 ft. off Greenwich, 14 ft. and less along the Pool, 9 ft. at London Bridge, 5 or 6 ft. at Hammersmith, and 4 to 6 ft. at Brentford and Teddington; dredging operations render the figures liable to variation.

In the non-tidal part, above the weir at Teddington, the fall is about 1½ ft. per mile, controlled largely by the locks and weirs of the Thames Conservancy. The average daily flow at Teddington for the twelve months ending March 1921 was 1,467·5 million gallons, that for the preceding 10 years being 1,792·2 and for 37 years 1,366·8. Taking the salts in solution at 19 grains per gallon, Huxley calculated that the river carried down daily about 1,000 tons of carbonate of lime and 238 tons of sulphate of lime, to which must be added the material carried in suspension. The Thames, therefore, although it has practically reached the base-level of erosion, is still an active agent in denudation.

The maximum and minimum flow of the river is reckoned to be about five months later than the corresponding points in the mean rainfall of the Thames Basin.[2]

The more important of the tributary streams are well known, and are of course shown on the maps. More interesting, perhaps, are the 'buried rivers' which once flowed through the London area; as they materially affect the geographical features and geological boundaries, and therefore the history of London (p. 89), a few particulars are necessary.

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[1] Kennard, A. S., and S. H. Warren, *Geol. Mag.*, 1903, p. 456.
[2] Lockyer, W. J. S., *Nature*, vol. lxxii, 1905, p. 178.

'Buried Rivers' of the Northern Side.

The *Little Ealing Brook* drains a small area south of Ealing and joins the Thames east of Brentford.

The *Stamford Brook* flowed through Acton Vale to the Thames at Hammersmith; Dr. A. Morley Davies states that 'the twin mouths can be seen—one opposite the east end of Chiswick Eyot, the other under Hammersmith Mall.'[1] It was not this stream, but a smaller one entering the river just below Hammersmith Bridge that gave its name to Brook Green.

The *Bridge Creek* (or Counters Creek) flowed through West Kensington past Addison Road Station and Walham Green to enter the Thames at Sands End. The lower part was at one time made navigable for barges.

The *West Bourne* (or Bayswater Brook) rose in the Bagshot Sand above West End, Hampstead, and after receiving the Kilburn as a tributary flowed to Bayswater, crossing the site of the Great Western Railway near Royal Oak. Early in the 12th century there was a hermitage near Kilburn Bridge, which developed into Kilburn Abbey, remembered now in the names Abbey Road and Abbot's Road; at the dissolution the Abbey passed to the Prior of St. John of Jerusalem, whence we get St. John's Wood. In 1730 the stream was dammed to form the Serpentine, at the instigation of Queen Caroline; it supplied the Bayswater district with water till 1844. Since the diversion of the stream into the sewers the Serpentine has been supplied from a well sunk at its northern end in 1861.

Like other streams draining a London Clay area the West Bourne filled up rapidly after a storm; in the lower course, below Knights' Bridge, where the fall is very slight, floods were frequent; as recently as 1809 the flood-waters stopped all traffic, except by boat, between Westminster and Chelsea. The Bourne entered the Thames just west of Chelsea Bridge; the storm-relief sewer which takes its place may be seen crossing over the railway at Sloane Square Station.

The *Ty Bourne* (Tyburn or Aye Brook) took its rise north of Belsize Park and Avenue in South Hampstead and flowed across the northern part of the area of the present lake in Regent's Park; past St. Mary-le-Bone (St. Mary by the Burn), by Marylebone Lane and Brook Street, and so by the depression in Piccadilly to the Green Park. Hay Hill is a Cockney corruption of Aye Hill, and gets its name from this stream's other title. Near Buckingham Palace the stream divided, one branch entering the river just above Vauxhall Bridge, the other again dividing on either side of Thorney Island, an eyot of gravel and sand in the alluvial marsh, on which Westminster Abbey stands. The southern branch passed along Great College Street, where the remains of an ancient bridge were found when St. Edward's House was built. The northern mouth was by Scotland Yard; this was rendered navigable for a short distance and was known as the Mersfleet; remains of the wharfs have been found at Storey's Gate.

The *Fleet River* (River of Wells, or Holebourne) took its rise on the slopes between Hampstead and Highgate, from the Vale of Health, whence it derived the supply for Hampstead Ponds (made about 1590), and from Ken (or Caen) Wood, whence comes the supply for the Highgate Ponds. Below these ponds the streams are buried, but formerly they united to the west of the Kentish Town Road, a little north of the North London Railway between Chalk Farm and Camden Town Stations. Thence the stream flowed past Old St. Pancras to Battle Bridge (now called King's Cross), the traditional site of the battle between Suetonius and Boadicea, and so along the valley where is now Farringdon Street, Ludgate Circus

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[1] 'The Geography of Greater London,' *Journ. School Geogr.*, vol. v, 1901, p. 44.

and New Bridge Street. For many centuries the mouth was navigable as far as Holborn Bridge, this part being the Fleet proper. Above that point the stream was known by several names, such as the Turnmill stream from the number of Mills utilizing its power or the River of Wells from the number of springs on its banks (*see below*).

The *Wall Brook* rose in the marshy tract of Moorfields, beyond Moorgate, flowing through the sites of the Bank and Mansion House, to the Thames at Dowgate; the mouth, as in the case of the Fleet, formed one of London's ports in early times; its liability to flood has been mentioned (p. 28). From its position athwart the city the Walbrook was the earliest of the London streams to be 'buried,' part of it having been arched over in late Roman times, and practically the whole by 1473. The marsh of Moorfields was partly caused by the Roman wall impeding the natural flow of the water.

The courses of these 'buried streams' have been carefully studied, notably by Mr. J. G. Head,[1] and are shown on the 6-inch geological maps. The subject is not without difficulty, since some have perished leaving no name, such as that flowing under the bridge in the Strand, while the Langbourne, fully described by Stow as a tributary of the Walbrook, is probably mythical. Mention should also be made of the Hackney Brook, a tributary of the Lea; part of its valley is indicated on the map, Sheet 2, by the narrow outcrop of London Clay running south from Stoke Newington to Shacklewell.

The South Side.

Of the tributaries of the Thames on the south or right bank, few of any importance are 'buried,' those flowing above the Wandle or below the Ravensbourne being open and shown on the map, though a part of the Quaggy, a tributary of the latter river, is concealed at Lewisham.

The *Falcon* or *Battersea Brook* rose near Balham and flowed down the valley between Wandsworth and Clapham Commons. From Clapham Junction it turned westward, the mouth being still visible between Wandsworth and Battersea railway bridges. Another exit, perhaps in part artificial, was to the east and along the strip of alluvium, shown on the map to Nine Elms. Perhaps these two mouths were originally a backwater of the Thames and so formed the eyot of Battersea.

The *Effra* rose in the hills of West Dulwich and Streatham at a height of 378 ft. above O.D., and followed a course of some 4 miles to the Thames near Vauxhall Bridge.[2] It was formerly navigable to Merton Bridge, near Kennington Gate; in Elizabeth's reign a nobleman living at Brixton proposed to render the stream navigable for the Queen's Barge up to his house, but the project was not carried out. On Rocque's map of the Environs of London (1745) the stream is called the Shore, an old form of the word sewer.

The *Neckinger*, with sources near Denmark Hill and Forest Hill, flowed through Bermondsey to St. Saviour's Dock, branches of it surrounding Jacob's Island, familiar to readers of Dickens. It crossed the Kent Road at St. Thomas Waterings, mentioned by Chaucer.

Springs.

The springs of the district are fully described in the Water Supply Memoirs of the various counties, those of London itself being dealt with from the historical point of view by Mr. A. S. Foord.[3]

[1] 'The Buried Rivers of London,' *Proc. Auctioneers' Inst.*, 1908.
[2] Leighton, D., *Proc. Geol. Assoc.*, vol. xxiii, 1912, pp. 172—174.
[3] 'Springs, Streams, and Spas of London,' 1910.

An important series of springs issues from the Chalk, at its junction with the Thanet Sand, between Ewell and Croydon; from Carshalton to Croydon the various sources of the River Wandle arise from springs, which have a marked effect on the water-level in neighbouring wells.[1]

Other Chalk springs are found in the Colne valley north of Watford,[2] at Erith and Greenhithe in Kent, and Purfleet in Essex.

From the Woolwich and Reading Beds and the Blackheath Beds, which consist of frequent alternations of pervious and impervious strata, numerous small springs are thrown out; these are frequently of use to the field geologist in mapping the various beds, but are of little importance, except, perhaps, on the east side of Croydon.[3]

Though on the whole an impervious stratum, the London Clay gives rise to a number of small springs, important because of their mineral qualities; these include the famous 'Epsom Waters' and nearly all the 'Spas' of London. The water is derived, as a rule, from gravels overlying the clay; by means of cracks, it finds its way into the mass of the clay and travels along a sandy parting or a layer of septaria; in its passage it becomes charged with salts, mainly the sulphates of magnesia and lime, sulphuric acid being the result of the decomposition of pyrites in the clay. The Epsom Springs are on the Common between Epsom and Ashtead, near a modern house called 'The Wells'; their medicinal quality was discovered in 1618; in the 17th and 18th centuries they were much resorted to and gave the name 'Epsom Salts' to the sulphate of magnesia.[4] Of the London Spas obtaining their water from the London Clay the more important were Kilburn, Streatham, Beulah and Sydenham, while in Essex genuine mineral springs were known at South Weald and Upminster.[5]

From the Bagshot Sand many springs are thrown out by the underlying clays. At Hampstead such springs form the sources of the Westbourne, Tyburn, Fleet and other small streams (p. 77).

The base of the sands is here marked by a band of ironstone (p. 34), and the water is often chalybeate, as, for instance, at the famous Spa in Well Walk, which flourished in the 18th century.[6] In Essex notable springs from the Bagshot Sand are found at High Beech and in the neighbourhood of Brentwood. A spring from the Barton Sands on St. George's Hill is interesting, as it formed the water supply for the ancient camp, and a special earthwork was constructed for its protection.[7]

At the junction of the various Pleistocene gravels with the London Clay, springs are of frequent occurrence; such springs formed the main supply for London and the neighbouring hamlets for centuries (p. 89), but few of them are now visible; the Glacial Gravel of Wimbledon Common gives rise to several, of which the largest is known as 'Cæsar's Well'; springs from similar gravel at Coombe were piped to Hampton Court in Tudor times.

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[1] 'Geology of South London' (*Mem. Geol. Surv.*), 1921, pp. 72, 75.

[2] *Proc. Geol. Assoc.*, vol. iv, 1875, p. 284.

[3] 'Water Supply of Surrey' (*Mem. Geol. Surv.*), 1912, p. 485; Fagg, C. C., *Proc. Croydon Nat. Hist. Soc.*, 1911, p. lii.

[4] 'Geology of South London' (*Mem. Geol. Surv.*), 1921, p. 75.

[5] Christy, M., and M. Thresh, 'Mineral Waters and Medicinal Springs of Essex,' *Essex Field Club*, 1910.

[6] Foord, A. S., *op. cit.*, pp. 137–152; Potter, G. W., 'Hampstead Wells,' 1904.

[7] Gardner, E., *Surrey Archæol. Coll.*, vol. xxiv, 1911.

CHAPTER X.

ECONOMIC GEOLOGY.

WATER SUPPLY.

In the economic geology of the district, Water Supply holds by far the most important position. The subject is dealt with fully in the special memoirs of the Geological Survey, which cover practically the whole area here dealt with. Those interested in the subject from the practical point of view should not fail to consult these volumes, while the student of geology will find the thousands of well-sections recorded invaluable, more particularly as aids to deciphering the detailed structure of the area. A special atlas of the 6-in. maps of the County of London, on which the exact sites of many wells are marked, is available for reference in the library of the Geological Survey.

In these circumstances a brief outline of the subject will suffice for our present purpose. The chief source of supply, apart from the Thames and other rivers, is the Chalk. The yield, however, varies considerably in quantity, in the depth at which it is obtained, and in quality. Chalk when saturated is capable of holding two gallons of water in a cubic foot, but even when the plane of saturation is reached, it is only along joints, fissures and cracks that it parts readily with its water.[1] Such openings are naturally more abundant where the Chalk is near the surface than where it is covered by a great thickness of Tertiary Beds. Consequently, heavily loaded areas like Richmond and Wimbledon, Hampstead and Highgate, the Norwood Hills and much of Essex yield little water, either from the Chalk or from the Thanet Sand, which also tends to be compacted. The minor structural folds appear to have little direct influence on the yield of water, but the effect of the fault running from Deptford to Raynes Park (*see* p. 37 and the New Series Map Sheet 270, South London) is considerable. Water coming from the surface-outcrops in the south is impeded by this fault, which brings the impervious London Clay down against the Chalk. Wells sunk on the north-west, or down-throw side have a much smaller yield than those to the south-east; in this part of the Wandle Valley many wells used to overflow at the surface; now the water-level is a few feet down.

The level of the water in Chalk wells is also largely affected by pumping. If the Chalk under London be regarded as a reservoir we may say that the contents are being used at a rate in excess of the supply by percolation from the outcrops. This subject receives special attention in 'Records of London Wells,' where three small-scale maps show the contours of the water-level in 1878, 1890 to 1900, and 1911 respectively. We may

[1] Prestwich, Sir J., *Quart. Journ. Geol. Soc.*, vol. xxviii, 1872, p. lviii.

refer to the well at the head of the Serpentine, where the level has fallen 93 ft. in less than 50 years, or those near the National Gallery, where the fall has been 115 ft. in 64 years.

The quality is normally good, the hardness of water from 37 wells in the City varying from 11 to 3·5 degrees, while the total solids average about 49 grains per gallon.[1] It is usually found that the water from wells sunk where the Chalk is near the surface contains a much higher proportion of lime than that from wells sunk through a thick cover of Tertiary Beds. In the latter case much of the water has really come from the Thanet Sand and has exchanged some of its lime salts for those of sodium; the proportion of salt is, however, much diminished where heavy pumping has continued for some years. Where there is no impervious cover to the Chalk, there is a danger of impure water from the surface gravels or from the Thames being drawn down into the Chalk.

The water from the river-gravels is in many parts abundant and can be used for certain industrial purposes where slight impurity is of no consequence. In excavations for the extension of the Victoria and Albert Museum in South Kensington more than 10,000 gallons per hour had to be pumped from the gravel. The extent of contamination naturally varies according to the locality. In West Kensington water encountered in making the incline for the Piccadilly Tube was found to be so poisonous that the men engaged on the work had to receive medical treatment for the slightest scratch.

The rocks beneath the Chalk are not of much value as a source of water around London, except where the Lower Greensand is present (p. 6), though a well at Mile End obtained half a million gallons per week from the Upper Greensand at a depth of 875 ft. The Devonian rocks, reached by most of the deeper borings, sometimes yield a fairly large supply, but the water is brackish; that from the boring at White Heather Laundry, Willesden, contained as much as 1·5 per cent. of salt.

The history of the Water Supply of London is of great interest, and a general outline may be given here. Apart from brooks and rivers, the first supply was from springs and shallow wells. Over much of the area of 'Greater London' river-gravels overlie the impervious London Clay, and under natural conditions contain a certain amount of water. This water appears in springs at the margins of the gravel, more especially where a once continuous spread is cut through by the valley of a little stream, and can be tapped by means of a shallow well (*see* p. 89). It was on such gravel patches that London itself and the outlying hamlets, for example, Camberwell, Clapham, Kensington, Paddington and Islington, sprang up. The intervening areas of bare clay were not built upon till the advent of the great Water Companies and the introduction of iron pipes and steam pumping.

[1] Report of the Medical Officer of Health for the City of London, May, 1910.

In the City area, the many wells long retained their importance and are used by Stow as landmarks; the names of Cornhill Pump and Clerkenwell are familiar to all; but this local supply soon became inadequate and the conduit system was introduced in 1236. The water from springs situated on the margins of the gravel where the little streams cut through it was conveyed to London by means of elm-wood pipes. The springs first called into service were at Tyburn, on the banks of the stream at what is now Stratford Place, Oxford Street.[1] Later on more water was brought from Paddington in 1471, and in 1535 a conduit was laid from Hackney to Aldgate; sometimes leaden pipes were substituted for wooden, but a drawing in the Soane Museum shows the latter in use in Clerkenwell about 1800 A.D.[2]

The next means adopted for increasing the supply was the London Bridge Water Works, which lasted from 1582 to 1817: water wheels, worked by the tides, were fixed under several of the arches of the bridge and pumped water to the top of a tower, whence it was distributed by pipes. In 1613 Sir Hugh Middleton constructed the New River, an open conduit bringing water from Chadwell and Amwell springs to New River Head; it is still in use. A somewhat similar enterprise was the Queen's or Cardinal's River, bringing water from the Colne to Hampton Court.

The great Water Companies were founded early in the 19th century, and for the most part drew their supplies from the Thames and its tributaries. The Vauxhall Company, founded in 1815, utilised first the Effra, but later the Thames: reservoirs were established in many parts, as, for instance, at the north-east corner of the Green Park and in the Sunken Garden in Hyde Park. Now they all lie further out, great areas being occupied, notably at Staines, Molesey and other parts of the Thames Valley and in that of the Lea above Walthamstow. The Metropolitan Water Board, combining many separate companies' undertakings, assumed authority in 1904.

The earliest deep well known to us was sunk in 1725 near Kilburn; water was obtained from the sands of the Reading and Woolwich Series at a depth of 300 ft.

In 1807 John Middleton remarked that deep wells dug into the strata beneath the great mass of clay (London Clay) reach water, 'which then rises in such large quantities as to have hitherto prevented any attempt to dig deeper; in fact, it seems to bid defiance to being drawn off by our most powerful hydraulic machines.' He mentioned a well at Chelsea, dug about the year 1793 to the depth of 394 ft. The well-digger then usually bored from 10 to 20 ft. at a time, lower than his work, a precaution justified by the sudden rising of the water—

[1] Davies, A. Morley, 'London's First Conduit System,' *Trans. London & Middlesex Arch. Soc.*, N.S. vol. ii, 1907, pp. 9–59.

[2] Reader, F. W., *Essex Nat.*, vol. xiii, 1903, pp. 272–274.

in the above-mentioned instance to the height of 200 ft. from the bottom of the well.[1]

Chalk and Flint, Whiting, Lime and Cement.

The Chalk has been excavated by means of shafts at various dates since Neolithic times, and for various purposes: to obtain flint and chalk, or water, or to provide places of refuge and storage.

Thus, certain shafts 2 or 3 ft. in diameter have been sunk to a depth of from 40 to 60 ft., and sometimes as much as 140 ft., through Eocene strata into the Chalk; and, at the base, they lead into simple or complex chambers.

They are met with over a considerable area in North Kent between Dartford Heath and Eltham, and from Abbey Wood west of Erith to the uplands of Joyden's Wood (Stankey and Cavey Spring pits) south of Bexley; indeed, about 200 shafts are reckoned to be present within an area of 6 by 4 miles.[2]

To these the name Dene-hole (meaning Dane-hole, not den-hole) has been applied. They occur in numbers near together, and yet are seldom connected below ground; and on this account Mr. T. V. Holmes argues that they were made and used rather for domestic purposes, as secret store-houses and hiding places, than for the material extracted.[3] It is held that some shafts may date back to Neolithic times, and were utilized by the Romans as well as by the Danes. The vertebrate remains found in the excavations, according to Mr. E. T. Newton, are all of Neolithic or later date.

We have no certain evidence in our area of shafts sunk to obtain flints from the Chalk. In the well-known instances at Grime's Graves and Cissbury, the shafts were wider than in the case of the Dene-holes.

In Hertfordshire and Buckinghamshire, 'wells,' for the purpose of obtaining chalk to marl adjacent land, have been sunk in old times, and also quite recently to depths of about 90 ft., and with a diameter of about 5 ft.; and at the present time chalk is obtained by shafts (80 to 150 ft. deep) and galleries for use in the brickyards near Plumstead.[4]

In the much debated area of Chislehurst there is a complex series of shafts and tunnels which have been shown on a plan, constructed by Mr. T. E. Foster, to extend over an area of about 20 acres.[5]

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[1] 'Agriculture of Middlesex,' Ed. 2, 1807, pp. 27, 28, 35.

[2] Youens, E. C., *Proc. Geol. Assoc.*, vol. xx, 1908, p. 458.

[3] *Essex Nat.*, vol. xv, 1907, p. 10; *see also* vol. i, 1887, p. 225. Much has been written on the subject also by F. C. J. Spurrell and others.

[4] Hayes, Rev. J. W., *Nature*, vol. lxxviii, 1908, p. 375; Bennett, F. J., *Essex Nat.*, vol. i, 1887, p. 260; and Leach, A. L., and B. C. Polkinghorne, *Proc. Geol. Assoc.*, vol. xix, 1906, p. 345.

[5] Ward, T., *Journ. Brit. Arch. Assoc.*, N.S., vol. xiii., 1907, p. 254.

Reference to the Chislehurst 'pit' occurs as early as the 13th century, as noted by Mr. W. Johnson, who mentions also that chalk was brought up in baskets from a shaft in the early part of the 19th century.[1] The mining of chalk for lime-burning was continued until about 1854. When it began is uncertain, but the opinion was long ago expressed, and is supported by Mr. W. J. Nichols, that the outer galleries may have been worked for the manufacture of lime by the Romans.[2]

Mr. T. V. Holmes has noted subterranean chalk-chambers on the northern side of Beacon Hill, Purfleet, and certain shafts met with at Aveley and near West Thurrock, that were probably made for domestic use as dene-holes.[3]

In the manufacture of lime, both for agricultural and building purposes, the Chalk has been largely utilized. The upper beds, which contain from 95 to 97 per cent. of calcic carbonate, yield the best 'white lime' for use on the land. Lime for mortar used in building St. Paul's Cathedral was obtained from the Chalk at Sutton.

Whiting is prepared from the Chalk in the neighbourhood of West Thurrock and Greenhithe; and in these areas lime and Portland cement are extensively manufactured from chalk, with an admixture of clay and other ingredients. Cement is also manufactured from the Chalk at Harefield and Waddon.

Septaria, or cement-stones from the London Clay, were formerly used in the manufacture of Roman cement, and quite recently they, and also London Clay, have been utilized for cement-making by the Associated Portland Cement Manufacturers in the neighbourhood of Swanscombe, not far from Greenhithe.

Gun-flints were manufactured from chalk-flints in olden times at Chislehurst, Crayford, Greenhithe and Purfleet. Flints have also been sent to Staffordshire for use in the manufacture of pottery.

Large quantities of chalk were carried away as ballast for vessels during the 18th century; much is now exported to America.

Brickearth and Clay.

In and around London extensive brickyards have been opened, more especially in the Thames Valley brickearth and in the London Clay.

Brickearth has been worked at intervals since the time of the Roman occupation, and potter's earth from the Bronze period. The Romans made bricks in the south of England, but subsequently to their occupation of this country the manufacture appears to have been abandoned until the latter half of the 15th century, although tiles were made.

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[1] 'Folk-Memory,' 1908, pp 231–233.

[2] *Athenæum*, Feb. 27, 1904, p. 276; *see also Journ. Brit. Arch. Assoc.*, N.S., vol. x, 1904, p. 64.

[3] *Essex Nat.*, vol. xv, 1907, p. 6.

In Sir Christopher Wren's account of the foundations of St. Paul's Cathedral he noted from 4 to 6 ft. of close hard pot-earth over sand and gravel. This pot-earth 'had been used at a Roman pottery, near the north-east angle of the present church.'[1]

In many places the level of the land has been considerably decreased by excavations for brickearth. Thus, along the borders of the Kingsland Road large areas were lowered from 4 to 10 ft., and afterwards levelled and laid down to grass.[2]

Brickearth from 2 to 9 ft. in thickness was formerly worked east of Bromley-by-Bow, at Bow, Old Ford, Homerton, and Hackney. It was cleared off large tracts, exposing the gravel beneath, which alone is depicted on the Geological Survey map. This process of artificial denudation is carried on at the present day in the neighbourhood of West Drayton, Hayes and Southall; at the last locality, as also at Shepherd's Bush and Acton Vale, the brickearth is practically exhausted. Near Hayes 'the bricks are made of a mixture of brickearth, ashes, and chalk. They are first sun-dried, and then stacked in kilns and burnt. The brickearth having been removed, the gravel is then sold at so much an acre, and worked to within a foot of the water level.'[3]

East of London the brickearth has been largely worked at Ilford and Upminster, but some of the famous brickyards at Uphall, south of Ilford, and elsewhere are abandoned or obscured by buildings.

Forty or fifty years ago brickearth was largely dug at Clapton, Stoke Newington, and over the area of Highbury New Park; here, in most cases, the old pits were filled with rubbish. Northwards brickyards are now worked near Edmonton and Enfield.

To the south of the Thames the brickearth is worked between Crayford and Erith; and an alluvial clay from the marshes of Stone has also been dug for brickmaking.

The Clay-with-flints and associated brickearth on the Chalk plateau have been used for brickmaking; and at one time the Boulder Clay and associated beds of reconstructed London Clay at Finchley were worked for the same purpose.

The plastic clay and sands of the Reading Beds are utilized in the manufacture of bricks, tiles and pottery, notably near Plumstead and East Wickham, while at Nonsuch Park, Ewell, bricks have been made from sandy clay, called 'fire-earth' (*see* p. 20). Reading Beds are now largely worked for bricks in the Harefield district.

The London Clay is extensively dug for making tiles, drain-pipes and pottery, and, mixed with sand and sometimes with chalk, largely utilized for brickmaking. The pits are mostly in the upper part, now known as Claygate Beds, as on the west of Harrow, at Willesden Green, Buckhurst Hill, Loughton and

[1] Buckland, *Trans. Geol. Soc.*, vol. iv, 1817, p. 288.
[2] Middleton, 'Agric. of Middlesex,' Ed. 2, 1807, p. 23.
[3] de Salis, R. Fane, *Proc. Geol. Assoc.*, vol. xviii, 1904, p. 410.

Upminster on the northern side of the Thames; and at Claygate, Norbiton, Norbury and elsewhere on the southern side.

The Bracklesham Beds were worked for brickmaking to the south-east of Weybridge Station, and west of Woburn Park, Addlestone.

Sand.

The Thanet Sand mixed with clay has been used in pottery work and brickmaking; but this formation is noted as yielding the finest moulding material for iron and brass foundries. Indeed, Mr. Whitaker has remarked that the occurrence of this good foundry sand is said to have determined the site of Woolwich Arsenal. It is now largely worked at Erith (p. 18), whence it is exported to the North of England and various parts of Europe.

Mixed with ashes and sharp sand the Thanet Sand has also been used in the preparation of mortar.

Some of the Tertiary sands have been found serviceable for glass-making, and recently the Thanet Sand at Beddington has been utilized in the manufacture of silica-lime bricks. At that locality, to the south-east of St. Mary's Church, there are extensive underground workings or 'caves' of unknown antiquity in the Thanet Sand. Some small isolated chambers in the Thanet Sand near Waddon House, Croydon, have been described by Clinch as probably places of burial during later Neolithic times.[1]

Grey and brown sand at the base of the Blackheath Beds at Addington has been dug for sale as 'silver sand.'

Sand for mortar is obtained in many places from layers in the Thames Valley gravels.

Gravel.

Gravel has been dug from very early periods for making and mending roads and path-ways, mostly from the Valley gravels, and the higher Plateau gravels. Sometimes the Eocene pebble-beds have been so utilized, but these and the more pebbly Plateau gravels are now more worked for concrete than for road-making. Under London there exist numerous excavations, now filled with made-earth or rubbish, from which the gravel was extracted; in more recent excavations in the central area, gravel is dug out for the purpose of carrying foundations of buildings into the London Clay.

The Kensington gravel-pits were famous early in the last century. At the present time among the more extensive pits, where the gravel is more than 40 ft. thick, are those of Dartford Heath, where different varieties are obtained for pathways, for ballast, etc. Other large pits are worked at Hanwell.

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[1] *Trans. Croydon Nat. Hist. Soc.*, 1902–3.

The Blackheath gravel, as noted by Mr. T. V. Holmes, had a high reputation in the 18th century and was sent to great distances.[1] Being composed almost wholly of flint-pebbles, it may have been used for pavements, grottoes, etc.

On the higher Chalk tracts flints picked off the fields are utilized for road-metal, for which purpose they are the more serviceable as they are well-seasoned; flints do not, however, bind sufficiently well for modern traffic, unless mixed with other stone; crushed flint is used in great quantity for drives and roads designed for light traffic only.

The term 'ballast' as applied to gravel probably arose from the fact that such material has been extensively used for ballasting vessels.

The term 'Thames ballast' has been applied to material taken from the bed of the river, comprising about two parts of pebbles to one of sharp sand, and adapted for making concrete.[2] This material, as we are informed by Mr. C. W. Osman, is not now obtained of such good quality as formerly.

The Thames sand after being washed has been used with Portland Cement for making bricks and concrete. It makes good mortar.

In early days querns or hand-mills for grinding corn were made from the Hertfordshire puddingstone. Specimens have also been cut, polished, and made into lids of snuff-boxes, as mentioned by Kalm in 1748.

Historical.

The influence of the geology and topography on the selection of the site of London in the first place, and on the subsequent growth to the 'Greater London' of to-day, forms an interesting study, of which the essential points may be briefly touched on here.

The reasons for the choice of the site have been discussed by many writers, some of whom have, unfortunately, based their remarks on a wrong idea of the geology. The best account is given by Mr. Hilaire Belloc, who makes use of the geological maps described in this Memoir.[3]

As may be seen from the map or gathered from the preceding chapter, the Thames below London Bridge flows through a wide spread of alluvium, which must originally have been marsh: this ground is now protected from the tide by banks which are usually thought to date from the Roman era. At various points down stream, *e.g.*, Purfleet, Woolwich and Greenwich, the river touches solid ground, but only on one side. Near London Bridge, however, gravel spreads on either side approach each

[1] *Geol. Mag.*, 1882, p. 137.

[2] *See* 'Ure's Dictionary,' Ed. 7, by R. Hunt and F. W. Rudler, Art. Concrete, vol. i, p. 906.

[3] 'The River of London,' 1912, Chap. iii.

other and it becomes possible to cross the Thames. Above the bridge only narrow strips of alluvium are found, and fords existed at several spots, notably at Westminster (Thorney) and Brentford: the latter is almost certainly that used by Julius Cæsar (B.C. 54); the ford and river banks were protected by rows of stakes which have been discovered, and a post to commemorate the event has now been erected beside the Ferry Stage.[1] Other fords across the Thames were at Halliford and Staines; of the various tributaries, the Colne was crossed at Uxbridge and Watford, the Brent at Brentford, the Lea at Chingford, Old Ford and Stratford, and the Roding at Woodford and Ilford, on the north; the Wey at Weybridge (an important crossing in Bronze Age times), the Ravensbourne at Deptford, the Cray at Crayford, and the Darent at Dartford, on the south.

In ancient times the traffic between Britain and the Continent mostly used the Kentish ports; that with eastern and northern England sought the lowest crossing of the Thames, where London Bridge now stands, that for the north-west and more immediately for the important town of Verulamium (St. Albans) found a more direct route by Westminster.

It is in Roman times that we first find an important and permanent settlement at London, which Tacitus describes (A.D. 100) as 'copia negotiatorum et commeatorum maxime celebre.' Systems of Roman roads converge both on London Bridge and Westminster: to the latter runs Watling Street (shown on the map Sheet 4), to the former the road from Chichester (Stane Street). The crossing in Bermondsey is marked by a large Roman cemetery; the sub-soil is Low Terrace gravel, but Besant pictures the marsh extending as far south as the rising ground of Camberwell and Denmark Hill.[2] On the northern side we find the great north-west road running to Hyde Park Corner along Park Lane and Edgware Road, while from London roads radiate west to Silchester and Bath, by several routes into the north-west road just mentioned, north by the 'Great North Road' and eastwards across the Lea at Old Ford to Colchester.[3]

The reasons for the greater prosperity of London, as compared with Westminster, are geological and geographical. The Westminster ford depends on the little eyot formerly known as Thorney, but behind this was the marshy alluvium of the Tyburn before firm ground was reached on the north. On this eyot space was only available for a tiny hamlet, and the mouth of the Tyburn, by Scotland Yard, formed only a small port, known as the Mersfleet. The City of London stands on twin hills of Middle Terrace gravel and brickearth, separated by the

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[1] *See* Sharpe, Montagu, 'Antiquities of Middlesex in British, Roman and Saxon Times,' 1905, pp. 1, 8, 18; Turner, Fred, 'History of Brentford,' Part I, 1921.

[2] 'South London,' 1898, Chap. I.

[3] Smith, R. A., 'Roman Roads and Saxon Churches of London,' *Archæologia*, vol. lxviii, 1917, pp. 229–262; 'Victoria County History of London,' vol. i.

valley of the Walbrook, bounded on the west by the Fleet valley and on the east by comparatively low ground. Here was a 'square mile' of dry healthy soil with a good water supply obtainable from shallow wells. From here adequate watch could for the first time be kept over traffic coming up the Thames; here, the mouths of the Walbrook (Dowgate) and the Fleet provided good ports and the steep bank of the latter a good defence; from here a road ran on dry gravel soil to Hyde Park Corner and diverted much of the traffic using the Westminster ford.

In late Roman times, therefore, we find a great walled City of London and a small isolated settlement at Westminster, and this state of things continued for centuries; in Domesday Book, Westminster is a small village. London remained practically confined by the walls till the end of mediæval times, when the need for a defence on the west became less urgent. It should be noted that the hill facing the river is now less steep than the natural bank which lies some 60 ft. north of the northern side of Thames Street; the intervening area, about 45 acres in extent, has been formed by successive encroachments on the River.

Westminster owed its importance to the Abbey and the Royal palace, the latter first built by Cnut. It remained small in extent, and the nucleus of Thorney Island can still be recognised in a map of Commonwealth date. It became linked up with London, through the village of Charing by a growth along the 'Strand,' where the gravel impinges on the river. As late as 1578 Agas's map shows only a line of great houses, such as the Savoy, facing the river, mean houses along the north side of the road, and then open fields, including the Convent (Covent) Garden. With the Restoration, an era of rapid expansion set in, and the gravel area between the Tyburn and Fleet was completely built over by the end of the 17th century. The northward limit of the gravel then became the limit of the town; the water supply was still from the Thames in its immediate neighbourhood and from the gravel by springs or wells elsewhere. The conduit system for bringing water from distant springs, as at Tyburn, Paddington and Hackney, had been developed as far as possible (p. 82). The clay areas could not be built upon before the beginning of the 19th century, when iron pipes and steam pumps came into use. Till then the spread of bare London Clay around North London was waste land; parts of the original forest remained, such as St. John's Wood. The railway termini from Paddington to King's Cross mark what was for a hundred years the outskirts of London.

The surrounding villages were also built upon water-bearing strata; Chelsea, Battersea and Bermondsey grew up on eyots of gravel near the river; Kensington, Paddington, Acton, Ealing, Islington and Highbury on the north, Putney, Roehampton, Clapham, Balham, Tooting, Brixton and others on the south, all owed their position to patches of River Gravel, Hampstead and Highgate to the water-bearing Bagshot Sand.[1]

It was the steam-pump and the iron main that enabled the intervening clay areas to be built over, rather than the discovery that water could be obtained by deep wells sunk through the London Clay. In this way the various hamlets became absorbed in what Cobbett called the 'Great Wen,' till the London of to-day extends in many directions beyond the limits of the Administrative County, constituted in 1888.

The gravels now have little influence on the growth, though a gravel soil is considered, not always correctly, as an advantage; and where concrete is used, a supply of gravel on the spot is convenient. The London Clay now encourages rather than checks expansion, since it is an ideal stratum in which to construct tube railways.

Building Stones.

The economic geology of London might be considered to include that of the stones used for building; but a complete list of such materials would include those from all parts of Britain and such distant lands as Norway and Greece; the few that are found within a short journey of London can alone be mentioned here.

By far the most important building material of to-day is reinforced concrete made from Portland Cement and either river gravel or the sand and pebbles of the Blackheath Beds (p. 87).

Ferruginous sandstone, ironstone, Kentish Rag, and flint were utilised in Roman times, and these materials with tiles were employed in the construction of London Wall; a good example of flint-work may be seen at the Tower. Of building stones, that of the Upper Greensand of the neighbourhood of Reigate, Gatton, Merstham and Godstone was much used in olden times, as, for instance in Old London Bridge. The harder rock, known as firestone, was employed not only for buildings, but for floors of furnaces; it was utilized in Hampton Court Palace; hearthstone is obtained from the softer calcareous sandstone. Chalk has been used at the Tower and in many old churches.

Blocks of sarsen or greywether sandstone from the Chiltern Hills have frequently been used for pitching in London; the Round Tower of Windsor Castle is built of this material.

The ancient monastic barn at Harmondsworth is built of puddingstone.

The iron railings round St. Paul's were made from Wealden iron ore at Lamberhurst at a time when charcoal was used in the furnaces.

[1] *See* Prestwich, Presidential Address to Geological Society, 1872; Bonney, T. G., in Besant's 'Early London.'

INDEX.

D.

E.

F.

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