London - Upper Cretaceous Chalk Group

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The main outcrop of the Chalk Group is on the scarp and dip slopes of the North Downs in the south of the district. A small outcrop around Watford, in the north-west of the district, lies on the dip slope of the Chiltern Hills. The typical thickness of Chalk Group is between about 175 and 200 m, with a general thinning of about 20 m from west to east (Figure 5). This is a relatively thin succession compared to over 400 m in the Hampshire Basin and East Anglia.

The BGS borehole at Fetcham Mill, near Leatherhead [1581 5650] provides the most useful information on the full chalk succession in the London region. (Wood in Murray, 1986; Mortimore and Pomerol, 1987). It is reasonably typical of the Chalk Group of the North Downs, although compared with other locations in the district the Lower Chalk is anomalously thin. The Fetcham Mill succession varies from that of the Chiltern Hills in several important aspects that are influenced by the depositional history of the chalk. Deeper water in the south-east led to more continuous sedimentation than in the north-west, where there were more breaks in sedimentation and development of more prominent indurated and mineralised chalk horizons, known as hardgrounds (Figure 5). This is particularly apparent in the Lewes Chalk in the north-west of the region, where the 'Chalk Rock' and 'Top Rock' occur, but south-eastwards these pass laterally into a thicker succession containing marls (calcareous mudstones), thin hardgrounds and nodular chalks.

There is an imbalance of information on the Chalk Group in the London district. The Upper Chalk is well documented at outcrop and in exposures in north Kent and south Essex, but the Middle and Lower Chalk stratigraphy is largely inferred from published information on the North Downs (see Robinson, 1986), including sections in quarries in the River Medway valley. In the majority of the London district, where the Chalk is concealed beneath Palaeogene deposits, information is available only from site investigation boreholes that penetrate the topmost 20 m or so.

Correlation of the subsurface chalk succession has been achieved using electrical resistivity logs (Murray 1986). In general terms these logs discriminate well between clay-rich intervals (marls; see below) and hard beds (nodular chalk and hardgrounds), which give high and low resistivity values respectively. However, the presence of numerous, closely spaced, flint-bearing horizons may give an irregular and unpredicatable signature that can be interpreted as either marl or hardground. Wood (in Murray, 1986), aware of this potential problem, cautioned against over interpretation of downhole logs and placing reliance on detailed correlations using them without good borehole core control such as is provided by the Fetcham Mill Borehole. Using this log as a standard, correlation of other selected resistivity logs is shown in Figure 6.

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Nomenclature

Shortly after the completion of mapping in the London district, Bristow et al. (1997) formally subdivided the Chalk Group, recognising up to ten members in the stratigraphically more complete succession in the Wessex Basin. Subsequently, Rawson et al. (2001) re-assigned these members to formational status, and divided the Chalk Group into two subgroups: the Grey Chalk Subgroup and White Chalk Subgroup. The boundary between these is defined at the base of a widespread clay-rich horizon, the Plenus Marls Member (Table 5). This represents the latest step in the progressive refinement of Chalk stratigraphy that has occurred over the last 20 years. Correlation formerly relied on traditional biozones that may include up to 80 m of strata, whereas current resolution, based on a combination of detailed biostratigraphy and lithostratigraphy, defines units of less than 5 m in much of the Chalk. Integration of the new detailed lithostratigraphy with the established biozonation (Table 5) means that former exposures from which fossils were collected can now be referenced to a lithostratigraphical framework. Many of the formations now defined correspond closely with the stratigraphical subdivisions recognised by Mortimore (1986) in the Chalk of the South Downs, and largely supersede the separate stratigraphy erected by Robinson (1986) for the Chalk of the North Downs.

In the London district, formations and their component members are mapped using a combination of topographical features, field brash and biostratigraphical data. However, because of local problems in mapping some of the subdivisions originally defined by Bristow et al. (1997), and partly because the revisions of Rawson et al. (2001) postdate work in the London district, a slightly modified succession is described herein and depicted on the published maps (sheets 256, 257, 270, 271).

The generalised Chalk Group succession, shown in Figure 7, includes several distinctive beds recognised in exposures and boreholes that are valuable for correlation. The locations of key successions, and their stratigraphical range, is also shown on Figure 7, and includes some that are outside the district but which are essential for correlation or as good reference exposures.

Lithology

Chalk is typically a very fine-grained white limestone. It consists predominantly of the disaggregated skeletal remains (coccoliths) of tiny planktonic algae, composed of almost pure calcium carbonate in the form of low magnesian calcite. The lower part contains up to 30 per cent clay and includes intercalated clay-rich horizons (marls) and spongiferous limestones.

Layers of flint generally provide the most prominent indication of bedding, and are a conspicuous feature of the higher part of the Chalk Group where they occur at regular intervals. Flint layers are most abundant in the upper part of the Lewes Chalk where they average one every metre. Flint is composed of silica, in the form of microscopic quartz amorphous, derived from the dissolved skeletons of siliceous sponges and microfossils (radiolarians and diatoms) that inhabited the Chalk sea. Silica preferentially replaced the sediment infill of animal burrows some distance below the sea bed while the chalk was still being deposited (Clayton, 1986).

Several types of flint are recognised. The most common is a branching, nodular horn-flint with shapes reflecting the shape of original burrow structures produced by soft-bodied organisms and hard-bodied organisms such as crustaceans (e.g. Thalassinoides-type burrows) (Clayton, 1986). These are up to 0.2 m thick and 1 m in length. Other beds contain elongated nodular flints 40 to 50 mm in diameter, some forming an interconnected branching network through a thickness of 3 to 4 m of chalk (for example the Lewes Tubular Flints in the Lewes Chalk). Laterally continuous or semi-continuous tabular flints, 10 to 100 mm thick (for example Whitaker's 3-inch Flint in the Upper Chalk), are typical in homogeneous, well-bedded chalk in which burrows are either absent or poorly defined. Layers such as this, which have a distinctive appearance and are geographically extensive, are valuable for correlation. Thin sheets of flint a few tens of millimetres or less in thickness, commonly with a medial cavity, are discordant or subparallel to bedding. They are inferred to have formed along fracture and shear surfaces developed by compressive stress in the Late Cretaceous (Mortimer and Pomerol, 1997).

Clay-rich, calcareous beds, generally described as 'marls', are a conspicuous feature particularly of the Lower Chalk. The marls are typically medium to pale grey in colour and occur either as discrete beds or more diffuse concentrations of anastamosing thin marl wisps. Marls in the Lower Chalk are typically up to 0.6 m thick (Ditchfield and Marshall, 1989); those higher in the succession are generally 0.1 to 0.15 m thick. In exposures, the marls are darker in colour than the adjacent chalk beds and where weathered have a rather flaky texture imparted by primary lamination. At outcrop they are preferentially vegetated on account of their relatively high moisture content, and in the subcrop give sharp responses in borehole resistivity and gamma-ray profiles, making them important for the long distance correlation of chalk successions (Murray, 1986; Mortimer and Pomerol, 1987). Some marls show a distinct trace element geochemistry (Wray and Gale, 1993), which is also potentially valuable for correlation. Relatively thick beds of marl in the lower part of the Chalk were probably deposited when carbonate sedimentation was suppressed (Ditchfield and Marshall, 1989). The origin of the thinner marls in the higher part of the Chalk is unresolved, but some are interpreted as decomposed volcanic ash (Wray, 1995; Wray and Wood, 1995) while others are thought to be the result of an enhanced influx of land-derived sediment.

At some levels in the Chalk, hard nodular beds that commonly contain fossil sponges are characteristic (Figure 7). The beds have a lumpy texture and maybe stained red or brown due to penecontemporaneous oxidation on the sea floor, rather than subaerial weathering. Nodular beds are thought to have formed in response to lower rates of sedimentation associated with a eustatic fall in sea level, tectonic uplift, or proximity to sea floor highs or basin margins (Hancock, 1989).

Horizons of highly indurated nodular chalk, which are locally iron stained, glauconitised and phosphatised, are referred to as hardgrounds. These formed by enhanced sea-floor cementation associated with periods of nondeposition (Hancock, 1989). Hardgrounds are well developed at or close to basin margins, but in progressively deeper water they pass into nodular beds and eventually become almost imperceptible 'omission surfaces', recognisable only by weakly developed iron -staining.

Macrofossils are rather rare in the Chalk. Ammonites, used as the basis of standard zonations elsewhere in the Mesozoic, are particularly uncommon and poorly preserved, except in the lower beds. The standard biozonation of the Chalk has developed, therefore, using a combination of ammonites, brachiopods, bivalves, crinoids and echinoids. Inoceramid bivalves have proved to be highly effective in Chalk biostratigraphy, and form the basis for several newly proposed zonal schemes (Jarvis and Woodroof, 1984; Gale, 1995, 1996). Microfossil biozonations for the Chalk (Carter and Hart, 1977; Hart et al., 1989) can be indirectly related to the macrofaunal zones, and are valuable where other faunal data is absent or ambiguous.

Concentrations of the trace fossil Zoophycos are observed at several horizons, and are locally useful for correlation. In unweathered exposures, they appear as dark grey lenses of marl a few millimetres thick, and represent a two-dimensional section through the spirally developed detrital feeding trace of a soft-bodied animal.

Lower Chalk

The Lower Chalk, 65 to 70 m thick, crops out in a tract of gently rising ground less than a kilometre wide at the foot of the North Downs escarpment where it overlies the Gault. In the Warlingham [3476 5719] and Fetcham Mill boreholes it is about 60 m thick (and overlies Upper Greensand), and in boreholes at Luddesdown over 70 m [6615 6588]. About 75 m of Lower Chalk are interpreted from the records of a borehole near Watford [1195 9577].

The lowest bed, the Glauconitic Marl, is soft grey marl rich in glauconite and phosphatic pebbles, typically less than 1 m thick. It is overlain by rhythmic alternations of marl and hard chalk that comprise the Chalk Marl (Jukes-Browne and Hill, 1903). These beds are approximately equivalent to the West Melbury Marly Chalk of Bristow et al. (1997). They were formerly exposed in the large quarry at Halling [694 645] in the Medway valley. Isotopic studies suggest that the rhythms in the Chalk Marl are due to the effect of regular climatic oscillations on patterns of sedimentation (Ditchfield and Marshall, 1989), probably induced by cyclical changes in the Earth's orbital parameters (Leary et al., 1989; Gale, 1995).

The higher part of the Lower Chalk succession in the North Downs corresponds to the Zig Zag Chalk of Bristow et al. (1997). It consists of slightly marly, massively bedded chalk, locally known as the Grey Chalk, overlain by soft, white chalk (the 'White Bed' of Jukes-Browne and Hill, 1903). The Grey Chalk and 'White Bed' are poorly fossiliferous, but close to their junction in the North Downs a 2 m-thick unit of bioclastic chalk contains large specimens of the zonal ammonite Acanthoceras jukesbrownei. The highest beds of the Lower Chalk are alternating greenish marls and marly chalk, typically 3 m thick (Wood in Sumbler, 1996), named the Plenus Marls after the belemnite Actinocamax plenus. In the North Downs, the Plenus Marls normally overlie a burrowed erosion surface. They form the lower part of the exposed succession in Halling quarry [694 645] where they contain large specimens of the oyster Pycnodonte vesiculare. Up to eight beds, some separated by erosion surfaces have been recognised (Jefferies, 1961, 1963). Jeans et al. (1991) have suggested that they were laid down during a period of enhanced erosion at a time of falling sea level. The Plenus Marls form a widespread marker in southern England and northern France and give a sharply defined, low-value spike in resistivity logs (Figure 6) and a peak in gamma-ray logs.

Middle Chalk

The Middle Chalk is subdivided into the Holywell Chalk overlain by the New Pit Chalk. Traditionally it has been defined as the strata between the top of the Plenus Marls and the base of the Chalk Rock. As the Chalk Rock is not present in the London district, the top of the Middle Chalk is defined at the appearance of the feature-forming hard, nodular chalk at the base of the Lewes Chalk (Figure 7; Table 5).

Holywell Chalk Member

The Holywell Chalk crops out at the base of the North Downs escarpment in the south-east of the district. It is between 13 and 18 m thick at Halling, and about 14 m are proved in boreholes in the southern and eastern parts of the district, including those at Fetcham Mill and Warlingham.

As a general rule flint does not occur in the Holywell Chalk. Anastomosing marl wisps, locally concentrated into horizons several tens of millimetres thick, are common. The basal few metres are typically indurated and nodular, and give rise to a conspicuous topographical feature above the much softer Plenus Marls. They contain the bivalve Inoceramus ex gr. pictus and acmes of the straight-shelled ammonite Sciponoceras (Mortimore, 1986; Gale, 1996). In previous accounts these basal beds were known as the Melbourn Rock (Jukes-Browne and Hill, 1903; Dewey et al., 1924). The remainder of the Holywell Chalk is less indurated, nodular and has a gritty texture caused by locally abundant, broken shells of the inoceramid bivalve Mytiloides. In borehole resistivity logs, the hard basal beds form a sharp spike and the entire unit gives relatively high values (Figure 6).

The best exposures in Holywell Chalk are in the pit at Halling [694 645] and the track at Court Farm [6891 6425].

New Pit Chalk

The New Pit Chalk forms much of the North Downs scarp face. It also crops out in the upper reaches of valleys flowing north on the dip slope of the North Downs. The thickness around Luddesdown [67 66] and Stansted [61 62] is 25 to 40 m and at Shoreham [52 62] 35 to 50 m. Boreholes at Winchester House in central London [3302 8142] and at Chingford [3740 9212] prove 46 m and 41 m of New Pit Chalk, respectively.

In contrast to the Holywell Chalk, the New Pit Chalk is softer, smooth textured and more massively bedded. The basal beds contain thin-shelled Mytiloides fragments that are usually poorly preserved chalky moulds. Common fossils in the remainder of the New Pit Chalk are T. lata, the bivalves Inoceramus cuvieri and I. lamarcki, and the echinoid Conulus subrotundus. Small flints occur near the base (Glyndebourne Flints of Mortimore and Pomerol, 1986) and top of the succession, but the greater part is flint free. Marl seams and marly chalk horizons, up to 0.1 m thick, are common throughout. The most widely correlated are the two New Pit Marls (Mortimore, 1986) and the Glynde Marls (Figure 7). The New Pit Marl 2 and Glynde Marls are exposed in the quarry at Dean Farm [696 657].

In borehole geophysical logs there is a sharp drop in resistivity values at the base of the New Pit Chalk. A further decline generally occurs for some metres above this horizon (Figure 6), punctuated by frequent sharp, low value resistivity-spikes representing marl beds. Similar profiles are identified in numerous boreholes across southern England (Mortimore and Pomerol, 1987).

The lower beds of the New Pit Chalk are exposed in the large quarry at Halling [694 645] and probably form the greater part of the mostly inaccessible faces in the abandoned quarries at Whorn's Place North Halling [7050 6610] and Wingate Wood [693 651] (Dibley, 1918). A track ascending the main escarpment above Upper Halling [6895 6448 to 6895 6460] shows sporadic exposures, but the best currently available section is in a newly opened quarry at Dean Farm [696 657] near Cuxton, just east of the district, where the top 22 m of New Pit Chalk and the contact with the overlying Lewes Chalk were exposed.

Upper Chalk

In the London district, the lower part of the Upper Chalk is mapped as the Lewes Chalk. The remainder is undivided, but includes strata equivalent to the Seaford Chalk, overlain by beds equivalent to the Margate Chalk and Newhaven Chalk (Robinson, 1986; Bristow et al., 1997; Table 5). The maximum total thickness is in the order of 100 m.

Dewey et al. (1924) appear to have partly relied on a distinctive molluscan fauna, known as the Reussianum Fauna (named after the ammonite Hyphantoceras reussianum) to infer the base of the Upper Chalk. However, this fauna apparently occurs below the Bridgewick Marl 1 (Figure 7) in railway cuttings between Coulsdon and Purley, and possibly also in the basal M. cortestudinarium

Zone (Davis, 1926, 1929). It is therefore concluded now that the presence of the fauna is an unreliable marker for indicating the base of the Upper Chalk.

Lewes Chalk

The Lewes Chalk crops out mainly in the south-east of the district, at or near the top of the North Downs escarpment, and in the upper reaches of northward-trending valleys around Luddesdown [67 66], Meopham Green [64 65], South Street [640 635], Stansted [61 62] West Kingsdown [570 625] and Shoreham [52 62]. It forms a positive feature on the sides of many of these valleys; the best example of this is in the Darent valley near Eynsford [540 655] where the higher beds of the Lewes Chalk also give rise to a narrow bench feature. Farther west, it occurs in valley floors between Pratt's Bottom [47 62] and west of Biggin Hill [40 61], and in an inlier in the floor of Swanscombe Western Quarry [5808 7344]. It may outcrop also in the north-west around Watford and Bushey (Jukes-Browne and Hill, 1904) but has not been mapped.

At outcrop, the Lewes Chalk is generally 25 to 35 m thick, but thins to 20 m locally around Luddesdown and Meopham Green, and is 35 to 40 m in the Darent valley. Geophysical logs indicate that the thickness ranges from 27 to 40 m.

The Lewes Chalk is characteristically hard, nodular, locally iron stained and flinty. Marl seams, up to 0.1 m thick, occur throughout, but are especially conspicuous in the lower beds. Hardgrounds occur locally, and at least some of the thickness variation within the Lewes Chalk may be caused by condensed sequences or depositional breaks at these horizons. Layers of nodular flints are regularly spaced throughout the succession, becoming distinctly carious (i.e. with abundant cavities) in the higher part. At some horizons these flints almost interlock to produce laterally continuous bands. Conspicuously large nodular flints, with dimensions exceeding 0.2 m are developed locally. Thin sheets of flint subparallel or strongly discordant to bedding also occur.

The Lewes Chalk is richly fossiliferous with sponges, brachiopods, bivalves and echinoids. Inoceramid bivalves and the echinoid Micraster are especially important for biostratigraphical correlation. In the higher part of the Lewes Chalk, the occurrence of the inoceramid Cremnoceramus near the junction of the S. plana and M. cortestudinarium zones can be used to identify the base of the Coniacian Stage (Kauffman et al., 1996).

Several of the marls and hardgrounds are useful for correlating the Lewes Chalk. The Southerham Marl 1 is 0.1 m thick with a plastic texture and is characterised by the acme occurrence of the foraminifer Labyrinthidoma (= Coskinophragma of Mortimore, 1986). It is underlain by the Southerham Flints (Mortimore, 1986) a bed characterised by a mixture of relatively large burrow-form nodular flints and smaller finger-like flints. They are exposed in the higher part of the Dean Farm Quarry [696 657].

Although not all are exposed in the district, the Southerham, Caburn, Bridgewick and Lewes marls of Sussex (Mortimore, 1986) have been traced across the region using geophysical logs (Figure 6); the Lewes Marl is known particularly for the occurrence of the large morphotype of Micraster leskei.

The 'Lewes Tubular Flints' (Mortimore, 1986) are vertically elongated burrow-form flints, typically with a central rod of silica surrounded by soft chalk. When weathered or broken open, the core is easily removed and the result is a hollow tube of flint. This is a good marker bed, exposed in Dean Farm Quarry, and identified in a borehole beneath the Thames [5911 7639] between Thurrock and Swanscombe.

The apparently localised and weakly developed Swanscombe Hardground occurs about 6.5 m below the top of the Lewes Chalk, at possibly the same stratigraphical position as the thicker Cornhill Hardgrounds on the Kent coast (Robinson, 1986).

In the top 5 m of the Lewes Chalk, two thin marl horizons about 2 m apart are underlain by chalk with Zoophycos, tubular flints and orange-stained sponge-bearing beds. The succession is correlated with the Shoreham Marls, Beachy Head Zoophycos and Beachy Head Sponge Beds (Mortimore, 1986). It is exposed in Swanscombe Western Quarry, and identified in boreholes in the Thurrock–Swanscombe area, at Swanscombe Marshes [6040 7534; 5997 7593] and Islington [3376 8495].

The beds containing the Shoreham Marls appear to pass laterally into the Rochester Hardground (Robinson, 1986) that has been recorded at the Rose and Crown Pit [337 594] near Croydon and Martin Earle's Pit in the Medway valley [722 679].

Upper Chalk undivided

The youngest Chalk in the region, including most of the chalk outcrops and all the chalk directly beneath the Palaeogene deposits, is mapped as Upper Chalk undivided. The most extensive outcrops are in the north-west and south-east of the region. There are also smaller outcrops in the cores of shallow anticlines at Lewisham [375 760], Chiselhurst [43 70], on the south bank of the Thames between Greenwich and Erith, and in the Grays–Purfleet area [55 78 to 61 79].

The succession in the Upper Chalk is particularly well known in the south-east of the district because of the extensive exposures in numerous large quarries. These are situated along the length of the Purfleet–Grays outcrop, in the Cray valley and along the south bank of the Thames and between Dartford and Gravesend. Many of the quarries are now abandoned but some still provide extensive sections, the best of them at Swanscombe (Blue Water Park) [5808 7344], Northfleet [6207 7394 and 6321 7410], Grays [605 795] and Purfleet [573 786]. Smaller exposures can be examined at Knockholt [4830 6300] and Farningham Road Station [5545 6920]. At Chiselhurst Caves [4322 6957], Camden Park, near Bromley [4275 7015], and Upper Ifield [6834 7124], the chalk was formerly worked in underground excavations; those at Chiselhurst are open to the public. Knowledge of the succession at depth is based on cored boreholes, principally between Stratford and Barking, and at London Docklands and the Thames Barrage.The thickness is 59 m in the Grays–Purfleet area (Figure 8), an estimated 50 m in the vicinity of Hook Green [614 705], 60 to 70 m between Orpington [45 65], Swanley [51 68], Hartley [61 68] and Cobham [67 69], and 50 m in the Fetcham Mill Borehole.

Firm to soft, non-nodular chalk with common large nodular, tabular and semitabular flints is the typical lithology, but the uppermost beds locally include soft, poorly flinty chalk. Beds rich in the sheet-like shell fragments of the inoceramid bivalve Platyceramus occur at intervals throughout most of the succession. In the lower beds, conspicuous concentrations of thick shell fragments also include the inoceramid bivalve Volviceramus involutus. Thin marls occur in the lower part of the succession, but are absent at higher levels. At least one hardground occurs locally near the top of the succession (see below).

The succession as a whole has relatively low resistivity values on geophysical logs; the profiles are typically spiky, mainly caused by flints, but too variable to allow detailed correlation between boreholes. A drop in average resistivity, accompanied by a reduction in the amplitude and frequency of spikes, occurs towards the top of the succession (Figure 6). It corresponds to the appearance of softer chalk, which in the Fetcham Mill Borehole has a higher water content than the underlying beds (Gray, 1965).

The Belle Tout Marls (Mortimore, 1986) are a series of thin marl seams in brittle chalk in the bottom 8 m of the succession, equating with Robinson's (1986) Hope Point Marls and Otty Bottom Marl. They have been seen at Swanscombe, Knockholt and in two boreholes at Swanscombe Marshes.

Three distinctive flint beds have proved useful for correlation between exposures and in shallow boreholes in the south-east of the region. None has been identified in the north and west. The lowest is the Seven Sisters Flint, a key marker identified in the North and South Downs and northern France (Mortimore, 1986; Mortimore and Pomerol, 1987). In the North Downs, Robinson (1986) named this flint the Oldstairs Bay Flint, and Bailey et al. (1983) referred to it in east Kent as the East Cliff Semitabular Flint. It crops out about 12 m above the top of the Lewes Chalk at Swanscombe Western Quarry [5808 7344], occurs in the cutting near Knockholt Station [4830 6300], and was formerly exposed in the deepest levels of the Pinden landfill site [5935 6970] (Figure 8). It is a massive rusty, carious semitabular flint about 0.2 m thick and containing inoceramid shell fragments. The chalk adjacent to, and especially below, the Seven Sisters Flint contains abundant, thick-shelled fragments of Platyceramus and Volviceramus.

The Bedwell's Columnar Flint was identified by Robinson (1986) in sections across the North Downs, although within the London district it has only locally developed 'columnar' morphology, and is generally difficult to recognise in sections. It is associated with the upper of two acmes of the inoceramid bivalve Cladoceramus undulatoplicatus. The lower one marks the boundary of the Coniacian and Santonian stages, and the upper is coincident with the flint horizon (Robinson, 1986). Both horizons crop out in the Grays–Purfleet quarries and at the Swanscombe Western Quarry. At Pinden, only the upper horizon is present, and one or other of them has been identified in boreholes around Islington [3376 8495], Stratford, [4129 8525], and in a quarry at Northfleet [6207 7394].

The semi-continuous Whitaker's 3-inch Flint forms a conspicuous marker horizon, a few metres below the Palaeogene in most of the quarries in the Grays– Purfleet area. It is tabular in form, typically about 0.07 m thick, and has a slightly irregular lower surface that distinguishes it from other (thinner) flat-sided, sheet flints that occur locally in this part of the succession. At Swanscombe Western Quarry [5808 7344] it lies 22 m above the Seven Sister's Flint, and may be the prominent flint recorded at the base of the former Ruxley Quarry [4895 7010] by Dibley (1909). It was also proved in a borehole near Aveley [5528 7932]. The thickest successions exposed above the Whitaker's 3-inch Flint are 13 m at Gibbs Quarry [595 787], 15 m at Swanscombe Eastern Quarry [590 735] and 20 m at Pinden [5935 6970] (Figure 8). The succession between this flint and Shoreham Marl 2 is particularly variable in thickness, being 46 m around Grays and 34 m at Swanscombe.

The Barrois Sponge Bed, recognised in east Kent, and its lateral equivalent the Clandon Hardground in Surrey, occur at the top of the Seaford Chalk in the London district; the upper surface of the sponge bed/hardground marks the base of the overlying Margate Chalk (Robinson, 1986; Bristow et al., 1997). This marker bed is probably represented by two conspicuous horizons of hard, yellow chalk formerly exposed in the pit at St Paul's Cray (Dewey et al., 1924), and by weakly developed spongiferous chalks at Pinden and in the lower part of the old quarry at Farningham Road Station. It also forms the hardground in the floor of the mines at Chiselhurst, and two indurated chalk horizons 3.6 m apart in the workings at Camden Park (Whitaker, 1889; Jukes-Browne and Hill, 1904). The interval of strata at outcrop between the Barrois Sponge Bed/Clandon Hardground and Whitaker's 3-inch Flint appears to thicken to the south-east of the region, ranging from 2.5 m at Chiselhurst to 21, 15 and 13 m at Pinden, Swanscombe and Gibbs Quarry [595 787].

Strata above the Barrois Sponge Bed consist of relatively flint-free chalk in the Orpington area, for example at Cacketshill Wood [5143 6677] near Crockenhill and north-east of Holwood Farm [4272 6365] where about 5 m are present beneath the Thanet Sand. Elsewhere the chalk above this horizon contains sporadic flints throughout and locally large flattened flints, typically 0.3 m across, forming discontinuous beds. Conulus albogalerus is locally abundant in these beds which can be seen in a pit at Upper Ifield [6834 7124] and the cutting at Farningham Road station [5545 6920] (Figure 8), and were formerly exposed at Ruxley Quarry [4895 7010] (Dibley, 1909).

In areas where marker beds in the Upper Chalk have not been recognised, fossils diagnostic of the U. socialis and M. testudinarius Zones, which lie above the Barrois Sponge Bed, support determination of the lithostratigraphy. These zones have been documented widely at outcrop around Croydon and south of Bromley (Young, 1905; Dewey et al., 1924). The key fossils are the calyx plates belonging to the index crinoid species although, in the case of U. socialis, these are quite inconspicuous. Notable records of U. socialis are from the former pits at St Paul's Cray and at Cacketshill Wood and a pit north-east of Holwood Farm [TQ 4272 6365] that apparently included the junction of the U. socialis and M. testudinarius zones (Dewey et al., 1924).

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