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Geological notes and local details for 1:10 000 Sheet SP61SW (Oakley)

Part of 1:50 000 Sheet 237 (Thame)

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INTRODUCTION

This account describes the geology of 1:10 000 Sheet SP61SW (Oakley). The area is included in the 1:50 000 Sheet 237 (Thame). The area was surveyed on the 1:10 560 scale by H B Woodward and T I Pocock in 1904-06 and the results were included in the one-inch scale Oxford 'Special' Sheet, published in 1908. The geology of that sheet was described by Pocock (1908) and Pringle (1926). The area was resurveyed at the 1:10 000 scale in 1986 by A Horton. Stratigraphical palaeontology was studied by B M Cox. The work was partly funded by the Thames Water Authority.

The area includes the village of Oakley, parts of Studley and the hamlet of Boarstall. It is largely devoted to agriculture and includes the extensive Shabbington, Oakley and Boarstall woods.

One of the alternative routes for the northward extension of the M40 motorway from near Great Milton to Wendlebury crosses the area and much geological information was obtained from the site investigation boreholes and trial pits. Access to boreholes cores and samples was generously granted by Sir William Halcrow and Partners on behalf of the Department of Transport.

GEOLOGICAL SEQUENCE

DRIFT DEPOSITS	QUATERNARY
	Alluvium
	First Terrace Deposits
	Head
SOLID DEPOSITS	LOWER CRETACEOUS
	Whitchurch Sand Formation
	UPPER JURASSIC
	Purbeck Formation
	Portland Formation
	Kimmeridge Clay Formation
	Ampthill Clay Formation
	Corallian Formation
	Oakley Member
	Arngrove Spiculite Member
	West Walton Formation
	Oxford Clay Formation
	Upper Oxford Clay
	Middle Oxford Clay

Solid Formations

A major part of the Upper Jurassic sequence of the district is made up of mudstones. Although distinguished by lithology and fauna when fresh, most of the component formations (Oxford Clay, West Walton Formation, Ampthill Clay and Kimmeridge Clay) readily weather to soft grey clay at outcrop. Physical weathering, particularly under periglacial conditions, fragments the mudstones which are then more susceptible to chemical weathering by downward percolating water. Calcareous material is leached, and pyrite, which occurs finely disseminated throughout the mudstones (giving them their grey colour), is oxidised. The free calcium and sulphate ions recombine and form crystals of selenite (gypsum; $CaSO_4.2H_2O$). The crystal size progressively increases from sand grade at 1 m depth, up to 5 cm or more at about 3 m. There is a zone of lithorelics below, where fragments of mudstone have been totally oxidised to khaki brown colours and then subsequently reduced along joint and fragment surfaces to a pale bluish grey colour. Unweathered material is usually found within 4 to 5 m of the surface. Selenite crystals are generally absent below

5 to 6 m depth.

Oxford Clay Formation

Middle Oxford Clay (Stewartby Member)

Up to 20 m of Middle Oxford Clay crop out in the north-western part of the district, around Whitecross Green Wood; the total thickness of the member is about 24 m. It consists of pale grey, blocky, calcareous mudstones interbedded with pale greenish grey silty mudstone often packed with immature shells of the bivalve *Bositra*. The Middle Oxford Clay fauna is generally limited, although beds rich in *Gryphaea lituola* Lamarck occur at some levels. Small uncrushed pyritic ammonites occur throughout. The calcareous worm *Genicularia vertebralis* occurs in the lower part of the member. Rather ill-defined thin beds of weakly cemented calcareous silty mudstone and siltstone occur in the upper part of the member. The most important of these, the Lamberti Limestone, which defines the top of the member, is a pale to medium grey, silty, argillaceous limestone. The Lamberti Limestone is very fossiliferous and contains a varied fauna, including serpulid and burrows, *Gryphaea, Lopha, Oxytoma,* pectinids, gastropods, belemnites and ammonite including *Choffatia, Kosmoceras, Peltoceras* and *Quenstedoceras*.

There are no natural exposures but the formation was exposed in trial pits dug as part of the M40 site investigation.

Beds in the lower part of the member were exposed in trial pit 195 [6059 1455]:

	Depth (m)
Pale grey and ochreous mottled clay, slightly silty and blocky. Becoming medium grey from 1.5 m with selenite and pale grey-stained fissures. Occasional pyrite nodules with pyrite trails, scattered ammonites, bivalves including *Gryphaea* and a solitary coral	seen to c 2.0
Fine grained silty nodular cementstone	0 to 0.1
Alternations of stiff, silty, blocky mudstone with smooth fissile mudstone	seen to c 4.0
Second cementstone nodule band	0 to 0.1
Alternations of mudstone as above with brown bituminous bands to 4.8 m. Becoming medium to dark grey downwards	seen to 5.1

Trial pit 190 [6128 1454] proved beds in the upper part of the Middle Oxford Clay:

	Depth (m)
Pale grey, silty, blocky mudstone with race (probably a weathered calcareous siltstone) at the top. Passing down to brown ochreous mudstone with grey, leached fissures with scattered oyster debris, belemnites and a pyritised ammonite	seen to 3.45
Ochreous and grey muddy calcareous siltstone with a few ammonites and bivalves	to 3.75
Medium grey silty, slightly fissile to blocky mudstone with silt layers	seen to 4.95

At a slightly higher stratigraphic level trial pit 185 [6139 1448] showed:

	Depth (m)
Pale to medium grey, silty, blocky mudstone with scattered *Gryphaea;* becoming ochreous-brown with grey, leached fissures and selenite downwards	seen to 3.62
Ochreous and grey mottled silty limestone, soft and more argillaceous downward. Scattered bivalves, ammonites and belemnites	to 3.85
Ochreous brown silty mudstone at top, becoming medium grey from 4.1 to 4.25 m. Scattered fossils. Becoming more calcareous downward	passing 4.55
Pale grey, silty, blocky, poorly fossiliferous limestone	seen to 4.95

The boundary with the Upper Oxford Clay was exposed in trial pit 171 [6145 1442]:

	Depth (m)
UPPER OXFORD CLAY	
Grey, smooth mudstone	seen to 4.55
MIDDLE OXFORD CLAY	
Lamberti Limestone, pale to dark grey muddy limestone with darker burrows. Abundant ammonites and bivalves with dark grey, dusty pyrite preservation	to 4.83
Grey mudstone with pyrite trails	seen to 5.00

Beds at the same stratigraphic level were exposed in trial pit 165 [6098 1413]:

	Depth (m)
UPPER OXFORD CLAY	
Pale grey and ochreous clay with race, becoming rich in selenite; blocky, a few bivalves with depth. Slip surfaces. Layer of limestone nodules and shells at 2.05 m	2.35
MIDDLE OXFORD CLAY	
Lamberti Limestone, pale grey and ochreous, silty limestone, ammonites and bivalves common; darker mud-filled burrows	2.68
Siltstone, pale to medium grey and ochreous; calcareous, locally cemented to limestone; scattered weathered pyrite nodules now oxidised to limonite and selenite	2.88
Mudstone, olive green to grey, silty, blocky, with grey-stained fissures and selenite crystals: scattered pyritic trails, burrows, bivalves, belemnites and ammonites. Becoming dark grey, poorly fissile and silty from 4.9 m with some ochreous staining	seen to 5.00

Upper Oxford Clay (Weymouth Member)

The Member crops out on the lower slopes beneath the Panshill escarpment and along the valley of the Danesbrook. There were no natural exposures at the time of survey, but the highest beds were formerly exposed in the Studley Brickpit [603 120], and the member was proved in a number of M40 site investigation boreholes and trial pits. The base is drawn at the top of the Lamberti Limestone; this horizon also defines the boundary between the Oxfordian and Callovian stages. The top of the member is less clearly defined but occurs within a sequence of rhythmic mudstones, at the first appearance of dark grey, silty mudstone lithologies typical of the West Walton Formation (see below). The thickness of the member is thought to be between 20.4 and 21.6 m (Appendix I).

The Upper Oxford Clay is characterised by pale grey, smooth-textured, silty and very slightly calcareous mudstone. A weak rhythmic pattern of sedimentation can be recognised, in which the base of each rhythm is marked by a very thin darker grey, slightly silty, slightly carbonaceous mudstone which infills burrows in the underlying bed. The proportion of ultra-fine plant detritus and shell debris decreases rapidly upwards in each cycle. Thin beds of calcareous siltstone or argillaceous, silty limestone are also present and beds rich in *Gryphaea dilatata* J Sowerby occur at several levels.

A distinctive bed of pale brownish grey mudstone with a calcareous silty mudstone or clayey silty limestone at or near the base, the newly defined 'Panshill Brown Bed' and 'Panshill Siltstone' respectively, occur about 3.6 m above the base of the member (Appendix 1). The M40 Borehole 130 (SP61SW/63) [6111 1392] is designated as the type section. The Panshill Brown Bed ranges in thickness from 3 to 4.8 m with an average of about 4 m. It is poorly fossiliferous and contains small bivalves, small turriform gastropods, rare ammonites and crustacean debris; crushed *Pinna* occur rarely. Fine-grained shell debris is scattered throughout, but is often concentrated into burrow linings; linear pyrite traces probably represent small burrows. The Panshill Siltstone ranges from 0.21 to 0.46 m in thickness, with an average value of 0.3 m. It produces a distinctive low radioactivity signature on the gamma logs. An additional geophysical marker, with a high radioactivity signature, occurs some 5.2 to 5.8 m below the top of the Member but cannot yet be equated with a specific distinctive lithology. Borehole cores at this level comprise pale grey silty mudstones with thin dark grey silty and carbonaceous inter-burrowed horizons which probably represent pauses in deposition.

The Upper Oxford Clay is generally poorly fossiliferous, although ammonites, belemnites, bivalves, gastropods and shell debris occur throughout. The ammonites are generally preserved in solid pyrite, although shells tend to be crushed and aragonitic in the darker grey mudstones. Pyritised nuclei/inner whorls of *Cardioceras (Scarburgiceras) praecordatum* Douvillé and *C. (S.) scarburgense* indicative of the Mariae Zone were collected from the spoil from M40 trial pit 171 [6145 1444] which proved 4.55 m of grey mudstone, above the Lamberti Limestone on grey mudstone. The spoil heap [6191 1310] from another investigation yielded a reddish fragment of a pyritised *Cardioceras (Vertebriceras?) sp.* indicative of the "Red Nodule Beds" part of the Dorset Upper Oxford Clay, i.e. the Costicardia Subzone of the Cordatum Zone.

West Walton Formation

The West Walton Formation was originally defined in Fenland. In the Oakley area the West Walton Formation consists almost entirely of mudstones with only thin calcareous siltstone beds. There are no sections visible at the present time, but the formation was proved in many of the M40 site investigation boreholes.

Two major lithological types of mudstone can be recognised in the unweathered cores and these alternate in rhythmic couplets. The basal bed of each rhythm consists of a dark grey, intensely burrowed, very silty, richly fossiliferous mudstone, with many ammonites, thick-shelled robust benthonic bivalves, coarse shell debris and much fine plant detritus. This passes gradually upward into pale grey calcareous mudstone with scattered fossils, ultra-fine shell detritus and pyrite patches, pins and trails.

The fauna in the upper part of the rhythm is generally thin-shelled and predominantly nektonic in character, and includes pyritised ammonites. The top of the rhythm is abrupt and is often marked by an intensely interburrowed junction with the overlying dark carbonaceous mudstone piping down into the pale grey mudstone. Many rhythms are incomplete. Similar sequences occur in the overlying Ampthill Clay and less well-defined rhythms can be seen in the Upper Oxford Clay Member. Gallois and Cox (1977, Fig 3) suggest that they may be related to changes in relative sea level, with progressive deepening of the sea floor as the rhythm developed. The darker mudstones are more prevalent in the upper part of the formation.

The base of the Formation is drawn at the first appearance of dark to medium grey, slightly silty mudstone. This coincides with an interburrowed horizon. However, because of the rhythmic nature of both the underlying Oxford Clay and the West Walton Formation, difficulty occurs in defining this junction, which is rather subjective even in borehole cores.

At outcrop, the slight change in lithology at this level often produces an ill-defined change of slope and this is used to define a mappable boundary between the two formations. The West Walton Formation outcrop is marked by clay soils which are much darker greyish brown than those of the underlying Upper Oxford Clay. It is characterised by the abundance of large specimens of *Gryphaea dilatata*, many of which are encrusted and extensively bored.

Evidence from boreholes indicates a total thickness of the West Walton Formation of 16.9 to 17.2 m.

Certain beds within the formation have distinctive gamma radiation signatures and these markers can be traced throughout the sheet area. Two low radioactivity beds, probably calcareous siltstones and silty mudstones, occur in the lower part of the formation, 1.8 to 2.3 m and 3.3 to 4.1 m above the base respectively. Beds with higher radioactivity, probably mudstones, occur at about 2.8 and 4.4 to 4.5 m above the base. A particularly distinctive marker 8.6 m or so above the base, is associated with the 'Black Bed' seen in temporary sections. This is a very dark grey, richly fossiliferous silty mudstone with much shell debris, large ammonites and trigonids. Two persistent silty mudstones or siltstones occur at about 12 and 13 m above the base.

Cardioceratid ammonites are common throughout the Formation and are associated with perisphinctid species. *Gryphaea dilatata* is the most abundant fossil found at outcrop. In unweathered material it is associated with *Grammatodon, Lopha, Pinna, Nanogyra nana* J Sowerby and *Dicroloma*. Chondrites mottling occurs at some levels.

The West Walton Formation accumulated in an offshore quiescent marine environment, with intermittent phases of current activity, which were more intense than during the deposition of the Upper Oxford Clay.

Corallian Formation

This new term is applied to the non-argillaceous sediments of the former "Corallian Beds". In the present district it comprises the Arngrove Spiculite Member and the Oakley Member.

Arngrove Spiculite Member

The Arngrove Spiculite Member, formerly known as the Arngrove Stone, consists of spiculite and spiculitic sandstones. Its distinct lithological character was noted by Buckland whose description was quoted by Phillips (1855, p 307) as 'a peculiar bed of clouded grey colour, and very tough and dense texture, a sort of argillaceous chert, rich in pinnae, ammonites, and other organic remains'. A H Green (1864, p 44) noted that the rock formed 'a good escarpment by Arngrove Farm ..., beyond we lose sight of it ...'. Davies (1907) noted active quarries [613 137] near Arngrove Farm (now Old Arngrove) and introduced the term Arngrove Stone for the 'rock' being worked. He applied this restricted definition in describing a well section at Boarstall Road, Studley [probably 6030 1271]:

		Thickness (m)
'5	Soil and Arngrove Stone rubble	0.91
4	Arngrove Stone	0.61
3	Reddish brown sandy clay: fish tooth, *'Alectryona'* fragments, traces of other shells	0.91
2	Argillaceous limestone	0.30
1	Clay, very black and stiff, *'Gryphaea dilatata'*, *'Cardioceras cordatum'*, at least	3.01'

The clay of bed 1, at that time thought to be Oxford Clay, is now placed in the West Walton Formation. The term Arngrove Spiculite Member is now applied to all the beds (2 to 4) which overlie this clay. In the present area the top of the Member is drawn at the base of the Oakley Member where the arenaceous beds are overlain by shelly mudstones, silty mudstones and calcareous siltstones, marls and limestones. The original type locality was one of the now abandoned Arngrove Farm quarries; the Brill Borehole [6570 1412] (depths 106.06 to 107.70 m) immediately to the north-east of the present district is now designated a reference section. The outcrop of the Arngrove Spiculite gives rise to the major escarpment at Studley, Arngrove and Boarstall, which stands high above the Oxford Clay vale. A lesser escarpment occurs on the south side of the Danes Brook, through Pasture Farm [615 126]. Small outliers at intermediate elevations cap small hills between the escarpments, indicating a south-easterly dip. The main outcrop continues as a small feature which can be traced southwards from Boarstall to the disused Worminghall Airfield [631 110].

The thickness ranges from 3.5 to 4.5 m. Boreholes starting on the outcrop near Arngrove proved up to 3.9 m [6135 1389] of beds.

Davies (1907) noted the characteristic thin bedding and roughly rectangular fracture of the Spiculite, giving blocks up to 10 cm x 10 cm x 4 cm thick.

The rock is pale bluish grey in colour and of distinctively low density. It contains ellipsoidal grains, most are translucent blue but some opaque white, which are the spicules of the tetractinallid sponge *Rhaxella perforata*. The colours reflect different degrees of recrystallisation which, in some cases, has led to complete solution of the spicules, leaving voids. Quartz grains are also present, the proportion varying so that there is a transition from spiculite to spiculitic sandstone. The former is characterised by a siliceous cement. Rarely the spiculitic sandstones are lime-cemented. Davies recorded one such bed at a pond near Warren Farm [134 606] and in the Well [6030 1271] on the road to Boarstall, in Studley. Trial pits along the proposed M40 showed that clayey silts, silty clays and siltstones are also present. Trial pit 127 [6148 1402] showed 2.98 m of beds:

	Thickness (m)
ARNGROVE SPICULITE MEMBER	
Spiculitic sandstone	1.46
Silty to sandy well-bedded clay with some sandstone	0.12
Spiculitic sandstone	0.13
Silty to sandy well-bedded clay with some sandstone	0.42
Very well-cemented spiculitic sandstone	0.20
Silty to sandy clay etc	0.49
Spiculitic sandstone	0.16
WEST WALTON FORMATION	
Ochreous and grey mudstone with much pyrite staining	seen to 0.07

Pit 133 [6138 1407] proved the basal 1.77 m

	Thickness (m)
ARNGROVE SPICULITE MEMBER	
Topsoil with sandstone and clay	1.0
Very well-cemented spiculitic sandstone	0.58
Clay, well-bedded with silty clay and some sandstone beds	0.02
Spiculitic sandstone with pyritic staining at the base	1.77
WEST WALTON FORMATION	
Ochreous grey clay with weathered pyrite nodules and oxidised staining	0.05
Grey and ochreous mottled silty mudstone with weathered pyrite nodules and selenite. Dark grey unweathered in basal 0.8. Interburrowed at bottom.	2.83
Greenish grey silty blocky mudstone	seen to 0.40

A temporary section recorded by K Ambrose in the foundations of the Panshill Overbridge [6159 1400] on the M40 was as follows:

	Thickness (m)
ARNGROVE SPICULITE MEMBER	
Spiculite, ochreous mottled pale grey, blocky	1.60
Mudstone, grey and ochreous, very silty, varying to siltstone, well-bedded with many spicules; soft but firmer better cemented in parts	0.41
Spiculite, grey with ochreous mottling, muddy. More dense than top layer, but varying from well to poorly cemented	0.12
Mudstone, grey with ochreous mottling, silty to very silty; spicules common	0.21
Siltstone, dark grey, slightly brown tinted, with ochreous mottling, muddy with very fine shell debris and plant fragments. Hard and well-cemented in basal 0.15 m with *Gryphaea dilatata*	0.40
WEST WALTON FORMATION	
Mudstone, dark grey with ochreous mottling, silty and blocky, fossiliferous with ammonites and bivalves with a few *Gryphaea dilatata* and many *Pinna*. Serpulid limestone nodules at top. Mottling absent below c 0.5 m	seen 2.10

Similar beds were seen during the excavation of the Panshill and Howeyburge cuttings on the M40. The degree of cementation varied rapidly both laterally and vertically.

Specimens of *Cardioceras* including *C. (Subvertebriceras) densiplicatum Boden* and *C. (S.) sowerbyi* (Arkell) indicative of the Densiplicatum Zone, Vertebrale Subzone, were collected at the edge [6154 1390] of the disused Arngrove Farmhouse quarry. They occurred with *Chlamys (Radulopecten) Fibrosa* (J Sowerby), *Myophorella* sp., *Nanogyra nana* (J Sowerby) and *Pleuromya alduini* (Brogniart). Debris from excavations at Tower Farm barn [6250 1435] yielded *C. (R.) fibrosa, 'Lucina' lirata* Phillips, *Nodiolus bipartitus* J Sowerby, *Pholadomya sp.* and *P. alduini* in association with the above-mentioned ammonites.

The Member is very fossiliferous in parts and casts of ammonites can be collected from field debris of the spiculitic sandstone.

The Member is thought to have been deposited as a sand bank close to an area colonised by sponges. It is contemporaneous with parts of the West Walton Formation which accumulated in slightly deeper water further offshore.

Oakley Member

The term Oakley Clay was first applied by Buckman (1927) to clays and clayey marls, previously known as "*Exogyra nana* beds/clay/zone" (Davies, 1907; Barrow, 1908) which outcrop in the vicinity of Oakley, Buckinghamshire, and which he considered to be older than most of the Ampthill Clay and the lateral equivalent of the [Upper] Corallian Beds around Oxford. The name was amended to Oakley Beds [Arkell, 1933, p 409, 1942, 1947] and the beds were recognised as being equivalent to the Coral Rag, Wheatley Limestone, Littlemore Clay Beds and the Elsworth Rock Group. The term Oakley Member is used here for this group of beds.

In the present district the member is the youngest division of the Corallian Formation. It consists of interbedded pale grey marls, silty limestones, siltstones and silty mudstones. Estimates of the thickness based on outcrop evidence range from 3 to 5 m. It is very richly fossiliferous and its outcrop is marked by abundant valves of *Nanogyra nana* (J Sowerby) and serpulid tubes. The base is drawn at the appearance of these calcareous beds which contrast strongly with the 'sandy' Arngrove Spiculite Member (or, to the south of the present district, the Beckley Sand Member) below. The overlying Ampthill Clay consists almost entirely of mudstones which weather to smooth clays.

No major exposures were seen during the survey and information on the member has been derived from the evidence of field debris. The member is calcareous throughout; marls and soft, commonly silty limestones occur everywhere and are associated with shelly mudstones. Oyster lumachelles occur, as for example [6251 1326], north of Boarstall Wood where an oyster limestone overlies a marl packed with cemented clusters of *Nanogyra nana* and serpulids plus bored and encrusted *Gryphaea dilatata*. Rarely more indurated limestones are present, for example at Boarstall Moat [6264 1408] where cream mottled marly limestone with bivalves, including *Pleuromya*, is associated with calcareous siltstone and marl debris. A serpulid-rich limestone [6295 1320] and a marly limestone with *Perisphinctes* [6261 1326] crop out north of Boarstall Wood. Field brash [6330 1188] near Jericho Farm comprised cemented clusters of *Nanogyra nana*, bored and lightly encrusted with serpulids, a yellowish, silty marly limestone with a fragmentary perisphinctid ammonite whorl, and a similarly sandy marly limestone with shell debris containing *N. nana*, some of which were bored. Oyster-rich clays and marls, with a silty limestone containing fragments of *Cardioceras* and *Perisphictes* with *Nanogyra* and *Isognomon?* were thrown out of house excavations [6392 1202] in Oakley village. A hard, blue-hearted, bioturbated sandy limestone was noted in field brash [6422 1105] east of Woodground Farm and again further south-west in debris from a pylon foundation [6355 1023]. At the western extremity [6321 1000] of the Worminghall Airfield a pale fawn, sandy, bio-oosparite appears to overlie marly oyster limestones and oyster lumachelles. The mudstones are silty and in places sandy and grade to marl. They generally contain an abundance of secondary race (calcite nodules) due to weathering.

The complete sequence was proved in the Brill No.1 Borehole [6570 1412], to the north-east of the present district, and confirmed the calcareous character of the formation and the presence of much bioturbation (Barron, 1988). Marls (40 per cent) and limestones (31 per cent) are the dominant rock types. Although most of the beds are silty, only 6 per cent are classified as siltstones. The lithological boundaries are arbitrary because the unweathered beds pass gradually into each other. Limonitic ooliths and pisoliths are common at some levels in the borehole; a fragment of shell-debris, ferruginous oolith limestone was found in the floor [6345 1384] of the Danes Brook. Its presence here, within the Ampthill Clay outcrop, suggests the Oakley Member may occur as a result of valley bulging.

Estimates of the thickness based on outcrop evidence range from 3 to 5 m, whilst some 4.2 m of beds were attributed to the member in the Brill No 1 Borehole [6570 1412], to the north-east of the present district.

Ampthill Clay Formation

The Ampthill Clay comprises all the clay strata between the Corallian Formation and the overlying Kimmeridge Clay. The base is drawn at the first appearance of smooth weathering clays which contrast with the underlying silty calcareous clays of the Oakley Beds. There are no major exposures and information has been largely derived from the Brill No. 1 Borehole. Dr Cox has suggested that the basal 2.01 m of the Ampthill Clay Formation, as defined here, are lithologically similar and laterally equivalent to the uppermost West Walton Formation of the type area. They comprise 0.15 m of pale grey, bioturbated, calcareous siltstone overlying 0.83 m of calcareous mudstone, 0.06 m of siltstone and 0.97 m of calcareous mudstone, which overlie typical Oakley Member. The upper and lower boundaries of this basal unit appear to be transitional. The first evidence of a non-sequence, marked by shelly, shell-debris rich mudstone with undetermined green sand grains, occurs 3.68 m above the Cumnor Formation. The remainder of the Ampthill Clay consists of pale grey, silty, calcareous mudstones with a thin cementstone band in the upper part, overlying medium greenish grey to grey mudstones with slightly bituminous and shell-rich layers. Estimates of thickness at outcrop range between 15 and 22 m. Some 22.26 m of beds, including possible West Walton Formation at the base, were attributed to the formation in the Brill No. 1 Borehole. A serpulid-rich mudstone occurs 4.25 m above the base whilst a 0.18 m marl and a 0.21 m thick cementstone occur 0.49 and 0.79 m respectively below the top of the formation in the Brill Borehole.

Other hard feature-forming beds can be traced locally. A pale brown silty marl with *Nanogyra* and bored *Gryphaea* occurs near the top of the formation in the fields [6433 1155] east of Oakley. At a slightly lower level, a pale brown decalcified siltstone crops out in the stream bank [6428 1201]. Similar beds occur downstream, at one point [6426 1184] some 0.7 m of clay overlies a 0.4 m silty marl with *Perisphinctes*, 0.6 m of grey clay and, at water level, 0.1 m of marl. These are probably the West Walton Formation equivalents discussed above. There is a silty marl in the graveyard [6420 1235] north of Oakley Church and a thin bed of grey, oyster-shell-debris rich, silty limestone (oyster biosparite) with serpulids and Lima in addition to a nodular shelly cementstone with small *Dicroloma* crop out on the west side [6405 1307] of the brook, north of Nap Farm, Oakley. A thin bed of flaggy limestone of similar lithology gives rise to a prominent feature [6305 1436] east of Manor Farm, Boarstall.

The highest beds of the Ampthill Clay, consisting of grey clay with oyster fragments and a small cementstone nodule band possibly overlain by a shelly cementstone nodule band, occur in a ditch [6326 1448] south-west of Muswell

Hill. Clays with oyster debris at the same horizon crop out on either side of the low ridge running south-west from Touchbridge. Debris from a ditch [6394 1375] on the south, or Span Green side, included loose and clustered fragments of *Nanogyra nana*, some with encrusting serpulids. A decalcified silty horizon was associated with extremely shelly cementstone fragments with *N. nana* and a whorl of a compressed 'perisphinctid' ammonite. Dr Cox suggests that these beds may be equivalent to beds AC40-42 of the standard Fenland sequence (Cox and Gallois, 1979).

The fauna comprises ammonites (Cardioceratid and perisphinctid species), belemnites, bivalves, including *Gryphaea dilatata* J Sowerby and, in the upper part, the characteristic bluish grey-shelled flat oyster *Deltoideum delta* (Wm Smith).

Kimmeridge Clay Formation

The formation crops out on the southern slopes of Muswell Hill in the north and on the western and southern slopes of Brill Hill. It generally forms the steep upper slopes, which have been extensively landslipped, but also extends down to form a bench-like feature above the Ampthill Clay outcrop.

The base of the Kimmeridge Clay in the Brill Borehole is marked by a non-sequence which is overlain by silty shelly mudstone with thick-shelled oysters and small black phosphatic pebbles. This basal bed can rarely be located at outcrop within a mostly clay sequence, so that the boundary between the Ampthill Clay and Kimmeridge Clay shown on the map is generalised. At the time of the survey, a thin cementstone band, which was thought to occur immediately above the base of the Kimmeridge Clay, provided a readily mappable horizon. Subsequently, the Brill No. 1 Borehole proved two cementstone bands, 1.0 and 2.0 m below the top of the Ampthill Clay. The higher band probably coincides with the mapped horizon so that the true base of the Kimmeridge Clay is probably slightly above the level depicted on the map.

Like all the other clay formations within the Ancholme Group, the Kimmeridge Clay is generally weathered to a depth of about 4 m and produces a brownish grey clay soil.

There are no natural exposures of the Kimmeridge Clay Formation, but the complete thickness of 55.1 m was proved in the Brill No. 1 Borehole (Ambrose and Barron, 1988; Barron, 1988) comprising some 15.85 m of Lower Kimmeridge Clay and 39.25 m of Upper Kimmeridge Clay. When unweathered, the Lower Kimmeridge Clay consists of greenish grey, smooth-textured, poorly fossiliferous mudstones interbedded with olive-tinted, shaly, fossiliferous mudstones and pale grey calcareous mudstones. The Upper Kimmeridge Clay comprises brownish grey shelly, bituminous mudstones (in the lower part), with medium to pale grey, blocky, calcareous mudstones and thin siltstones, with interbedded silty calcareous mudstones, siltstones and sandstones. These lithologies occur in a rhythmic sequence which ideally comprises a siltstone at the base overlain by dark grey mudstone and, at the top, a pale grey calcareous mudstone which may contain a cementstone band. In the lower and middle parts of the Kimmeridge Clay oil shale may form the basal lithology. Field mapping permitted the separation of an upper arenaceous unit, within which sand/sandstone beds can be recognised. The silts and sands are fine-grained, poorly sorted and only weakly indurated for the most part, although dogger-like cemented masses occur. Three predominantly sandy beds were recognised in the Brill Borehole; a 5.25 m bed at the top, and two others below, approximately 1.35 m and 3.29 m in thickness, separated by 5.64 m of silty mudstone with silt partings. The youngest bed was recognised at outcrop only on the eastern slopes of Muswell Hill, and is probably equivalent to the Wheatley Sand (sensu Arkell, 1947, p 108). This overlies a silty clay (Hartwell Clay) which in turn occurs above an outcrop of sand. The latter includes a strong morphological feature which is probably equivalent to one of the coarser, more indurated horizons within the lower beds of sand and interbedded mudstone, proved in the Brill No. 1 Borehole. These lower sands correlate in total or possibly in part with the Pectinatus Sands of Arkell (1947). Both beds of sand were difficult to recognise on the steep, grass-covered and landslipped slopes of Muswell and Brill Hill. Traced southwards from The Crossroads [6499 1441], the upper horizon has not been recognised and the characteristic landform of the lower horizon disappears. The entire slope appears to be underlain by sandy loam and is mapped as a unit within the Kimmeridge Clay. However, the outcrops as drawn may be over-simplified, reflecting the lack of evidence due to drift cover and also structural disturbance including landslip and cambering; the latter is particularly evident on the south-west slopes of Brill Hill.

A persistent cementstone nodule band mapped in the fields [6423 1400] near Touchbridge may be that proved 12.6 m above the base of the formation in the Brill Borehole. A block of fine-grained calcareous sandstone with pebbles of silty cementstone, probably derived from the base of the lowest sand bed in the Kimmeridge Clay, was noted at the western extremity of Muswell Hill [6317 1487].

When unweathered the Kimmeridge Clay is richly fossiliferous, yielding ammonites and bivalves with lustrous aragonite shells. Some horizons are packed with shells whilst others contain a dispersed fauna.

There are no workings in the present district. The brickpit [6501 1438] immediately east of The Crossroads, just beyond the district (Pringle, 1926, p 75), formerly exposed about 7 m (23 ft) of clay, stratigraphically equivalent to the 'Hartwell Clay', which was overlain unconformably by the basal lydite bed of the Portland Formation. This may have been the site of the Brill brickyard (Woodward, 1895, p 221) where the lydite bed was seen to overlie 0.9 m (13 ft) of 'brown and greenish mealy *(sic)* sand' and 6.1 m (20 ft) of 'sandy clay, passing down into stiff blue clay'.

Portland Formation

The formation crops out on the margins of the summits of Muswell and Brill Hills. These topographic features dominate the local scenery and their preservation results from the contrast in lithology between the Portland Formation and the clays of the underlying Ancholme Group.

The formation comprises two members, the Portland Sand at the base and the Portland Stone above. The Portland Sand consists of greenish grey glauconitic marls and soft marly limestones, with glauconitic sands and calcareous sandstones. It equates with the Glauconite Beds of earlier authors. The base of the Sand Member is marked by a bed containing abundant small well-rounded pebbles of black lydite (chert), the Upper Lydite Bed. The overlying Portland Stone Member consists of oolitic and shell-debris limestones, with thin marl and clay seams.

Only very shallow and degraded pits existed at the time of the survey, but the formation was extensively worked in the past for building stone. The area was visited many times by geologists (Brodie (1857), Blake (1880), Davies (1899) and Buckman (1922 and 1927)), but many of their sections were derived from the early records of Fitton (1836, p 280-1). His composite section of the geology of Brill Hill is given in Appendix 3. Mitchell (1836) appears to have visited the area at the same time, and noted the following sequence at Brill (possible modern classification in brackets):

	Thickness (m)
Vegetable mould (soil)	1.2
(Portland Stone Member)	
White, soft limestone with fossils	2.1
(Portland Sand Member)	
Sand	0.9
Rubble with fossils	1.2
(?Kimmeridge Clay Formation)	
Sand and clay with nodules of blue stone in the lower part	2.4
Coarse, white sand	0.6
Blue clay	0.6

He notes an 'abundance of green sand in lower part of the quarry' but does not specify the horizon at which it occurs.

Woodward (1895) described the section at the Brill Brickyard [probably 6501 1438] immediately east of the present district, and in an adjacent quarry. The sequence (reclassified and metricated) was as follows:

	Thickness (m)
'PORTLAND STONE MEMBER	
Oolitic and shelly rock on Oolitic Marl	0.61
Marl, with *Ostrea expansa*	0.30
Chalky rock, with *Ammonites*, *Lucina portlandica*, *Trigonia*	1.22
Brown clay, with *Ostrea*	0.13
Oolitic earthy rock	0.30
PORTLAND SAND MEMBER	
Greenish sandy and marly beds: *Pecten lamellosus*	2.13 to 2.44 (bracketed, covering this and the two following entries)
Glauconitic marly limestone, becoming sandy in lower part: *Cardium dissimile*, *Ammonites giganteus*, *Trigonia*, *Ostrea*. Nests of green sand in places.	
Lydite bed: brown clay with pebbles	
KIMMERIDGE CLAY FORMATION	
Brown and greenish mealy sand	0.3
Sandy clay, passing down into stiff blue clay, with iridescent Ammonites: *A.*	

biplex, Thracia, Astarte hartwellensis seen 6.1'

Blake (1893, p 73) had visited the clay pit previously and collected the following fossils from the Portland Sand Member which he described as a 'remarkable rubbly glauconitic mass of shells: *Ammonites bolniensis (sic), Am. biplex, Pleuromya tellina, Cardium pellati, Mytilus boloniensis, Trigonia pellati, T. muricata, Perna bouchardi, Lima rustica* and *Pecten lamellosus*'.

The characteristic rubbly glauconitic marl and limestone lithologies of the Portland Sand Member, the Glauconitic Beds can be readily recognised at outcrop. They are associated with many ammonites, *Trigonia* and other bivalves. The Portland Stone lithologies seen in the field brash include fine-grained sandy limestones and oolitic limestones (biosparites). The former occur near the base of the member. A 0.8 m thick bed of fine-grained sandy limestone with *Trigonia* overlying silty marl, with a dip of 40° west, was seen at a spring [6472 1343] west of Portree, on Brill Hill. The same bed, dipping 45° to the west, crops out at a spring [6478 1357] 165 m away. The following sequence was noted in a temporary section [6374 1466] south-west of Muswell Hill Farm:

	Thickness (m)
PORTLAND STONE MEMBER	
Marl, greenish pale grey, silty, shell-debris-rich. Almost a limestone in less decalcified parts	0.2
Limestone, pale cream with slightly orange-tinted platy shell debris. Abundant bivalves and some ammonites. Original planar bedding almost lost through differential rubbly weathering. Contains soft marl bands which had been dug out by badgers	1.25
PORTLAND SAND MEMBER	
Sand, pale greenish grey, silty, fine grained with decalcified shell traces	1.00

This section shows extensive dip-and-fault structures (see below) which probably affect the entire hill-top outcrops. This makes it impossible to establish lithological sequences or valid estimates of thickness from outcrop evidence. In the Brill No. 1 Borehole, the estimated thickness of the formation was 7.5 m; only 3.3 m of core were recovered. The Portland Stone

Member, possibly 1.8 m thick, consists of oolitic and shelly-shell-debris limestones (oo-biomicrite and biomicrite) above pale grey, silty, shell-debris marls and silty limestones. The underlying Portland Sand Member comprises glauconitic calcareous sandstones and sandy limestones in which the shells are characteristically replaced by orange to brown-tinted calcite.

In the Portland Sand, the Glauconitic Beds with the Upper Lydite Bed at the base persist throughout the district. The Portland Stone Member is very thin and cannot be correlated with the standard sequence of the Aylesbury area, where Creamy Limestones rest on Crendon Sand, on Aylesbury (Rubbly) Limestone. Crendon Sand type lithologies have not been recorded locally.

Purbeck Formation

The formation has a narrow outcrop on the western extremity of Brill Hill and the southern and western parts of Muswell Hill, and two outliers occur at the western extremity of Muswell Hill. The details of the formation have been derived from debris on the surface of the outcrop. The base of the formation is drawn at the first appearance of grey silty and locally shelly clays with oysters. Lilac-tinted stiff clays also occur and appear as field debris in association with white porcellanous limestones (micrites). The Purbeck Beds of Brill Hill were first recognised as such by Brodie (1873), but they had previously been described (as Portland Beds) by Fitton (1836, p 280-1). Brodie (p 198) described a limestone seen as debris from an unlocated excavation as being drab-coloured, coarse-grained and concretionary, in blocks 0.15 to 0.2 m thick, with a coarser sandy upper surface containing *Cypris*, fish-bones, teeth and scales. Another section, also on the adjacent sheet, was examined by Lamplugh (Pringle, 1926, p 85) (see Appendix) who described 1.1 m of beds consisting of a tough, bright green clay overlying 0.9 m of brecciated white limestone and marl. Because of cambering and the lack of exposure it is impossible to accurately estimate the thickness of the Purbeck Formation, but it is probably of the order of 3 to 4 m. However, on the adjacent sheet, Barron (1988, p 7), thinks that up to 8 m of beds may be present. The Brill No. 1 Borehole, in that area, proved an estimated thickness of 1.8 m, the 1.26 m of core recovered at this level consisting of grey marl and clay with shell debris. Other boreholes, Brill No. 2 [6606 1403] and Brill No. 3 [6629 1402], proved incomplete sequences of 4.41 m and 2.7 m respectively of clays, marls and thin limestones. These wide variations in apparent thickness probably result largely from the displacements associated with cambering.

Whitchurch Sand Formation

The name Whitchurch Sand was proposed by Casey and Bristow (1964) for deposits of ferruginous sand which overlie the Portland or Purbeck Beds at Quainton [748 221] and Whitchurch [802 207]. Similar sands occur elsewhere in the Thame district including Brill and Muswell Hills, and Shotover Hill, near Oxford. Strickland (1836) recorded the freshwater species *Paludina* (= *Viviparus*) from the sediments at Shotover. Phillips (1857, pp 236-8) variously described these deposits as 'Estuary Sands' and 'Ironsand and Ochre-series'. They were subsequently described as 'Freshwater Ironsand' (Hull and Whittaker, 1861, p 15), Shotover Sands (Blake, 1893) and Shotover Ironsands (Davies, 1899, p 40). Arkell (1947) uses both the latter terms and also replaces them by 'Wealden Beds'. Casey and Bristow (1964) thought the Shotover Hill deposits were younger (of Wealden age) than their Whitchurch Sand, which, on the basis of its fauna, they correlated with the basal Cretaceous Cinder Bed of Dorset. Throughout the area of the Thame Sheet these ferruginous sands constitute a single lithological association to which the term Whitchurch Sand Formation is now applied. This is now considered to be of Valanginian (Early Cretaceous) age.

The formation is predominantly arenaceous and the base is drawn at the first appearance of quartz sand. The sediments are non-calcareous, unlike the underlying Purbeck Formation. At least 15 m of the formation cap Muswell Hill and Brill Hill and locally rest on the Purbeck Formation. Eastwards it oversteps the latter to rest on the Portland Stone Member and the Portland Sand Member (Barron, 1988, p.8).

The outcrop is characterised by a reddish brown sandy soil with fragments of ironstone. The latter are generally sandy and probably derived from secondary ironstone veins and geothite replacement of sand beds. Soft, uncemented, medium to coarse-grained sands can be identified by augering. Stiff pale grey silty clay seams also occur.

The formation has been extensively quarried in the past but only two shallow exposures remain. In the first [6398 1500], just north of Muswell Hill Farm House, the sequence consisted of 1.5 m of strata, primarily ferruginous sandstone with thin beds of sand and pale grey clay seams. In the second [6434 1459], SSE of Middle Farm, the sequence was:

	Thickness (m)
Soil with ironstone debris	0.3
Sand, clean brown with grey silty clay laminae	0.4
Sand, brown, fine to medium-grained, well-sorted	seen 0.3

Blake (1893, p 83) described the sequences in several roadside pits [possibly including those at 6439 1500 and 6469 1476] as 'false-bedded, ferruginous, probably manganiferous in places, with occasional doggers and bands of white marl and sand'. The freshwater bivalve *Unio* was collected from a nodule and subsequently Arkell (1947, p 133) recorded the presence of 'blocks of ironstone crowded with casts of *Neomiodon medius* and rarely *Unio porrectus* J de C Sowerby' on the roadside banks and adjacent ploughed fields on the south-west slope of Muswell Hill.

Important sequences were proved in boreholes drilled on the remainder of Brill Hill (Barron, 1988, p.8). They consisted of 'ochreous and brown, very fine to medium-grained sand with pale grey and brown clay and mudstone beds up to to 0.2 m thick, with thin dark purplish brown sandy ironstone beds'.

STRUCTURE

The regional structure is dominated by a low dip ($\frac{1}{2}^{\circ}$, 1 in 115) to the south-east. This is clearly illustrated by the progressively lower altitude south-eastwards of the small outliers of Arngrove Spiculite near the Danes Brook.

Three faults were recognised in the area. The Studley Fault trends west-east and has a small displacement to the north. At Pasture Farm it is truncated by a north-easterly trending fault whose downthrow is to the east north of the intersection [6154 1262], but to the west, south of it. A wedge of down-faulted strata [626 133] occurs east of Honeyburge and north of Boarstall Wood. Finally the major north-south feature Little London Fault can be traced from near Hillside Farm, Brill [6500 1252] to near Worminghall Airfield [6444 1000]. The downthrow is to the west, being up to 25 m in the north, but diminishes southward to less than 8 m in the south.

SUPERFICIAL STRUCTURES

The geology of Muswell and Brill Hills has been extensively modified by cambering, with the result that the younger formations, which cap the hills, dip radially from the highest points and appear to drape the hill tops. Thus the Whitchurch Sand and Purbeck Formations, which crop out at about 180 and 175 m OD respectively near Muswell Hill Farmhouse, are found at 160 and 155 m OD in the western extremity of the upland. Similarly, the base of the main outcrop of the Portland Sand lies at 140 m OD near Nashway Farm [6492 3118] but outliers to the west descend to 120 m OD.

Cambered strata are intensely disturbed by dip-and-fault structures trending normal to the slope direction with downslope displacements of the faulted blocks. The beds in faulted blocks dip more steeply downhill than the overall slope of the base of the formation within the camber (Horswill and Horton, 1976).

Green (1864, p 48) noted the presence of step-faulting within the Portland Limestone on adjacent Brill Hill. Similar structures were recorded in a temporary section [6374 1466] on Muswell Hill. A shallow roadside trench [6500 1348], near Portree, on the south-western edge of Brill Hill, was floored by a variety of lithologies which cropped out in displaced bands 1 to 4 m wide, the structure was interpreted as block-faulting resulting from cambering.

Repetition of strata due to faulting results in a wider outcrop than normal and leads to enhanced apparent thickness of formations. It is difficult to determine the true thickness and sequence within cambered strata. In addition, cambering results in a decrease in thickness of the underlying Kimmeridge Clay by 'squeezing' (Horton and Coleman, 1977).

Valley bulging, i.e. the development of superficial anticlinal structures orientated along the valley floors, is probably present. It has not been proven but the possible presence of the Oakley Member in the floor of the Danes Brook [6339 1394] may result from this process.

LANDSLIP

Landslipping probably occurs on all the steep slopes where a porous limestone/ sandstone sequence overlies a softer clay formation. Differential erosion produces steep slopes within the clay formation. The instability of these slopes is enhanced by water issuing from the base of the younger porous strata. Cambering and erosion releases the pressure within the strata, rapidly enabling seepage waters to gain access to the open joints within the clay thereby reducing its strength. If slopes are sufficiently steep, failure may occur as rotational slips, or as slab-like translation slips. Locally, the slipped masses degenerate to highly mobile mud flows.

In addition to those landslipped areas showing clear topographical features which are depicted on the map, there are others which have been masked by agricultural activity. This can be clearly seen north of Old Arngrove where the grass field [613 141] south of the road shows active landslip and mudflow features with ridges, slacks and marshy areas. In contrast, the field [615 143] to the north of the road has been regraded and ploughed many times, and there is now no geomorphological evidence of landslip. However, collapse of many of the motorway site investigation trenches in this area soon after digging bears witness to the presence of shear surfaces down to at least 6 m below surface.

The areas of most active landslip are the slopes between Studley and Arngrove. Where the Arngrove Spiculite Member forms an escarpment above the West Walton Formation, and the western and southern slopes of Muswell Hill where the Kimmeridge Clay Formation has failed beneath an overburden of Portland Formation. Landslip may have occurred on these slopes beyond the limits shown on the published map, but in these areas evidence of failure has been destroyed by human activity.

DRIFT

Quaternary

Head

Only seven small outcrops have been recognised. In the west, at Tippens Copse [6018 1325] and Warren Farm [6045 1355], sandy loam with spiculitic sandstone debris has been transported downslope by solifluction from the Arngrove

Spiculite outcrop. Two of the head deposits are associated with the small stream east of Oakley. In the north [6412 1343] an ill-defined bench adjacent to the stream is covered with brown, silty, pebbly clay, whilst south-east of the village near Moorley's Farm, a deposit of reddish brown sandy clay covers the lower valley slope and overlies the Oakley Member. Four deposits of Head, consisting of sandy pebbly clay derived from the Portland, Purbeck and Whitchurch Sand Formations, floor the small valley-like depressions draining the western slopes of Muswell Hill.

These Head deposits only rarely exceed 1 m in thickness. Thinner deposits of colluvium and Head resulting from hillwash and solifluction may be found elsewhere. They, like the described Head deposits, occur on steep slopes beneath escarpment features, on slopes or benches adjacent to small streams, and in the floors of tributary valleys.

Spreads of ironstone debris characterise the soils on the summits of low-lying spurs extending out from Muswell and Brill Hills. These probably originated as older Heads and possibly screes, which may have been deposited as sheets during an earlier periglacial period.

First Terrace Deposits

Small outcrops of reddish brown, silty, sandy clay and pebbly sand occur in the south-western extremity of the district, where the valley of the Danes Brook opens into the broad clay vale of Menmarsh. The pebbles are small, of local origin, and include transported *Gryphaea* valves. The deposits are less than 1 m thick and cryoturbated. The upper surface lies only just above the alluvium and they probably originated as flood plain deposits.

Alluvium

Narrow tracts of alluvium floor most of the stream valleys. The alluvium consists of greyish brown to grey silty clay with scattered pebbles, generally less than 1.5 m thick. It may contain a basal sandy clay and, rarely, a coarse grey sandy gravel, often with large *Gryphaea*. Generally a thin bed, up to 0.4 m thick, of reddish brown, fine to medium-grained, silty sand or pebbly sand with gravel seams underlies the Alluvium. This may be a relict of earlier deposits of First Terrace age.

WATER SUPPLY

There are no major aquifers in the district. Local supplies were obtained from shallow wells in the porous formations. A well [c 6070 1272] at Studley, 5.8 m deep, tapped the Arngrove Spiculite, whilst one at Manor Farm, Oakley [6409 1224], at least 10 m deep, is sited on the Ampthill Clay and was probably fed by permeable beds within either the Oakley or Arngrove Spiculite Members. Other supplies may have been obtained from springs issuing from the base of the Arngrove Spiculite and the Portland Sand Members. Whittaker (1921) describes the water supply of the region.

ECONOMIC GEOLOGY

The Arngrove Spiculite Member has been extensively quarried around Studley and Arngrove and, although rather weak, was probably used mainly as a road aggregate. Small pits also occur near Pasture Farm [615 124].

Small pits on the outcrops of the Portland Stone were probably used as a source of lime for local agriculture. Others in the Purbeck Formation outcrop on Muswell Hill may have been worked for pottery clay, or they may have been excavated into the underlying Portland Stone Member for building material. The Whitchurch Sand Formation has probably been dug for sand for building and for ochre, as on Brill Hill.

A small excavation [6297 1455] in the Ampthill Clay in the field east-south-east of Manor Farm, Boarstall was probably dug as a source of clay for brick/tile making.

The Studley Brick pit [603 120] in the Upper Oxford Clay was worked for brick clay into the 1920s and was the last working pit in the district. The Kimmeridge Clay was similarly exploited in the Brill Brickpit [6500 1438] at the margin of the district.

Engineering Hazards

The areas defined as landslip present the greatest problems to construction. Landslipping may have occurred beyond the areas recognised wherever relatively steep slopes are developed on the clay formations, particularly the Oxford Clay, the West Walton Formation and the Kimmeridge Clay. Slope failure may occur wherever deep excavations are made in clay strata and are inevitable in landslipped areas. This may be facilitated wherever water gains access to the cutting, generally as a result of land drainage.

In clays, major seasonal changes in water table may occur. Consequently foundations which lie above the permanent water table may fail. Collapse can also occur where structures are built on shallow foundations on poorly consolidated ground such as alluvium or head.

REFERENCES

AMBROSE, K and BARRON, A J M. 1988. The Brill Borehole, in BGS Boreholes 1984-1986. *Report of the British Geological Survey,* 19 (1), pp 4-5.

ARKELL, W J. 1947. The geology of Oxford. (Oxford: Clarendon Press).

BARRON, A J M. 1988. Geological notes and local details for 1:10 000 sheets: SP61SE (Brill). (Keyworth: British Geological Survey).

BARROW, G. 1908. The new Great Western Railway from Ashendon to Aynho, near Banbury. *Summary of Progress, Geological Survey* (for 1907), 141-154.

BLAKE, J F. 1880. The Portland rocks of England. *Quarterly Journal of the Geological Society of London,* Vol. 36, 189-236.

---------- 1893. Excursion to Brill. *Proceedings of the Geologists' Association,* Vol. 13, 71-74.

BRODIE, P B. 1867. On the presence of the Purbeck Beds at Brill, in Buckinghamshire; and on the Superior Estuarine Sands there, and at certain places in Oxfordshire and Wiltshire. *Quarterly Journal of the Geological Society of London,* Vol. 23, 197.

BUCKMAN, S S. 1922. Type Ammonites. Vol. 4. (London).

---------- 1925-1927. Type Ammonites. Vol. 6. (London).

CASEY, R and BRISTOW, C R. 1964. Notes of some ferruginous strata in Buckinghamshire and Wiltshire. *Geological Magazine,* Vol. 101, Pt. 2, 116-128.

COX, B M, and GALLOIS, R W. 1979. Description of the standard stratigraphical sequence of the Upper Kimmeridge Clay and West Walton Beds, pp 68-72. In Gallois, R W. 1979. Geological investigations for the Wash Water Storage Scheme. *Report of the Institute of Geological Sciences,* No. 78, 19.

DAVIES, A M. 1899. Contributions to the Geology of the Thame Valley. *Proceedings of the Geologists' Association*, Vol. 16, 15-58.

---------- 1907. The Kimmeridge Clay and Corallian rocks of the neighbourhood of Brill (Buckinghamshire). *Quarterly Journal of the Geological Society of London*, Vol. 63, 29-49.

GALLOIS, R W and COX, B M. 1977. The Stratigraphy of the Middle and Upper Oxfordian sediments of Fenland. *Proceedings of the Geologists' Association*, Vol. 88, pp 207-28.

FITTON, W H. 1836. Observations on some of the strata between the Chalk and the Oxford Oolite in the south-east of England. *Transactions of the Geological Society of London* (Ser. 2), Vol. 4, 103-390.

GREEN, A H. 1864. The geology of the country around Banbury, Woodstock, Bicester and Buckingham. *Memoir of the Geological Survey of Great Britain.*

HORSWILL, P and HORTON, A. 1976. Cambering and valley bulging in the Gwash valley at Empingham, Rutland. *Philosophical Transactions of the Royal Society of London.* Ser. A, Vol. 283, 427-462.

HORTON, A and COLEMAN, B. 1977. Lithostratigraphy and Micropalaeontology of the Upper Lias at Empingham, Rutland. *Bulletin of the Geological Survey of Great Britain*, 62, pp 1-12.

HULL, J and WHITAKER, W. 1861. The geology of parts of Oxfordshire and Berkshire (Sheet 13). *Memoir of the Geological Survey of Great Britain.*

MITCHELL, J. 1836. Strata of Quainton and Brill. *Proceedings of the Geological Society of London*, Vol. 2, p.7.

PHILLIPS, J. 1857. On the Estuary Sands in the upper part of Shotover Hill. *Quarterly Journal of the Geological Society of London*, Vol. 14, pp 236-241.

POCOCK, T I. 1908. The geology of the country around Oxford. Explanation of the Special Oxford Sheet. *Memoir of the Geological Survey of Great Britain.*

PRINGLE, J. 1926. The geology of the country around Oxford. *Memoir of the Geological Survey of England*. Explanation of the Special Oxford Sheet. (2nd edition).

STRICKLAND, H E. 1836. Letter to George Bellas Greenough Esq. *Proceedings of the Geological Society of London*, Vol. 2, p.6.

WHITAKER, W. 1921. The water supply of Buckinghamshire and Hertfordshire from underground sources. *Memoirs of the Geological Survey of England and Wales*.

WOODWARD, H B. 1895. The Jurassic Rocks of Britain. Vol. 5. The Middle and Upper Oolitic rocks of England (Yorkshire excepted). *Memoirs of the Geological Survey of the United Kingdom*.

APPENDIX 1

Thickness of West Walton Formation and Upper Oxford Clay and Middle Oxford Clay Members

Bh	Thickness Panshill Brown Bed	Thickness Panshill Siltstone	Interval Panshill Brown Bed to Lamberti Limestone	Thickness Lamberti Limestone	Interval Lamberti Limestone to Pale Brown Bed	Thickness Upper Oxford Clay Member	Thickness West Walton Formation
99	3.78+	0.29+	3.55	0.53	1.44	21.6	17.2
123	c 4.78+	0.41	3.33	0.72	0.85	21.1	16.9
129	1.94+	0.25+	3.0	0.24	0.76	21.1	17.0
128	4.3	0.09 to 0.74	2.78	0.63	0.52	21.4	16.9
130	3.16	0.46	3.52	0.47	0.84	20.4/20.7	17.0
132	3.00	0.35	3.48	0.18	0.96	20.4	17.2
134	-	-	(3.8)	0.63	?	(20.8)	-
135	2.5+	0.21	3.4 (3.8)	0.67	0.62	(21.4)	-
137	-	-	(3.9j)	0.56	0.99	(21.8)	-
141	-	-	3.4(4.15)	0.35	?	(19.8)	-
150	-	-	(3.7)	0.2+	?	(20.1)	-
156	-	-	(3.7)	0.42	0.46	(21.1)	-
159	-	-	-	0.22	0.42	-	-
160	-	-	(3.6)	-	-	(20.3)	-
162	-	-	(3.6)	0.5+	-	(21.5)	-
177	-	-	(3.7)	-	-	-	-
285	c 4.1	?	-	-	-	-	-
	3.0-4.8 4.0 m	0.21-0.46 0.3 m	2.78-4.15 3.6 m	0.18-0.72 0.45 m	0.42-1.44 0.75 m	19.8-21.8 20.8 m	16.9-17.2 17.0 m

Figures in brackets based on interpretation of Gamma ray geophysical log

APPENDIX 2

Availability of detailed lithological descriptions by BGS and of geophysical logs for M40 Site Investigation boreholes

Borehole Registration Number	Descriptions available			Formations proved			
	Core	U100	log	Arngrove Spiculite Member	West Walton Formation	Upper Oxford Clay	Middle Oxford Clay
6		/	/		/	/	
32	/	/	/	/	/	/	
40		/			/		
44			/		/	/	
56	/		/	/	/	/	
61	/		/	/	/	/	/
62	/		/	/	/	/	/
63	/		/		/	/	/
65	/	/	/	/	/	/	/
67	/		/		/	/	/
68	/		/		/	/	/
70	/	/	/		/	/	/
74	/		/		/	/	/
83	/		/		/	/	/
89	/		/		/	/	/
92	/				/	/	/
93			/		/	/	/
95		/	/		/	/	/
100		/				/	/
108		/				/	/
109		/				/	/
110		/	/			/	/
116		/					/

APPENDIX 3

Sections near Brill described by Fitton (1836, pp 280-1)

Fitton's original classification in brackets.

At a clay pit about 20 feet below the road on the south-west of Brill, the beds, declining to the west and south, were thus:-

	Thickness metres	Thickness feet inches
Whitchurch Sand Formation [*Lower Green-sand*]		
1 Sand; white at top, yellow and ferruginous below	1.83 to 2.13	6 0 to 7 0
2 Gravel, with concretions of "Carstone"; coarse quartz sand, cemented by oxide of iron	0.46	1 6
3 Yellow ochre, of very good quality, much used in commerce	0.51 to 0.56	1 8 to 1 10
4 Clay; containing thin bands of ochre, a quarter of an inch and less in thickness	about 0.30	1 0
5 Clay; light bluish grey, uniform: here visible to a depth of	about 1.52	5 0

No shells of any kind are known to occur in this bed; but about six feet down an entire tree was found, converted into lignite much mixed with pyrites. The trunk about a foot in diameter, and full 12.2 m (40 ft) long, lay almost horizontally, nearly east and west; and branches extended to about 3 m (10 ft) beyond it on both sides, beginning about 7.6 m (25 ft) from the extremity. It was preserved and shown in an adjoining house as an object of curiosity; and though in a state of ruin, when I saw it, from the decomposition of the pyrites, was one of the finest fossil specimens I had ever seen. Beneath the tree, it had been ascertained by boring, that clay, but of darker colour, extended to about 3.7 m (12 ft) in depth.

In another pit, on the outside of the inclosure where the tree was found, the strata were:-

	Thickness metres	Thickness feet inches
Grey sand	about 1.5	5 0
(5) Clay said to be the same with (5) of the list above; but darker and of more slaty structure. It is very like 4 of the List A above, and breaks into pieces with polished surfaces: the lower part for about two feet alternates and is mixed with yellow ochre	1.37	4 6

6	Yellow ochre, a duller hue than (3) above; some Fuller's earth at the lower part	about 0.10	0 4

?Purbeck Formation

7	Under the ochre are irregular flattened ovoid masses, about 18 inches thick, consisting of stratified matter which contains shells. These masses were divided thus:-		
	a) Thinly stratified, greenish grey, Fuller's earth, decomposed. The lowest part sometimes including thin seams of coaly matter, the remains, apparently, of highly compressed stems of plants; with fragments of shells.		
	b) Thinly stratified, dark grey, alternating with lighter-coloured, sandy clay. Like the alternation which is frequent at the bottom of the lower green-sand, and in the Wealden, described above at p 168 (83)	0.46	
8	Greenish matter, often stratified; - coarse Fuller's earth	0.91	3 0

Portland Formation [*Portland stone:*] -

9	Whitish rubbly stone, not unlike freshwater limestone, but containing *Perna quadrata*, with ribbed and tuberculated Trigoniæ	0.38	1 3 to 1 6
10	*"Pitching-stone"*, consisting of:-		
	a) Hard compact grit: sand concreted by a very large proportion of calcareous matter	about 0.23	0 9
	b) Fuller's earth, yellowish-green	0.15 to 0.20	6 in to 0 8
	c) Compact grit; - more siliceous than *a* ..	0.18	0 7
11	Grey clay, in about three layers	0.60	0 6
12	Limestone in two beds, including Pernae	about 0.15	2 6 to 3 0
13	*"White limestone"*; as below. *Pecten orbicularis* abundant	0.76 to 0.91	3 0 to 4 0

At a pit on the south-west brow of Brill Hill (a continuation downwards of beds above enumerated), the following is the order:-

	Thickness metres	feet inches
(13) *"White limestone"* (like the *"Chalk"* of Chicksgrove, 7. p.253) used only for making lime; sometimes harder and bluish. It occurs in irregular masses, and has the aspect of freshwater stone, but contains numerous *Trigoniæ*	about 0.91	3 0

14 *"Cap of the Greys".* Brownish clay, full of fragments of shells	0.30	1 0
15 *"Greys".* Good stone for building, full of Pernæ. Some of the beds contain stems, like those of Siphoniæ		

Below the "Greys" are about 2.7 metres (9 feet) of alternate courses of indifferent stone and of yellowish grey sand, with Portland fossils - *Cardium dissimile, Pecten lamellosus, Trigonia gibbosa.* These are succeeded by sand charged with green particles, which, in the following list, is referred to the Portland Sand; in which *Ammonites giganteus* is frequent, in some specimens with Oysters attached.

Fuller's earth lithologies were not discovered during the present survey.