BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/89/76

Onshore Geology Series

TECHNICAL REPORT WA/89/76

# Geological notes and local details for 1:10000 Sheet SP60NE: Long Crendon

Part of 1:50 000 Sheet 237 (Thame)

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 KEYWORTH BRITISH GEOLOGICAL SURVEY 1989

CONTENTS

## 1. INTRODUCTION

This report describes the geology of 1:10,000 sheet SP60NE (Long Crendon) which is included in 1:50 000 geological sheet 237 (Thame). The original geological survey was part of Old Series One Inch Sheets 13 and 45, surveyed by E Hull, H Bauerman, W Whitaker, W T Aveline and T R Polwhele, and published in 1860 and 1863 respectively. Accounts of the geology are given in Hull and Whitaker (1861) and Green (1864). Surveys at 1:10,560 were carried out by A J Jukes-Browne in 1885, south of the River Thame (Oxford County Sheets 35 and 41), and by H B Woodward in 1905, west of grid line 616 (Buckinghamshire County Sheet 32).

The 1:10 000 survey was carried out in 1987 by K. Ambrose under the direction of A Horton, Project Leader and R G Thurrell, Regional Geologist. Fossils were identified by B M Cox. The project was jointly funded by BGS and the Thames Water Authority.

The area lies on the Buckinghamshire-Oxfordshire border immediately west of Thame. The principal settlement is Long Crendon with the smaller villages of Shabbington and parts of Ickford and Tiddington. The area is almost entirely rural but includes the westernmost urban area of Thame.

Topographically, the district is dominated by the east-west flowing River Thame and its tributaries. Extensive tracts of alluvium and river terrace deposits are associated with the drainage basin which is mostly on Upper Jurassic clay formations. The clays form a gently undulating terrain masked in places by river deposits. In the north-east, Long Crendon is sited on higher ground formed by the resistant sands, sandstones and limestones of the Portland Formation, with sands in the Kimmeridge Clay producing less pronounced topographical features here and in the south. Cretaceous rocks cap the highest ground immediately north of Long Crendon (Gault) and in the extreme south (Gault and Lower Greensand).

Parallel reports covering adjoining 1:10 000 sheets are:

| | | | |
|---|---|---|---|
| SP60NW | Wheatley and Worminghall | Horton | In preparation |
| SP61SW | Oakley | " | 1989a |
| SP61SE | Brill | Barron | 1988a |
| SP70NW | Thame and Haddenham | Lake | 1989 |
| SP71SW | Chearsley | Barron | 1988b |

## 2. GEOLOGICAL SEQUENCE

DRIFT

QUATERNARY

- Alluvium
- Second Terrace
- Third Terrace
- Fourth Terrace
- Fifth Terrace
- Head

(Second to Fifth Terrace and Head: River Terrace Deposits)

SOLID

CRETACEOUS

- Gault
- Lower Greensand

UPPER JURASSIC

- Whitchurch Sand Formation
- Purbeck Formation
- Portland Formation
  - Portland Stone Member
  - Portland Sand Member
- Ancholme Clay Group
  - Kimmeridge Clay Formation
  - Ampthill Clay Formation
  - Cumnor Formation
    - Oakley Member

## 3. SOLID GEOLOGY

### 3.1 UPPER JURASSIC

#### 3.1.1 Ancholme Clay Group

This group comprises all the predominantly mudstone formations of the Upper Jurassic from the Kellaways Formation up to the Kimmeridge Clay Formation. The term was introduced in the Hull-Brigg area (Gaunt et al, in press) where difficulty was encountered in separating the clay formations in the field.

##### 3.1.1.1 Cumnor Formation

The Cumnor Formation comprises all the predominantly limestone and sandstone facies formerly included in the 'Corallian'. The name derives from the Cumnor Borehole south-west of Oxford (Cox, 1978; Wilson, 1978) which is the type section. In the Long Crendon area, the Oakley Member is the only representative of the formation.

###### 3.1.1.1.1 Oakley Member

The term Oakley Member replaces the previously used names "*Exogyra nana* beds/clay/zone" (Davies, 1907; Barrow, 1908), "Oakley Clay" (Buckman, 1927) and "Oakley Beds" (Arkell, 1933, 1942). They were originally included in the Ampthill Clay.

The member consists of about 5 m of interbedded pale to medium grey mudstones, siltstones and marls with impersistent, sometimes nodular limestones. The beds are usually crowded with the small oyster *Nanogyra nana* which is abundant in the brown clay soils and a useful guide in mapping the member. Serpulid worm tubes are also common and ferruginous ooliths may be present. The topmost part of the weathered zone usually contains small calcareous nodules (race).

The member crops out in the extreme north-west corner of the district. The more resistant limestones and marls have produced local south-easterly dipping dip slopes over the outcrop. A thin bed of poorly fossiliferous silt has been mapped locally at the top of the member.

##### 3.1.1.2 Ampthill Clay Formation

The division mapped as Ampthill Clay comprises all strata between the Oakley Member and the Kimmeridge Clay Formation. In the BGS Brill Borehole [6570 1412] sited about 4.1 km north of the district, 2.05 m of strata immediately overlying the Oakley Member correspond to the topmost part of the type 'West Walton Beds' (Cox, 1987, Ambrose et al, 1988). If present locally these strata have been mapped as part of the Ampthill Clay.

The formation consists of medium to dark grey, fossiliferous mudstones which are noticeably silty in the lower part of the formation. Phosphatic nodules occur mainly in the upper part and nodular cementstones are developed at some levels. The fauna comprises mainly ammonites (Cardioceratid and perisphinctid types), belemnites and bivalves, including *Gryphaea dilatata* J Sowerby and, in the upper part, the flat oyster *Deltoideum delta* (Wm Smith). The local sequence can be compared to that in Eastern England where individual beds AC 1-42 were defined on the basis of their lithological and faunal character (Cox and Gallois, 1979; Gallois and Cox, 1977).

The Ampthill Clay in this area is estimated to be 15-20 m thick. In the Brill Borehole, the formation sensu stricto is 20.25 m thick (Ambrose et al, 1988 while the mapped unit would be 22.3 m thick (see above). West of Tiddington, a thickness of about 19m is estimated from the gamma ray log of borehole SP60SW/69 [6259 0498].

There are no natural exposures within the area but smooth pale to dark grey clay is commonly seen in the ditches and ploughed fields. Selenite and race are often present in the weathered zone. North of Peacehaven Farm [651 079], *Nanogyra* is present in the clays. Elsewhere, the recoverable fauna is sparse. A cementstone nodule dredged from beneath alluvium [6586 0855] yielded a specimen of *Amoeboceras*, and is probably from Bed AC 17 of the standard sequence (Cox, 1988a). This bed lies about 6.7 m above the base of the formation (sensu stricto) in the Brill Borehole. Debris from a pipeline trench [673 079 - 080] showed a few cementstone nodule fragments, again from beneath alluvium. Broken whorl fragments of *Ringsteadia*? together with scattered shells including *Dicroloma* were identified. They are indicative of a position high in the Ampthill Clay (? Beds 40-42 of the standard sequence) (Cox, 1988a). Pale grey clays with common *Deltoideum delta* seen to the south west [6681 0769] are also indicative of a similar horizon.

The low hill west of Westfield Farm [669 093] is capped by two strong topographical features and a bed of pale weathering clay. The stratigraphical position here is around the Ampthill Clay - Kimmeridge Clay boundary, and in the absence of any diagnostic cementstone debris, the highest beds are included in the Ampthill Clay.

#### 3.1.1.3 Kimmeridge Clay Formation

The Kimmeridge Clay consists of 40-50 m of interbedded grey, silty mudstone and dark grey, fissile, bituminous mudstones with subordinate oil shales and nodular cementstones. The upper part contains beds of silt and fine sand with a prominent sand unit at the top, the Thame Sand of Buckman (1922). Phosphatic nodules occur locally. Most of the formation is richly fossiliferous with many ammonites and bivalves. The Kimmeridge Clay of Dorset and Eastern England has been described in detail (Gallois and Cox, 1976; Cox and Gallois, 1979, 1981) and a standard sequence of beds (KC1-49) set up. The Brill Borehole proved 55.6 m of Kimmeridge Clay (Ambrose et al, 1988; Barron, 1988a). Correlation with the standard sequence shows 39.65 m of Upper Kimmeridge Clay and 15.85 m of Lower Kimmeridge Clay. The oil shale facies, well developed over much of the UK outcrop, is poorly represented at Brill. Some of the major bituminous mudstones are absent, sands occurring at the same level. The highest beds of the Upper Kimmeridge Clay, the Hartwell Clay and Wheatley Sands, are not proven in the Long Crendon area. Table 1 shows the litho- and biostratigraphy of the Upper Kimmeridge Clay of Long Crendon and neighbouring areas.

Seven limestone and cementstone beds have been mapped within the Kimmeridge Clay. A pale grey, poorly fossiliferous, silty limestone which crops out south from and about 0.5 km east of Peppershill Farm [668 088] may be Bed KC18. Four

| Ammonite Zone | Littleworth Brick Pit, Wheatley (Pringle, 1926; Arkell, 1947) | Brill No.1 Borehole [6570 1412] | Long Crendon area |
|---|---|---|---|
| Pallasioides Zone | WHEATLEY SANDS | WHEATLEY SANDS | |
| | HARTWELL/SWINDON CLAY | HARTWELL CLAY | |
| Pectinatus Zone | PECTINATUS/ SHOTOVER GRIT SANDS | SANDS, SILTS and SILTY CLAYS | THAME SAND |
| Hudlestoni Zone | (UPPER) | (UPPER) | (UPPER) |
| Wheatleyensis Zone | KIMMERIDGE | KIMMERIDGE | KIMMERIDGE |
| Scitulus Zone | CLAY | CLAY | CLAY |
| Elegans Zone | | | |

TABLE 1. Litho- and biostratigraphical subdivisions of the Upper Kimmeridge Clay of Long Crendon and neighbouring areas.

cementstones encircle the hill north-east [672 075] of Shabbington and are truncated by the Shabbington Fault. The lowest, a pale and dark grey mottled, slightly silty, shelly cementstone yielded *Nanogyra virgula* (Defrance) and *Protocardia* at one locality [673 074]. Cox (1988a) suggested it may be Bed KC24, but it occurs near to the base of the formation. The succeeding bed which is lithologically similar contained *N.virgula* and *Amoeboceras*? at one locality [6730 0773] and may be either Bed KC15 or KC17. The highest two cementstones are both dark grey, silty, fossiliferous and weakly septarian; they may both be from Bed KC18 (Cox, 1988a).

Three stratigraphically higher cementstones crop out in the village of Shabbington. The lowest, a dark grey silty cementstone may be Bed KC24, while the succeeding one, pale grey in colour, is probably Bed KC30. A specimen of *'Propectinatites'*? in mudstone alleged to have come from just below the nodule bed [c. 667 067] is in the BGS collection.

Beds KC24 and KC30 have been tentatively identified cropping out between Woodway Farm [679 098] and Hill Farm [679 089]. The lowest nodule bed (?Bed 24) is a dark grey, splintery, fossiliferous cementstone containing *N. virgula* and serpulids. It also crops out on the downthrow side of the Long Crendon Fault. The highest (?Bed 30) comprises two closely spaced cementstones; the lower one grey and very silty, the upper one dark grey and splintery.

Two beds of glauconitic clayey silt and fine sand crop out in the upper part of the formation. The youngest of these is the Thame Sand. The intervening mudstones are generally silty. The lowest sand bed is 1-2 m thick and it lenses out in places south of Long Crendon, and west of the village, is inseparable from the Thame Sand. South of the river Thame the bed can be traced from Thame to Albury where it is overstepped by the Gault.

The overlying mudstones vary from 0-10 m in thickness but are commonly 5-10 m. The thinning is largely in response to thickening of the overlying Thame Sand. An unknown thickness of these mudstones and presumably the lower sand bed were formerly exposed in a brickyard [697 081] south of Long Crendon (see below). They were reported to be poorly fossiliferous (Davies, 1899).

The Thame Sand is dominantly a green, fine-grained, glauconitic sand. Davies (1899) recorded lydite pebbles in the top 1-2 m. It thickens southwards from about 5 m in the extreme north to around 10 m in Long Crendon. Fitton (1836) noted about 9.1 m (30') along Thame Road, south from the village and nearby, borehole SP60NE/65 [6956 0849] proved at least 11.3 m. Buckman's (1926) claim of 24.4 m (80') of Thame Sand here is incorrect. Arkell (1947) and Buckman (1922, 1926) recorded 'Paravirgatites' from the Thame Sand of Barrel Hill, Long Crendon and south-west of Thame, which indicates a Pectinatus Zone age.

Four outliers of Thame Sand crop out between Long Crendon and Thame. At Lopemede Farm, the basal strata are exposed in a ditch [6971 0744 - 6978 0744]:

| | (m) |
|---|---|
| Sand, greenish grey, fine-grained locally clayey and ironstained, much ferruginous staining at base | c.2.0 |
| Clay dark grey, with ochreous mottling, smooth to silty, some fossil debris | c.0.5 |
| Clay, pale grey and ochreous mottled, smooth. | |

On the western outskirts of Thame, the Thame Sand is up to 12 m thick, but thins rapidly westwards and is overstepped by the Gault. A disused sandpit [696 058] formerly exposed 4.6 m (15') of sand, locally cemented into sandstone (Davies 1899). The Thame Sand crops out on either side of the North Weston Fault in the village of North Weston. On the eastern (downthrow) side of the fault, borehole SP60NE/3 [6798 0594] proved 1.3 m of sand below Fourth Terrace gravel resting on clay at 3 m, while on the upthrow side, borehole SP60NE/68 [6809 0573] proved terrace gravel and sand to 5.0 m without reaching the base.
The interpretation of the sequence below the Portland at Long Crendon is problematical and is not helped by the absence of lithological descriptions and thickness data for the various sand pits and the brickyard south of the village. The pit exposed poorly fossiliferous strata immediately below the Thame Sand while clays excavated in the floor of the pit yielded Wheatleyensis Zone ammonites (Arkell, 1933, 1947). The *'Exogyra virgula* clays' recorded by the same author at c.6' (2 m) below the floor of the pit may be either the main Lower Kimmeridge Clay Eudoxus Zone occurrence (Beds KC 27-30) or possibly a thin horizon in the Upper Kimmeridge Clay Scitulus Zone (Bed KC 38). Their estimated stratigraphical position is 10-15 m below the Thame Sand. The limited faunal evidence suggests that the Thame Sand is, at least in part, of

Pectinatus Zone Age while notes in the literature (Fitton, 1836; Blake, 1880, 1893; Woodward, 1895; Davies, 1899; Buckman, 1922, 1926; Arkell, 1933, 1947) suggest the clays in the brickyard were not Hartwell Clay. They more likely belong, together with at least part of the overlying Thame Sand, to a lower horizon in the Pectinatus Zone. Part of the Thame Sand may be equivalent to the Hartwell Clay and possibly the Wheatley Sands. Both are present in the Brill Borehole to the north but the Wheatley Sands are absent in the Hartwell Borehole [7926 1223] to the east. The sand facies of the Pectinatus Zone (Thame Sand) passes laterally into silty to sandy, poorly fossiliferous mudstones elsewhere in Buckinghamshire e.g. 35.57 - 43.35 m in the Hartwell Borehole and 43.76 - 54.04 m in the Brill Borehole (Cox, 1988b, 1989). Such lithologies are typical of the Hartwell Clay and explain their presence beneath the Thame Sand.

Alternative, hypotheses are:
(i) The Hartwell Clay may be absent through erosion at Long Crendon, the Thame Sand being equivalent to the Wheatley Sands and the Shotover Grit Sands.
(ii) The Thame Sand is equivalent only to the Wheatley Sand; the Hartwell Clay is absent or represented by the poorly fossiliferous mudstones as a lateral facies change. This model has to question the palaeontological evidence of age for the Thame Sand.
(iii) The Thame Sand is restricted to the Pectinatus Zone.

The lydite pebbles reported from the top of the Thame Sand (Fitton, 1836; Davies, 1899) may represent the same horizon proved at the top of the Wheatley Sands in the Brill No. 1 Borehole (Ambrose et al, 1988; Barron, 1988a) and on Muswell Hill (Ambrose, 1988). If the Pallasioides Zone is absent at Long Crendon, the lydite pebbles may be the Lower Lydite Bed which occurs at the top of the Pectinatus Zone elsewhere in Oxfordshire and Buckinghamshire.

3.1.1.4 Portland Formation

The Portland Formation is restricted to the Long Crendon area. It has been separated into the Portland Sand and Portland Stone Members. The present and previous classification of the Portland of this area are shown in Table 2.

It proved impracticable to subdivide the Portland in any more detail largely because most of the outcrop is either built over or under pasture and has been subjected to cambering. The once numerous pits are now largely obscured. The Crendon Sand, prominent in many former quarry sections in Oxfordshire and Buckinghamshire, could not be separated in the field.

The junction between the two Members is rather arbitrary. Here, and in other outliers of the Portland, the upward junction is transitional with glauconite not dying out altogether at the top of the Portland Sand. Sandy lithologies occur within the Rubbly (Aylesbury) Limestones.

The works cited in Table 2 all contain details of the Long Crendon area while Wimbledon (1974) reinterpreted and listed many of the ammonites collected in the area by Buckman. No new palaeontological data was obtained during the present survey.

| FITTON, 1836 HULL & WHITTAKER, 1861 | BLAKE, 1880 | WOODWARD, 1895 DAVIES, 1899 | BUCKMAN, 1922–6 | ARKELL, 1933, 1947 | BALLANCE, 1963 | COPE et al, 1980 | PRESENT CLASSIFICATION |
|---|---|---|---|---|---|---|---|
| PORTLAND STONE | Shell–brash | UPPER PORTLAND BEDS | CREAMY LIMESTONES | CREAMY LIMESTONES (PORTLAND STONE; UPPER PORTLAND BEDS) | CREAMY LIMESTONE (PORTLAND BEDS) | CREAMY LIMESTONES (PORTLAND BEDS) | PORTLAND STONE MEMBER (PORTLAND FORMATION) |
| | CREAMY LIMESTONES | | | | | | |
| | SAND | | CRENDON SAND | CRENDON SAND (MIDDLE PORTLAND BEDS) | CRENDON SAND | CRENDON SAND | |
| | RUBBLY LIMESTONES | | RUBBLY BEDS | RUBBLY OR AYLESBURY LIMESTONES (LOWER PORTLAND BEDS) | RUBBLY LIMESTONE | RUBBLY LIMESTONES | |
| PORTLAND SAND | GLAUCONITIC BEDS pebble bed at base | | GLAUCONITIC BEDS | GLAUCONITIC BEDS (PORTLAND SAND) | GLAUCONITIC BEDS | GLAUCONITIC BEDS | PORTLAND SAND MEMBER |
| | | | LYDITE BED | UPPER LYDITE BED | UPPER LYDITE BED | UPPER LYDITE BED | |
| | SHOTOVER SANDS | LOWER PORTLAND BEDS including HARTWELL CLAY | THAME SAND(S) | THAME SAND(S) or SHOTOVER GRIT SANDS or PECTINATUS SANDS (KIMMERIDGE CLAY) | THAME SAND(S) (KIMMERIDGE CLAY) | SHOTOVER GRIT SANDS (KIMMERIDGE CLAY FORMATION) | SAND IN KIMMERIDGE CLAY (THAME SAND) (KIMMERIDGE CLAY FORMATION) |
| (clay) | KIMMERIDGE CLAY | | HARTWELL CLAY and/or CRENDON CLAY | KIMMERIDGE CLAY | KIMMERIDGE CLAY | KIMMERIDGE CLAY FORMATION | KIMMERIDGE CLAY FORMATION |

TABLE 2. Comparative classifications of the Portland Formation of the Long Crendon area.

3.1.1.4.1 Portland Sand Member

The Portland Sand, 3-6 m thick, consists predominantly of a buff to greenish grey, fine-grained calcareous, glauconitic sandstone varying to sandy limestone. Locally the beds are highly glauconitic and in places are weakly cemented, for example in trial pits [6957 0848] on the south side of Long Crendon.
The base is usually marked by a conglomerate (Upper Lydite Bed of Arkell 1933) up to about 0.2 m thick. The bed has a variable matrix of either well cemented sandy limestone/calcareous sandstone, or soft sands and clays. The pebbles are mostly of black phosphate ('Lydite') but include quartzite, chert and limestone. A temporary section [6928 0851] on Frogmore Lane, Long Crendon, exposed the Upper Lydite Bed together with over- and underlying strata:

| | (m) |
|---|---|
| PORTLAND SAND MEMBER | |
| Sandstone, pale grey to buff, fine-grained, calcareous varying to sandy limestone; shelly including common oysters; layers with ironstained bivalves; a little glauconite; rubbly weathering; abrupt base. | c.1.0 |
| Sandstone, green to buff, fine-grained, highly glauconitic, some shells; rubbly; 2-5 cm thick, hard, well cemented layers, one of pale grey, fine-grained, calcareous sandstone with rare glauconite, and one of pale buff to grey, fine-grained, porcellanous, bioclastic limestone. | c.0.5 |
| Conglomerate, grey, fine-grained, sandy limestone matrix with well rounded quartz grains; pebbles up to 2 cm of lydite, chert, quartzite, limestone; ochreous stained bivalves; a little glauconite. | c.0.1 |
| Conglomerate, brown with iron staining, soft clayey sand matrix; pebbles as above; some shell debris; a little glauconite. | c.0.05 |
| KIMMERIDGE CLAY FORMATION (THAME SAND) | |
| Sand, yellowish green, fine-grained, poorly cemented. | 0.2 |

The Upper Lydite Bed sensu stricto may be restricted to the upper conglomerate. In the other reported occurrences of the Lydite Bed at Long Crendon. Fitton (1836) and Davies (1899) described the pebbles as occurring sporadically in the topmost part of the Thame Sand and in abundance in a bed of laminated clayey sand. A section on Muswell Hill (Ambrose 1988) and the Brill Borehole [6570 1412] (Ambrose et al 1988, Barron 1988a) both showed lydite pebbles in the topmost c.0.2 m of the Kimmeridge Clay Formation (Wheatley Sand). Thus at Long Crendon, the lower conglomerate seen in Frogmore Lane may represent a non-sequence between the Thame Sand and Portland Sand.

Typical rubbly glauconitic sandstone of the lowermost Portland Sand is exposed in an old quarry [6880 0922] at the north-west end of the village, and visible in ploughed fields to the north. Higher beds are exposed at a number of localities [6889 0907, 6976 0915, 6980 0916, 6980 0918, 6988 0920]. They show predominantly flaggy weathering, fine-grained, calcareous sandstones with variable amounts of glauconite, shell debris and ooliths.

3.1.1.4.2 Portland Stone Member

The Portland Stone is 3 to 5 m of interbedded grey to buff shell detrital micritic and sandy limestones which are commonly oolitic or pisolitic. Porcellanous limestones, micrites and oolites are locally developed. Glauconite grains are sometimes present.

Four exposures were noted in the Portland Stone. Scrapings occur at the top of the cutting in Thame Road [696 083] and there are three sections in Carters Lane. Two [6891 0915, 6892 0917] show up to 0.7 m of cream to pale brown, fine-grained, rubbly, shell detrital limestone, while a little further down [6888 0910] an inaccessible micritic limestone overlies sand. The sand, from its stratigraphical position, is assumed to be weathered Portland Sand, rather than the Crendon Sand, which was not found.

In fields north of Long Crendon, the uppermost part of the Portland Stone is a porcellanous limestone, similar to the lowest bed of the overlying Purbeck Formation. The two cannot be separated, but relict ooliths in several fragments are suggestive of Portland Stone.

3.1.1.5 Purbeck Formation

The Purbeck Formation overlies the Portland Formation in the Long Crendon area apparently conformably. In places it is overstepped by both the Whitchurch Sand Formation and Gault. It comprises up to 2 m of pale grey, porcellanous limestones and pale grey clays. In places, only limestone is present. The porcellanous texture is thought to result from post-depositional recrystallization as locally [684 097], north-east of Long Crendon, the recrystallization appears to extend down into the underlying Portland Stone Member.

Fitton, 1836; Blake, 1893; Woodward, 1895; Davies, 1899; Jukes-Browne, 1900 and Lamplugh, 1922 all record section in Long Crendon and most can be assigned to one locality, a former pit [693 692]. The recorded thicknesses range from 0.9 to 1.8 m. Davies (1899) lists two freshwater ostracods found at this locality. More recent discussion on the Purbeck of the area appear in Merrett (1924) and Ballance (1963).

The only exposure seen during the present survey was in the ha-ha [693 084] of Long Crendon Manor where up to 1 m of grey clay with cryoturbated pockets of Whitchurch Sand (ochreous silty clay with abundant ironstone) is visible.

3.1.1.6 Whitchurch Sand Formation

Formerly known as "ironsands" (Fitton, 1836), Shotover Sands (Blake, 1893) or Shotover Ironsands (Davies, 1899), the term Whitchurch Sands was introduced by Casey and Bristow (1964) and is here modified to the Whitchurch Sand Formation. It consists of up to 2 m of orange to brown, fine to coarse-grained, well rounded, ferruginous sandstone interbedded with pale grey silty mudstone. Secondary ironstone is common at the surface. The deposits have generally been considered to be of freshwater origin, first noted by Strickland (1836, Proc. Geol. Soc., Vol.II, p6) who found the freshwater mollusc *"Paludina"* on the Shotover Hill outlier near Oxford. Casey and Bristow (1964), however, concluded that the environment of deposition was marine to brackish.

The age of the formation is uncertain and it has been variously assigned at times to the Purbeck, Wealden and Lower Greensand. The early research is summarised by Pringle (1926) and Ballance (1960, 1963). Most workers favoured a correlation with the Wealden Beds. Casey and Bristow (1964) assigned a Middle Purbeck (Cretaceous) age while Morter (1984) placed it lower in the sequence, "close to the top of the 'Lower Purbeck' and base of the 'Middle Purbeck' i.e. within the Portlandian Stage as defined by Wimbledon and Cope (1978)". The age of the formation is still unresolved and for the purpose of this report, it is taken to be in the Portlandian (Jurassic).
The formation crops out only in the north-east corner, north of Long Crendon. It generally overlies but in places oversteps the Purbeck to rest on the underlying Portland Stone. This relationship suggests a disconformity between the Whitchurch Sand and Purbeck Formations. Locally the Whitchurch Sand is overstepped by the Gault. The formation is easily recognisable at the surface by the abundance of ironstone fragments. In the area it is mostly an iron-rich clay with only a little silt and sand.

No exposures were seen during the present survey but the Whitchurch Sand was formerly exposed in quarries, beneath a capping of the Gault clay. The Main quarry sited [c.693 092] was near a windmill and was described mainly around the turn of the century (Blake 1893, Woodward 1895, Davies 1899, Jukes-Browne 1900, Lamplugh 1922). A section described earlier by Fitton (1836) may be a different locality. The strata described suggest a lateral facies variation of the deposit. Blake (1893) recorded 0.46 m of ferruginous sandstone while other workers noted mainly clay, variable sandy, with ironstone nodules. The recorded thicknesses range from 0.46 - 0.76 m for beds here assigned to the Whitchurch Sand Formation. Lamplugh (1922) included all the strata in the Purbeck, while a pebbly ferruginous clay included in the ?Shotover Ironsands by Davies (1899) is here included in the overlying Gault (see section 3.2.2). Ballance (1960) placed the clay with ironstone in the Wealden Beds.

## 3.2 CRETACEOUS

### 3.2.1 Lower Greensand

The Lower Greensand crops out in the south-west corner at Albury where it rests unconformably on the Kimmeridge Clay. It consists of red-brown, medium to fine-grained poorly sorted, pebbly sandstone. The pebbles, up to 5 mm in diameter, are mainly of quartz and chert. The deposit can be readily distinguished from the Whitchurch Sand Formation and sands in the Kimmeridge Clay. by the presence of pebbles and its coarser grain size. The base is sharp and undulating, overstepping beds within the Kimmeridge Clay, and is commonly marked by springs. The irregularities are suggestive of channeling. A maximum of 13 m are estimated to crop out, with 10.7 m being proved in borehole SP60NE/48 [6562 0507].

Ballance (1963) discussed the age of the Lower Greensand based on correlations made by Arkell (1947).

### 3.2.2 Gault

There are two outcrops of Gault in the area, one in the north at Long Crendon and one in the south between Thame and North Weston. At the former it is about 25 m thick, including 12-13 m each of Upper and Lower Gault, while at the latter outcrop, it is at least 12.2 m thick and probably all Lower Gault.

The Gault consists of rhythmically deposited fossiliferous mudstones and siltstones with phosphate nodules. The idealised cycle commences with an erosion surface overlain by grey sandy, glauconitic siltstone and silty mudstone with phosphate nodules at the base and much interburrowing. Upwards the clastic content decreases and the carbonate increases. The fauna includes bivalves, ammonites (mainly hoplitids) and belemnites. It weathers to a pale grey clay commonly with selenite.

The outlier of Gault at Long Crendon was formerly exposed in a number of pits. One [c.693 092] showed up to 3.2 m of Gault clay (Jukes-Browne 1900) which yielded impressions of *'Inoceramus'*. The section was recorded in 1885. At a later date, Davies (1899) noted 2.4 m of clay with *I. concentricus, Belemnites minimum* and foraminifera. A bed immediately underlying the clay and noted only in some of the published sections, suggesting it may be lenticular, has been placed variably in the 'Lower Greensand' (Jukes-Browne 1900, Lamplugh 1922) Shotover sand (Whitchurch Sand Formation, Blake 1893, Davies 1899) or at the base of the Gault (Kitchin and Pringle 1922). The bed is variably described as a ferruginous sandstone, (Jukes-Browne 1900), sand, (Davies 1899), ferruginous clay or glauconitic loam (Lamplugh 1922), with pebbles of lydite quartz and ironstone. Jukes-Browne (1900) noted the presence of 'lumps of calcareous stone' which Lamplugh (1922) likened both lithologically and palaeontologically to the Shenley Limestone which occurs at the base of the Gault in the Leighton Buzzard area. The conglomerate is here placed at the base of the Gault. Lamplugh (1922) lists a number of fossils, mainly brachiopods collected from the limestone in the conglomerate at Long Crendon.

The higher strata on the Long Crendon outlier include two horizontally bedded phosphate nodule beds which form good topographical features and showed scattered debris in a ploughed field [688-9 109]. Twenty shallow shell and auger boreholes nearby (SP60NE/49 [691 098]) have furnished details of the stratigraphy and the sequence can be broadly correlated with that in East Anglia (Beds EA 1-19) described by Gallois and Morter (1982). Dr A A Morter, formerly of the British Geological Survey, examined and collected fossil specimens from short sections of U4 samples in each of the Long Crendon boreholes. The Lower Gault was proved in borehole 18 at a level of c.129.2 m OD by the presence of *Birostrina concentricum*, but showed no lithological distinction from the Upper Gault. Beds at the base of boreholes 1, 6 and 15 respectively at levels 131.3, 130.8 and 131.6 AOD were also tentatively assigned to the Lower Gault.

The lowest three subzones, *Dipoloceras cristatum, Hysteroceras orbignyi* and *H. varicosum*, of the Upper Gault, have all been proved in the boreholes, with the succeeding *Callihoplites auritus* Subzone tentatively identified in borehole 6. Much of the sediments are heavily bioturbated, particularly with *Chondrites* and *Thalassinoides*, and many are infilled with glauconitic silt/sand. The *orbignyi* Subzone commonly contains numerous *B. sulcata*, similar to Bed EA 13.

Bed EA 12 was identified in borehole 12 and possibly at the base of borehole 14. The lower of the two phosphate nodule beds cropping out at the surface occurs at the base of the *varicosum* Subzone, proved in borehole 5 (base of Bed EA 14). The higher one at crop is probably within the *auritus* Subzone and may correlate with either the base of Bed EA 15 or 16. The following fauna has been identified from the Upper Gault in these boreholes:

*?auritus* Subzone: *Atreta, Plicatula radiola gurgitis.*

*varicosum* Subzone: Crustacean remains; *Cyclocyathus, ?Dentalium, Hysteroceras orbignyi, Neohibolites, ?Trochocyathus.*

*orbignyi* Subzone: *?Beudanticeras, Birostrina sulcata, B. sulcata subsulcata, Dentalium, ?Euhoplites inornatus, E. sublautus monocantha,* fish debris, *Hamites, Hysteroceras orbignyi, Neohibolites, Nucula (Pectinucula), Pinna.*

*cristatum* Subzone: *B. sulcata, Entolium, Neohibolites, ?N.minimus.*

In the southern outcrop, the Gault unconformably overlies the Kimmeridge Clay Formation. Along most of the outcrop, the Thame Sand underlies the Gault, but locally it rests directly on clay and the mapped base is conjectural. Generally the Gault contains scattered phosphate nodules and is paler, greyer and less silty than the Kimmeridge Clay. The infilled brick pit [689 054] formerly exposed at least 12.2 m of Gault with plentiful impressions of ammonites of the *dentatus* Zone (Spath 1943). This is the lowermost zone of the Lower Gault. Borehole SP60NE/67 [6918 0558] sited northeast of the pit, proved 10.2 m of grey silty micaceous ironstained mudstones with siltstone beds, glauconite, pyritic trails, shells and shell debris, some phosphatised, including ammonites, bivalves, belemnites, serpulid worm tubes. The fauna has not been identified at the time of writing.

## 4. STRUCTURE

The regional dip of the strata in this area is about ½° to the south-east. This is modified locally by minor folding, faulting and coarsening, with dip values of up to 3°.

### 4.1 Faulting

There are three major faults and seven minor ones. Several show a preferred north-west - south-east orientation, but the major faults show a random orientation. The North Weston Fault trends north-south across the entire district with an easterly throw of 10-15 m. It is intersected by the Long Crendon and Shabbington Faults which trend roughly east-west and north-west - south-east respectively. Both have throws of 2-4 m. The North Weston Fault is assumed to displace these two faults where they cross, but the exact relationship is not known. The minor faults have displacements of about 2 m.

The faulting affects the Gault and therefore indicates post-Lower Cretaceous movements. A Tertiary age associated with the Alpine Orogeny is most likely.

## 4.2 Folding

Five minor fold axes occur and apart from complementary synclines and anticlines, show no preferred orientation. A shallow syncline trends north-north-east - south-south-west from near Westfield Farm [669 094] to Ickford. Another syncline, trending north-north-west - south-south-east, occupies the ground south-west of Long Crendon, extending from near [685 090] the Long Crendon Fault to [697 069] where it is obscured beneath the river deposits of the Thame valley.

The structure is accentuated by variations in the thickness of the Thame Sand. There is a complementary anticline 0.8 - 1 km to the south-west, traceable between the North Weston Fault [680 077] and the outskirts of Thame [695 060]. Another pair of folds trend east - west between the North Weston Fault and Albury. The syncline trace follows northing 054, while the anticline to the south is only partly on the sheet.

## 4.3 Superficial Structures

Cambering is developed at Long Crendon where the permeable hard limestones and sandstones of the Portland Formation overlie less competent sands and clays of the Kimmeridge Clay Formation. The competent beds arch over everywhere dipping towards the lower ground. The cambered beds have fractured resulting in 'dip-and-fault structures'; 'gulls' may have formed between fault blocks and some may remain as open fissures.

# 5. QUATERNARY (DRIFT) DEPOSITS

## 5.1 Head

Extensive head deposits flank the southern side of the Thame valley, and occur on the northern side in the vicinity of Long Crendon. An isolated patch of head crops out west of Lower Peppershill Farm [666 091].

South of the River Thame, the head occupies the lower slopes immediately above the Second Terrace or alluvium. In places it extends along tributary valleys. It is a brown to orange-brown variably pebbly sand which is locally clayey. The pebbles are mostly flints, quartzites and ironstones. It is generally 1-2 m thick but locally exceeds this. Borehole SP60NE/41 [673 055] proved 2.8 m of pebbly sand passing up into sandy, silty clay. Boreholes SP60NE/5 [6867 0601] and 6 [6870 0599] proved respectively 3.1 and 2.8 m of head, varying from pebbly sand to sandy pebbly clay. The head in this area is derived mainly from higher river terraces together with sand and clay from the Kimmeridge Clay Formation.

North of the Thame, the head is mainly composed of sand, which is locally clayey, derived from the Thame Sand and Portland Sand. Pebbles, particularly of ironstone, are common at the base of the deposit along the valley extending northwards to Long Crendon. In excess of 2 m is exposed [6857 0887] near the head of the valley.

An isolated lobe of head [691 082] on the scarp face of the Portland Formation is composed of sand, clay and rock debris from the Kimmeridge Clay and Portland formations.

The small patch of head near Lower Peppershill Farm infills a shallow hollow and is up to about 2 m thick. It is composed of grey to orange-brown sand, clayey sand and sandy clay. Its origin is not certain; the nearest sandy strata crop out about 2 km to the east and 3 km to the north.

## 5.2 River Terrace Deposits

Terrace deposits of the River Thame are developed at 5 levels, but only 4 are present within the district. The lowest (First Terrace) disappears beneath the alluvium a little downstream to the west (Horton, in prep.).

The terraces are all broadly similar in composition: fine, locally clayey gravels. The pebbles are dominantly flints with quartzite, chert, ironstone and shell fragments.

### 5.2.1 Fifth Terrace

A small patch of Fifth Terrace extends onto the southern margin [661 050] near Albury. The base is at about 84 m AOD, 25 m above the modern alluvium.

### 5.2.2 Fourth Terrace

Three small patches of Fourth Terrace crop out south of the Thame and one to the north. The base is about 15 m above the Thame alluvium and falls westwards from 78 m to 73 m AOD. The westernmost deposit [652 053] has shallow workings; Jukes-Browne recorded flint, quartz, quartzite and jasper pebbles on his fieldslips (1885). The deposit at North Weston is poorly exposed [6798 0587] in a disused pit, showing a poorly sorted clayey gravel with flint and quartzite pebbles ranging in size from a few mms to over 10 cm in diameter. Five boreholes prove thicknesses of 1.3 - 1.7 m. Borehole SP60NE/68 [6809 0573] proved 1.1 m of yellow to orange-brown and grey mottled clayey sandy gravel with flinty, quartzite, ironstone and chert pebbles.

A little to the west of this deposit, Third and Fourth Terrace deposits cannot be separated because of extensive hillwash.

Boreholes through a small patch of Fourth Terrace [693 058] on the outskirt of Thame, prove a variable thickness of 1.0 - 3.4 m of brown sandy pebbly clay.

### 5.2.3 Third Terrace

The Third Terrace crops out in six areas. The height of the base is more variable than the higher terraces, ranging from 5 to 10 m above the present alluvium.

The small outcrops [658 054, 666 053] cap low hills near Albury. The deposits here are thin (c.1 m) with flinty gravel ploughed on the easterly of the two. A sizeable spread of the terrace caps the interfluve immediately south [66 06] of Shabbington. It is up to 3 m thick and former workings [666 060] show traces of flinty gravel with additionally chert, quartzite, ironstone pebbles and shell fragments. Most of the pebbles are less than 1 cm in diameter, but range up to 4 cm.

The deposit [674 054] south-west of North Weston was formerly exposed in the now disused railway cutting Codrington (1864) noted the following section:

Sandy clay with angular flints and other pebbles.

Reddish-yellow sand with a few small flints and rare chalk pebble. Passes laterally into blue sandy clay and stiff blue clay with chalk seams.

Coarse gravel with angular flints (50%), quartz 'hornstone', ironstone, chalk, Tertiary pebbles, large sandstone blocks; 1 fragment of mica-schist. c.0.6 m

No thicknesses are given for the upper two beds, but the illustration suggests they are both at least 1 m thick.
The lower two beds both yielded freshwater bivalves and mammalian remains. Codrington listed the following bivalves: *Ancyclus fluviatilis, Anodon, Unio litoralis(?), Cyclas, Helix, Limnoea, Pisidium, Planorbis.*

The mammalian remains were abundant and included elephant, horse, rhinoceras, ox, deer and a carnivore. Dawkins (1869) listed the following identifications from the same locality: *Bison priscus, Bos primigenius, Canis lupus, Cervus elaphus, Elephas primigenius, Hippopotamus major, Rhinoceras leptorhinus, R. tichorhinus.*

Two deposits near North Weston both show flinty gravel soils. Both have markedly inclined bases, falling into the valley by up to 5 m.

### 5.2.4 Second Terrace

This terrace is the most extensive and flanks the Thame alluvium, virtually uninterrupted, on both sides. It also extends back along tributary valleys north-north-east of Ickford. The terrace surface is everywhere 1 to 2 m above the alluvium. The back of the terrace climbs to about 5 m above the alluvium, while along the tributary valley, it is about 10 m above the Thame alluvium at its most distant points.

The upper part of the deposit is commonly a clayey sand with scattered pebbles, and overlies a fine flinty gravel. The lithological change may reflect a reduction in bed load in the final stages of deposition of the terrace deposit, or it may be a later coating of soliflucted material.

The thickness is mostly between 1 and 2 m. Jukes-Browne recorded '5-6 feet (1.5-1.8 m) gravel on clay' in a disused pit [6560 0621] immediately adjacent to the alluvium and borehole SP60NE/26 [6945 0640] proved 2.3 m. A nearby borehole SP60NE/29 [6954 0642] sited adjacent to the alluvium proved 5.0 m of gravel. The thickness is anomalous when compared to nearby thicknesses for the alluvium (2.2 - 4.0 m) and must represent a local channel fill or scour hollow.

North of Ickford Second Terrace thicknesses are variable due to undulations in the bedrock and cryoturbation. There is a small bench of Oakley Member occurring between the terrace and alluvium at one point [654 090 - 657 094].

## 5.3 Alluvium

Alluvial deposits floor the Thame valley, where the flood plain is 0.2 - 0.75 km wide, and extend along tributary valleys. North-east of Ickford the flat, low-lying ground underlain by the easily eroded Ampthill - Kimmeridge Clay is now drained by misfit streams flowing across extensive belts of alluvium.

The Thame valley was flooded for long periods during the present survey and little detail was seen of the deposits. The upper part is predominantly a grey clay with ochreous mottling. Boreholes which penetrate the alluvium in two areas show a thickness range of 2.2 - 4.9 m. A little east of Shabbington, 4 holes prove sequences through the alluvium as follows:

| | Thickness (m) | Depth(m) |
|---|---|---|
| SP60NE/40 [673 070] | | |
| Clay, brown silty some shells | 1.45 | 1.45 |
| Clay, dark brown, peaty, becoming grey, sandy and pebbly downwards | 1.45 | 2.90 |
| Sand and gravel, clayey in basal 0.35 m | 1.85 | 4.75 |
| SP60NE/41 [675 067] | | |
| Clay, orange-brown, silty to sandy | 2.00 | 2.00 |
| Sand, pebbly | 2.90 | 4.90 |
| SP60NE/42 [672 065] | | |
| Clay, brown, silty to sandy | 2.00 | 2.00 |
| Sand, clayey, pebbly in basal 0.2 m | 2.00 | 4.00 |
| SP60NE/43 [673 055] | | |
| Clay, orange-brown, silty to sandy | 2.00 | 2.00 |
| Sand, some pebbles | 1.50 | 3.50 |

In the extreme east, eight boreholes prove a complete sequence through the alluvium. In three, SP60NE/30 [6964 0654], 31 [6978 0638] and 32 [6979 0658], there is no basal gravel; the lowermost clays are peaty in boreholes 31 and 32, while in borehole 30, a 1.2 m bed of very soft greenish grey clayey silt is the lowermost alluvial deposit, at 3.2 m depth. The remaining five boreholes prove between 0.2 - 1.5 m of underlying gravel. The thickness variations of the alluvium are locally rapid for example 4.0 m in borehole 31, with no gravel and 2.2 m in borehole 34 with a 0.2 m basal gravel, some 40 m away. The basal gravels are probably erosional remnants of the First Terrace Deposits, preserved in pockets, which originally extended upstream.

The alluvium of the tributary streams is generally similar i.e. a grey, orange mottled clay which is locally silty or sandy. Thin gravel is commonly present at the base, and the deposits rarely exceed 1.5 m thick. The pebbles are the same as in the terrace deposits. In the stream south-west of Long Crendon, the alluvium is predominantly sand and silty, reflecting the Kimmeridge and Portland Sand source rocks.

## 6. ECONOMIC GEOLOGY

### 6.1 Brick Clay

The large expanse of mudstone bedrock in the area provides a potential resource of brick-making. There are no working brickyards, but both the Gault and Kimmeridge Clay have been quarried in the past for this purpose.

To the west [689 053] of Thame, the Gault was dug for brick-making, to a depth of at least 12 m. The original works opened in the late 19th Century but ceased operations before the First World War. It was reopened in 1929 and continued operating until at least 1943.

Several former brick clay pits existed in the Long Crendon area, mostly in the Kimmeridge Clay but the Gault may also have been worked.

### 6.2 Sand and gravel

Gravel has been extracted from the Third and Fourth Terraces at North Weston, Shabbington and Albury, but despite the extensive spreads, most is uneconomic. It is both thin and commonly clayey.

Sand has been quarried from the Thame Sand on the western outskirts of Thame and in Long Crendon.

### 6.3 Building Stone

Several quarries once existed in Long Crendon, quarrying the Portland Formation for building stone. Quarrying was mentioned in records as early as 1343 (Donald 1970). Many of the stone houses in the High Street date from the early 16th Century.

### 6.4 Other Products

A number of former pits in the Portland Stone Member were dug for 'Witchett' (White earth), a local building material. This was the soft, fine-grained, micritic limestones which were ground up and mixed with water to make a weak mortar to bind the stone or "mixed with horse-dung will of itself make durable walls" (John Burnham, 1705, from Donald 1970).

## 7. HYDROGEOLOGY

The Portland Formation and underlying 'Thame Sand' provide a sizeable aquifer at Long Crendon, with spring commonly developed along the base of the sand. On the Thame Sand outcrop west of Thame, springs were not noted but the thick (10 m+) development of sand may have potential as a small aquifer. The Lower Greensand at Albury which is of similar thickness is marked by a persistent seepage line at its base.

Small, perched water tables will be present in the terrace gravels which line the Thame Valley. Water has been extracted from shallow wells in these gravels, at Ickford (Whitaker 1921) but is probably no longer potable. Elsewhere, water is scarce in the clay formations, but very small quantities may migrate along some limestones or shelly beds.

## 8. MAN-MADE DEPOSITS

### 8.1 Made Ground

Only one small area of made ground has been identified immediately south-east [698 082] of Long Crendon.

### 8.2 Backfilled Excavations

There are a number of wholly or partially backfilled excavations in the area, which include brick pits, stone pits, sand pits and gravel pits. Most have only a thin partial backfill, but at least three are completely backfilled. The former brickyard [689 053] west of Thame contains at least 12 m of fill, while in a former brickyard [697 081] and stone pit [694 091] at Long Crendon the thickness of fill is not known. In all cases, the nature of the fill is unknown.

The limits of excavations shown on the map are, in many cases, only approximate, particularly in Long Crendon. Other, undetected sites, may be present in the area.

## 9. ENGINEERING HAZARDS

**This section is intended as a summary of the principal geological hazards identified in the area at the last date of survey. It is not exhaustive and should not, under any circumstances, be used to replace any part of a geotechnical investigation.**

### 9.1 Slopes

No landslips were detected during the present survey but there are steep slopes of up to 1 in 4 around much of Long Crendon, and east of Shabbington. Erosion coupled with modern farming techniques and drainage may have stabilised any landslips and destroyed the surface features which identify them. Weathered clay commonly contains small shear surfaces and can be unstable even on gentle slopes. Both can be reactivated when subjected to renewed stress such as are caused by loading, excavation, or the introduction of water into the slope.

Springs issuing from the base of the Thame Sand and lower Greensand pose a potential instability problem in the underlying Kimmeridge Clay. Both sand beds are poorly consolidated which could also result in instability. The Portland Formation at Long Crendon has cambered and the associated 'dip-and-fault' and 'gull' structures may result in instability. However, there are many buildings constructed on the Portland Beds; several of these date from the 16th Century, and none show any obvious evidence of structural defects.

## 9.2 Head

Head in this area is composed predominantly of sand with a little clay and gravel. It is unconsolidated and as such poses a geological hazard when subjected to stress, either by loading or by excavation made into it. Water commonly flows along the base of the deposit and can act as a lubricant generating a slip plane. Head is widespread along the Thame Valley and south-west of Long Crendon and is usually up to 2 m thick. The boundaries shown on the map are approximate and do not necessarily include all deposits. Even thin, unmappable head can pose problems.

## 9.3 Alluvium

Like head, alluvium is unconsolidated. It is dominantly composed of clay and may contain peaty or organic layers. Both are liable to subside when loaded, as a result of compaction. Small shear surfaces may be present.

## 9.4 Man-made Deposits

Man-made deposits represent a hazard in three main ways:

(i) The commonly uncompacted or poorly compacted nature of such deposits can give rise to unstable foundations. The composition can be very variable from site to site and within short distances on a single site. In places it may be very weak or cavernous and cause extensive or uneven settlement. Organic matter may rot, causing cavitation and settlement. When spoil is dumped on a slope, the buried soil/organic layer may be weak and therefore might be a potential failure surface. Poorly controlled groundwater flow can produce catastrophic failure of poorly compacted embankments and spoil heaps.

(ii) Toxic residues either as a primary component of the man-made deposit or generated secondarily by chemical or biological reaction, can migrate both within the deposit itself, and into adjacent permeable strata, polluting water supplies.

(iii) Toxic or explosive gases, particularly methane, can be generated within waste tips and landfill sites, and away from the sites by bacterial decay of chemicals in the leachate. Such gases can migrate - sometimes through adjacent permeable strata - and accumulate within buildings or excavations either nearby or some distance away (cf. Aitkenhead and Williams, 1987).
The man-made deposits shown on the map represent only those identified at the time of survey. The boundaries shown are likely to be inaccurate.

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## 11. APPENDIX

Boreholes:-
BGS files contain 87 borehole records for 1:10000 sheet SP 60 NE. They comprise the following:

35 boreholes and trial pits for the Thame By-pass, proving alluvium, Second Terrace, Fourth Terrace, Head, Kimmeridge Clay Formation and Gault (max. depth 16.5m).

20 percussion boreholes for a reservoir at Long Crendon. All prove Gault and faunal specimens are held in the BGS collections (max. depth 11.4m).

19 shallow site investigation boreholes in Long Crendon, most proving Portland Formation and some the Thame Sand (max. depth 16.5m).

10 site investigation boreholes for a gas feeder pipeline, proving Kimmeridge Clay Formation, Head and Alluvium (max. depth 6.5m).

3 water wells 5.8m, 18.3m and 36.6m deep proving Lower Greensand, Kimmeridge Clay Formation and Ampthill Clay Formation.

2 BGS percussion boreholes, one 5m deep proving Fourth Terrace on Thame Sand; one 10.2m deep proving Gault with faunal specimens held in the BGS collections.

Sections:-
Additional details of sections are held in BGS files and on the fieldslips.