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The Geology of the Pang-Lambourn Catchment, Berkshire

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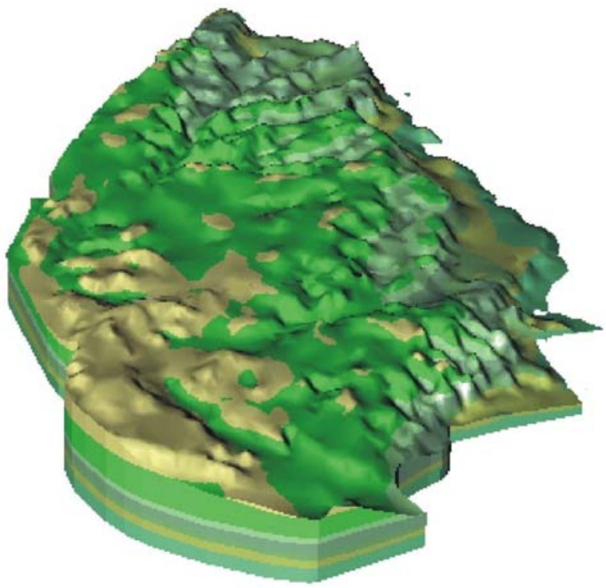

BRITISH GEOLOGICAL SURVEY

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The Geology of the Pang-Lambourn Catchment, Berkshire

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Key words

Geology, Berkshire, Chalk, Palaeogene, superficial deposits, structure.

Front cover

Perspective view of 3D geological model of the Pang-Lambourn Project area, looking towards the west.

Bibliographical reference

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Summary

This report describes the geology of most of the Berkshire Downs. Together with a complementary geological map at 1:50 000 scale, it was produced as part of the infrastructural information provided for the LOCAR (Lowland Catchment Research) Project, under the NERC Thematic Programme.

The introduction describes the topographic and geological setting of the project area. Subsequent chapters respectively describe the solid (or bedrock) geology, the superficial (or drift) geology, and the geological structure.

Most of the area is underlain by the Upper Cretaceous Chalk Group. The Lower Cretaceous Upper Greensand and Gault, and a small area of the Jurassic Kimmeridge Clay, occur in the north. The Palaeogene Lambeth Group, London Clay Formation and Bagshot Formation occur in the south.

Superficial deposits are landslip, head, clay-with-flints, sand in clay-with-flints, peat, alluvium, river terrace deposits. Areas of worked ground, made ground, infilled ground and landscaped ground have also been delineated.

Figures and tables appear at the end of the report.

1 Introduction

1.1 RATIONALE AND SETTING

This report describes the geology of the topographic catchments of the River Pang and the River Lambourn (including that of the Winterbourne Stream), together with the immediately adjoining surrounding area (Figure 1). Together with a complementary geological map at 1:50 000 scale, it was produced as part of the infrastructural information provided for the LOCAR (Lowland Catchment Research) Project, under the NERC Thematic Programme.

The area described mostly lies within Berkshire, with a northern strip in Oxfordshire and a small western part in Wiltshire. It comprises the greater part of the chalklands of the Berkshire Downs, extending from Didcot and the Vale of the White Horse in the north and west, to Newbury and the River Kennet in the south, and to the River Thames at Goring and Pangbourne in the east. A section of the M4 motorway, between Reading and Swindon, crosses the area from east to west, and part of the north-south A34(T) road between Oxford and Newbury intersects the M4 just north of Newbury.

The Berkshire Downs comprise an escarpment (or more exactly, a series of escarpments) facing north over the Vale of the White Horse, with a corresponding dip slope descending more gradually southwards to the Kennet Valley. The crest of the escarpment is marked by the Ridge Way track (Figure 1). The dip slope is dissected by the River Pang, the River Lambourn and their tributaries. The Berkshire Downs are bounded in the east by the Goring Gap, where the River Thames passes through a breach in the escarpment. A subsidiary breach, between Chilton and Compton, carries one of the upper tributary valleys of the River Pang (Figure 2). In the south of the area, the chalk downland is surmounted by another, heavily dissected, escarpment formed by Palaeogene deposits and Quaternary river terrace deposits.

The River Pang, in the eastern part of the area, flows first south, then east, then north, to join the River Thames at Pangbourne. Its surface catchment is some 24 km long and up to about 9 km wide. The River Lambourn, in the western part of the area, flows south-east to join the River Kennet at Newbury. The Kennet joins the Thames at Reading. Its surface catchment is some 26 km long and almost 12 km wide (Figure 2).

Most of the area described lies within 1:50 000 scale geological Sheet 267 (Newbury) (Figure 1), published in 1898. This is currently being revised, and is due to be republished with a brief explanation in 2004. The coincident part of the geological map of the Pang-Lambourn catchment is based on 1:10 000 scale geological maps prepared as part of that revision. An eastern part of the area is covered by Sheet 268 (Reading). This was published with a brief explanation in 2000 (Mathers and Smith, 2000). However, the geological map of those parts of the Reading District within the LOCAR Pang-Lambourn area had been revised by desk study with only limited field checking. Further revisions by desk study were carried out for the present project, mainly to subdivide the Chalk according to the modern lithostratigraphic scheme (Section 2.3) and to identify dissolution hollows and areas of Made Ground or Worked Ground by interpretation of aerial photographs at 1:10 000 scale. The northern part of the area lies mostly within Sheet 253 (Abingdon) with minor marginal sections on Sheet 252 (Swindon), Sheet 254 (Henley-on-Thames) and Sheet 266 (Marlborough). These were all published in the 1970s and in 1980, although without corresponding Memoirs or other forms of sheet description. For this project relevant parts of these maps were revised at 1:10 000 scale by a combination of desk study, interpretation of aerial photographs (at 1:10 000 scale) and rapid field survey.

Details of the component 1:10 000 geological maps were captured digitally and compiled for presentation at 1:50 000 scale.

In addition, data from the interpretation of borehole records was used to construct a three-dimensional digital model of the Chalk of the Berkshire Downs (Section 4.2).

1.2 GEOLOGICAL OUTLINE

The area lies at the southern edge of the London Platform, part of the Variscan foreland, just north of the late Carboniferous Variscan deformation front. It is partly underlain by a section of the Berkshire Carboniferous depositional basin (Allsop et al., 1982; Foster et al., 1989; Mathers and Smith, 2000). It lies just north of the Wessex Basin, a post-Variscan depositional basin that extends across central southern England and adjacent offshore areas. It occurs at the north-western edge of the London Basin, which formed during Cenozoic folding and structural inversion of the Wessex Basin (Hawkes et al., 1998; Underhill and Stoneley, 1998).

The surface geology of the area is shown on the 1:50 000 scale geological map which accompanies this report. This map is summarised in Figures 3 and 4.

The catchments of the River Pang and the River Lambourn are principally within the Chalk, the main aquifer of the region. The siltstones and sandstones of the underlying Upper Greensand, which crops out in the north of the area, are probably in hydraulic continuity with the Chalk. This aquifer is thought to be effectively sealed from those in older bedrock formations by the mudrocks of the Gault and the Kimmeridge Clay, the oldest formations described in this report. Older formations are described by Sumbler

(1996) and, in the eastern part of the area, by Mathers and Smith (2000). The Chalk is of Upper Cretaceous age, the Upper Greensand and Gault are of Lower Cretaceous age, and the Kimmeridge Clay is of Jurassic age.

In the south of the area, the Chalk is overlain by deposits of Palaeogene age, namely the clays and sands of the Lambeth Group (comprising the thin basal Upnor Formation and the thicker overlying Reading Formation), the silty clay of the London Clay Formation and the sands of the Bagshot Formation.

Superficial (drift) deposits of Quaternary age comprise clay-with-flints, some of which is sandy, head deposits in a variety of topographic situations, alluvium, peat, and river terrace deposits. In the eastern part of the area individual terrace deposits have been classified according to schemes applied to the river terrace systems of the Thames and of the Kennet (Mathers and Smith, 2000). In the rest of the area (and on Figure 4), the terraces remain unclassified. Landslips are present locally on the Palaeogene outcrop.

The geological map also shows areas of Made Ground (chiefly road and rail embankments), Worked Ground (including road and rail cuttings and quarries for chalk, gravel or other minerals), Infilled Ground (typically, backfilled mineral workings) and Landscaped Ground (where areas of Worked, Made or Infilled Ground are present but cannot be distinguished with confidence).

Also identified are springs and dissolution hollows (dolines), including swallow holes on minor streams and closed depressions with no afferent drainage channels.

The structure is dominated by a gentle regional dip of up to about 2º to the south-south-east or south. Faulting is present, but minor. Drainage channels tend to follow one of several linear trends, thought to reflect the distribution of jointing in the Chalk.

1.3 CONVENTIONS

In the following descriptions, estimates of the stratigraphic thickness of a particular part of the geological sequence should be taken to refer to its occurrence within the Pang-Lambourn catchments, unless stated otherwise.

National Grid References quoted in this report are given in the form [2928 4352]. All lie within Grid Zone SU, unless otherwise stated. Boreholes mentioned in the text are identified by a BGS Borehole Registration Number in the form SU24SW 23.

2 Solid geology of the Pang-Lambourn catchment

2.1 JURASSIC

2.1.1 Kimmeridge Clay

The Kimmeridge Clay Formation, of Late Jurassic Kimmeridgian age, is seen only in a small part of the area, at the northern edge. This outcrop continues north beneath the Vale of the White Horse.

The Kimmeridge Clay comprises rhythmic sequences of pale calcareous mudstones, dark, shelly, carbonaceous mudstones, and silty mudstones, commonly with beds of cementstone (impure limestone) nodules. At Swindon, just to the west of the area, it is about 100 m in thickness, decreasing towards the north-east.

It is overlain unconformably by the Gault.

2.2 LOWER CRETACEOUS

2.2.1 Gault

The Gault Formation, of Middle to Late Albian age, crops out in a strip at the northern edge of the area, just below the escarpment formed by the Upper Greensand.

The Gault comprises grey mudstones and silty mudstones, commonly with small phosphatic nodules. It is typically about 70 m in thickness.

It is overlain conformably by the Upper Greensand.

2.2.2 Upper Greensand

The Upper Greensand Formation, of Late Albian age, forms a minor escarpment in the north of the area, marking the southern edge of the Vale of the White Horse.

In much of this area, the Upper Greensand can be divided into a thicker lower unit, and a thinner upper unit.

The lower unit is generally some 10 to 30 m thick, composed of evenly bedded, whitish, micaceous, sparsely glauconitic, calcareous siltstones and fine sandstones, with some chert and malmstone (typically sandstone composed of siliceous sponge spicules in a siliceous cement). Jukes-Browne and Hill (1900) describe this unit as 'malmstone' and sandstone, together about 11 m thick below White Horse Hill, passing east into 'calcareous malmstone' up to 30 m thick between Didcot and the River Thames. Recent mapping has shown a marked change in thickness from about 9 m just west of Wantage to about 40 m just to the east of that town, presumably structurally controlled (Section 4.3). The base of the Upper Greensand is likely to be gradational with the Gault. It can be placed at the change from silty clay below to clayey silts and sands above.

This lower part of the Upper Greensand forms a subsidiary escarpment at the base of the main Chalk escarpment. The scarp slope shows a strong positive break of slope within a convex crest at the top, passing south into a planar dip slope. This dip slope is more than one kilometre long near Wantage and to the east, but decreases in length markedly to the west of the town. In the field, the base of the Upper Greensand was taken at a fairly strong, persistent negative break of slope near the base of the Upper Greensand escarpment. This is commonly a spring line. It lies as much as 10 m vertically below the level of the boundary shown on published maps of the area, such as Sheet 253 (Abingdon).

Where present, the upper unit of the Upper Greensand comprises 3 m to 10 m of dark green glauconite sand and sandstone, containing numerous small grains of glauconite and quartz sand in a clayey matrix. The top of the unit is sufficiently cemented to be impenetrable to a hand auger, suggesting that a minor nonsequence might be present. Gallois and Worssam (1983), describing borehole core from the site of the Rutherford Appleton Laboratory, Harwell, described an interval of about 4 m of non-fossiliferous, highly glauconitic, clayey, calcareous sand (which they ascribed to the Glauconitic Marl, see Section 2.3.1) resting on typical Upper Greensand siltstones at an intensely bioturbated junction. Jukes-Browne and Hill (1900) record 6 m of 'soft green sand' at Uffington, and 4.5 m to 5 m at Wantage and Didcot. However, to the west of Wantage much of this part of the Upper Greensand outcrop is obscured by head deposits: the upper unit may be absent locally, possibly as a consequence of late Albian or very early Cenomanian erosion, as found in the Fareham District of Hampshire, for example (Hopson, 1999).

Part or all of this upper unit locally forms a strong positive feature at the foot of the Chalk escarpment. Its base is approximately marked by a negative feature above the dip slope formed on the lower unit of the Upper Greensand.

Micropalaeontological examination of samples of the upper unit collected from shallow, purpose-dug pits near East Hendred found faunal assemblages indicating foraminiferal zones 6 (upper) and 6a of Hart et al. (1990), in the very youngest Albian. If a non-sequence has occurred between the Upper Greensand and the overlying Chalk Group at this locality, then it is within the limits of resolution of micropalaeontological biostratigraphy (Wilkinson, 2002a).

The Upper Greensand is overlain by the Chalk Group, possibly with minor disconformity or unconformity in places.

2.3 UPPER CRETACEOUS

The Chalk Group, of Upper Cretaceous age, underlies most of the area, forming a prominent escarpment in the north.

Traditionally, the Chalk was divided into three units, effectively of formation status: the Lower Chalk, the Middle Chalk and the Upper Chalk. Named members or beds within these units, such as the Glauconitic Marl, the Melbourn Rock and the Chalk Rock (which occur at the respective bases of the three traditional units) are widely recognised (Table 1). However, following work by Mortimore (1986) and by Bristow et al. (1995), it was found that a more detailed lithostratigraphic subdivision of the Chalk was possible (Bristow et al., 1997). After further discussion, it was proposed that the Chalk Group be divided into an older Grey Chalk Subgroup and a younger White Chalk Subgroup, the boundary between being placed at the base of the Plenus Marls, slightly below the base of the traditional Middle Chalk (Rawson et al., 2001).

Each subgroup is divided into formations (Table 1). The two youngest do not extend as far north as Berkshire, but the remainder are present in the Berkshire Downs. These formations are now described separately, in order of decreasing age. Each one can be recognised during field survey and in borehole records.

Several of the formations include named members or beds. Two named members have been shown on the face of the map, where their outcrop has been mapped reliably. These are the Chalk Rock, in the lower part of the Lewes Chalk, and the Stockbridge Rock, near the top of the Seaford Chalk.

The correspondence of biostratigraphic zones with the lithostratigraphic scheme used here is shown in Table 1, and described by Mortimore et al. (2001). The biostratigraphical significance of fossil material in the BGS collections and found during recent surveys is discussed by Woods (2000a; 2000b; 2000c) and Wilkinson (2001b, d, e, f; 2002a, b). The stratigraphy of two cored boreholes in the area (Winterbourne, SU47SE 56 and North Farm, SU37NW 8) is described by Woods (2001b) and Wilkinson (2001a; 2001c). Geophysical logging of these two boreholes is discussed by Tate et al. (1971). The correlation of geophysical logs from boreholes in the Chalk is discussed more generally by Woods (2000a). Jukes-Browne and Hill (1903; 1904) describe the Chalk of the area in general, and of that found at specific localities.

2.3.1 West Melbury Marly Chalk

The West Melbury Marly Chalk Formation, comprising the lower part of the Grey Chalk Subgroup, crops out in the north of the area, at the base of the main escarpment. Except in the western third of the area, it forms a subsidiary escarpment up to 50 m high. The dip slope is more than 1.5 km long in places.

The West Melbury Chalk includes a basal member, the Glauconitic Marl. Certain beds, particularly the main limestone beds, have been given informal names (Sumbler, 1996; Mortimore et al., 2001), or are designated by alphanumeric codes (Gale, 1989). The Chilton Stone, a limestone bed near the top of the formation, was named after a locality in the north-east of the area, but this name has only local significance.

The Glauconitic Marl Member is composed of locally fossiliferous pale brownish grey clay-rich chalk (marl), with conspicuous sand-grade glauconite grains. Quartz sand, if present, is sparse. The member is between about 0.3 m and 2 m thick. It is very likely that some interpretations of borehole records have grouped the glauconite sand at the top of the Upper Greensand with the Glauconitic Marl. For example, descriptions of cored boreholes from the site of the Rutherford Appleton Laboratory, Harwell, by Gallois and Worssam (1983), ascribed some 5.2 m of sequence to the Glauconitic Marl. It seems very likely that most of that interval would now be placed in the Upper Greensand.

The Glauconitic Marl can be distinguished from the upper part of the Upper Greensand by differences in body colour, in the proportion of quartz sand and in the amount of glauconite. A burrowed erosion surface would be expected to occur between the two units, and there are some indications in the older accounts that it is present but not recognised as such. Augering near the base of the Chalk encounters an impenetrable bed at or close to the top of the Upper Greensand.

Micropalaeontological examination of samples of the Glauconitic Marl collected from shallow, purpose-dug pits near East Hendred found faunal assemblages indicating foraminiferal zone BGS1 (Table 1) in the Lower Cenomanian (Wilkinson, 2002a).

The rest of the formation comprises bedded soft off-white to grey clay-rich chalks (marls), grey marly chalks and hard grey or brownish grey limestones, in rhythms. Glauconite grains occur in the lowest few metres of marly chalk. Some of the limestones are nodular, some are fossiliferous, and some are sparsely glauconitic. The West Melbury Chalk includes a locally abundant, moderately diverse marine invertebrate fossil fauna dominated by ammonites, bivalves, brachiopods, and in some limestone beds, sponges. The foraminifera low in the West Melbury Marly Chalk are typically dominated by agglutinated benthonic taxa that extend up from the Albian, but include species such as *Plectina mariae* and *Hagenowina anglica* which evolved at the base of the Cenomanian.

The equivalent sequences at Chinnor in Oxfordshire are described by Sumbler and Woods (1992) and at Folkestone and elsewhere by Gale (1989) and Mortimore et al. (2001). The West Melbury Marly Chalk has generally clayey soils, commonly with dense spreads of limestone debris in places. Springs occur at some of the limestones.

Good exposures of about six limestone – marl rhythms are exposed in a disused railway cutting east of Chilton [5007 8628]. One of these beds was named the ‘Chilton Stone’ by BGS geologists who surveyed the area of the Abingdon Sheet (Gallois and Worssam, 1983, p. 8). This appears to form a prominent positive feature (commonly associated with numerous fragments of hard limestone in the soil) where it occurs in unexposed ground to the west. These occurrences seem to have been mistakenly interpreted as the outcrop of the Totternhoe Stone, as shown on the published 1:50 000 Sheet 253 (Abingdon). As noted in the next section, the horizon of the Totternhoe Stone is inferred to occur at a higher stratigraphic level.

The West Melbury Chalk can underlie gently sloping ground at the foot of the escarpment but in most of the area it forms a subsidiary escarpment, in which the limestones tend to form minor positive features. Note that such positive features might be formed by different limestone beds in different sectors of the escarpment. Some of these limestones form outliers, creating a belt of low hills extending north-east along strike from Chain Hill (Wantage), through Roundabout Hill (Ardington) and Park Hill (East Hendred) to the Sinodun Hills, some 4 km north-east of the area.

The base of the Chalk is typically marked by a weak negative topographic feature. This lies a short distance above the positive feature formed by the glauconite sand at the top of the Upper Greensand, or, where that sand is absent, at the lower end of the Upper Greensand dip slope.

Outcrop patterns and borehole evidence suggest that the West Melbury Chalk varies between 20 m and 55 m in thickness. It is overlain conformably by the Zig Zag Chalk.

2.3.2 Zig Zag Chalk

The Zig Zag Chalk Formation, comprising the upper part of the Grey Chalk Subgroup, crops out in the north of the area. It occurs low in the main escarpment, above the dip slope formed by the West Melbury Chalk, where that landform is present.

The Zig Zag Chalk is typically composed of soft to medium hard greyish blocky chalk with some resistant limestone beds, especially in its lower portion. With some exceptions, it tends to be more sparsely fossiliferous than the West Melbury Chalk, the most usual forms being ammonites, brachiopods, bivalves and thin-tested echinoids.

In the Zigzag Chalk the percentage of agglutinating species suddenly drops and planktonic foraminifera become particularly common, in some samples forming over half of the foraminifera present. This change in fauna may have been caused by an increase in water depth, an event that can be recognised throughout Britain, France and Germany. *Rotalipora cushmani,* first appears in foraminiferal zone BGS 4 (in the *acutus* macrofaunal zone). Of the benthonic taxa, species of *Gavelinella* and *Plectina* are present, *P. cenomana* first appearing at the base of zone BGS 4 (Table 1).

The character of the basal bed of the Zig Zag Chalk changes regionally. In the basinal sequences of the South Downs and North Downs, it is the Cast Bed. In the Chilterns (on the London Platform), the basal bed is the Totternhoe Stone, which rests on a surface eroded into the West Melbury Chalk. It seems likely that this erosion surface passes gradually basinwards into a conformable sequence, with the Totternhoe Stone concomitantly passing into the Cast Bed, but the precise nature of the relationship between the two is not known, nor where the change from one to the other occurs (Sumbler, 1996; Bristow et al., 1997; Mortimore et al., 2001). The Totternhoe Stone is known to be present in the north-east of the present area but has not yet been observed elsewhere. The Cast Bed might be present in part of the area.

The Cast Bed is composed of a distinctive brown silty chalk with abundant composite moulds of gastropods and other molluscs, and small brachiopods. In the North Downs it is calcarenitic, but seems not to include phosphatic nodules. A bed of silty chalk some 0.4 m thick, at about 64 m depth in the North Farm cored borehole (SU37NW 8) at [3321 7971], has been tentatively identified as the Cast Bed (Woods, 2001b).

The Totternhoe Stone is composed of rather friable brownish glauconitic calcarenite, commonly with small phosphatic nodules, some of which are visible without a hand lens. It can include derived fossils, as well as fauna characteristic of the Cast Bed, but the age of the youngest included fossils varies across the outcrop, presumably reflecting increasing diachroneity of the unit and increasing condensation of this part of the succession. The Totternhoe Stone is fairly uniform and not particularly well cemented, although it hardens on exposure to air. It has been described from sections previously exposed in the disused railway cutting east of Chilton, where it is about 0.6 m thick (Jukes-Browne and Hill, 1903). Loose fragments have been found close to Upton during recent surveys. An interval of 0.9 m of brownish grey, bioturbated, silty chalk with small dark brown phosphate nodules and phosphatic grains was found in a cored borehole at the Rutherford Appleton Laboratory Site, Harwell (Gallois and Worssam, 1983). This was ascribed to the 'Chilton Stone', but the presence of phosphatic material suggests it is more likely to be the Totternhoe Stone. No other records of the Totternhoe Stone are known from the area, and it is possible that this unit dies out rapidly to the west and south of Chilton and Harwell.

During previous surveys, the Totternhoe Stone was mapped as far west as Wantage, as shown on the published 1:50 000 Sheet 253 (Abingdon). However, in the unexposed ground near Harwell it appears to have been confused with the 'Chilton Stone' a limestone forming a positive break of slope (Section 2.3.1), and to the west placed along a spring line. In the type area in the Chilterns the Totternhoe Stone does not give rise to springs (Aldiss, 1990). Moreover, in Sussex and Hampshire the base of the Zig Zag Chalk normally coincides with a negative break of slope, although this can be very weak. During recent surveys the base of the Zig Zag Chalk (and so the inferred horizon of the Totternhoe Stone or Cast Bed) was placed at a persistent, albeit locally very faint negative break of slope, some 10 m higher in the sequence than the position of the Totternhoe Stone shown on the published map. This break of slope separates fairly steep ground underlain by the Zig Zag Chalk and more gently sloping ground which merges gradually with the West Melbury Chalk dip slope. Micropalaeontological analysis of limestone debris in soil either side of this break of slope near Wantage [405 861] and [410 856] is consistent with this interpretation (Wilkinson, 2002b).

Outcrop patterns and borehole evidence suggest that the Zig Zag Chalk could vary between 12 m and 55 m in thickness. It is overlain conformably by the Holywell Chalk.

2.3.3 Holywell Nodular Chalk

The Holywell Nodular Chalk Formation, comprising the lowest part of the White Chalk Subgroup, crops out in the northern half of the area. It typically occurs in the middle part of the main escarpment. Being relatively resistant, it tends to form its own subsidiary escarpment, with a few outliers. In the west of the area, several headwater tributaries of the River Lambourn lie in broad valleys floored by the Holywell Chalk, cut into the face of the escarpment.

The Plenus Marls, previously considered to be the topmost beds of the Lower Chalk (Table 1), are now treated as a basal member of the Holywell Chalk. They are succeeded by the Melbourn Rock, also of member status.

The Holywell Chalk is relatively lithologically varied, comprising medium hard to very hard, nodular, white to creamy white chalk with beds and laminae of clay-rich chalk (marl), including flaser-laminated marls.

The Plenus Marls Member consists of alternating beds of slightly greenish grey marls and marly limestones, resting with marked colour contrast on the eroded and burrowed surface of the Zig Zag Chalk. A standard succession of eight beds can be recognised at many localities (Jefferies, 1963). The Plenus Marls Member appears to be between 0.6 and 0.9 m thick in the Berkshire Downs. A section measured by Jefferies near Lockinge [4246 8549], but now obscured by talus and vegetation, showed the Plenus Marls as 0.82 m thick.

The resistant, poorly fossiliferous creamy white Melbourn Rock (3 to 4 m) occurs above the Plenus Marls. The upper two-thirds of the Holywell Chalk is mostly conspicuously fossiliferous: most beds contain gritty shell debris, some have mytiloid inoceramid bivalves preserved in three dimensions. The straight-shelled ammonite *Sciponoceras* is locally abundant in the lower part, and the rhynchonellid brachiopod *Orbirhynchia* is locally common throughout. In the absence of shell debris, the rather grainy texture of typical Holywell Chalk distinguishes it from the smooth chalks of the succeeding New Pit Chalk.

Foraminifera are generally rare in this formation, although species of *Gavelinella* and *Lingulogavelinella,* suggesting foraminiferal zone BGS9, have been found. The planktonic species *Whiteinella aprica* and *Dicarinella imbricata* also appear in the zone.

The Holywell Chalk commonly caps spurs and outliers in front of the escarpment, forming hard rubbly brash (rock fragments in the soil). The Melbourn Rock tends to form a distinct positive break of slope, often just above a zone of soft ground or a slight negative feature marking the Plenus Marls. In places near Wantage, a resistant bed of grey chalk high in the Zig Zag Chalk tends to form an additional distinct positive feature a few metres below the similar feature formed by the Melbourn Rock. This can be confused with the Melbourn Rock feature.

Outcrop patterns and borehole evidence suggest that the Holywell Chalk could vary between 15 m and 30 m in thickness. It is overlain conformably by the New Pit Chalk.

2.3.4 New Pit Chalk

The New Pit Chalk Formation, in the lower part of the White Chalk Subgroup, crops out in the north and west of the area, typically forming steep ground near the top of the main escarpment.

The New Pit Chalk typically comprises rather massive, blocky, soft to medium hard, smooth white chalk with regular thin marl seams and sparse smallish flints. Hard, rather gritty calcarenitic chalk occurs locally at the top of the formation, for example near Warren Down [3597 7981], perhaps reflecting local condensation of the sequence or intraformational reworking.

The New Pit Chalk is much less fossiliferous than the Holywell Chalk, and brachiopods tend to be more conspicuous than inoceramids in the lower and middle parts of the formation. In the lower part, those inoceramids which are present tend to occur as flattened moulds, lacking preserved shell. Low diversity benthonic assemblages continue up into the New Pit Chalk although *Globorotalites michelinianus* appears for the first time in foraminiferal zone BGS10. Planktonic species are more diverse and include, for example, *Marginotruncana marginata, M. pseudolinneana* and *Dicarinella imbricata* in BGS11.

The New Pit Chalk underlies steep slopes in the upper part of the Chalk escarpment. The base is marked by a distinct negative break of slope. Fragments of rock (brash) from the New Pit Chalk found in the soil tend to be smooth and rather flaggy, so are fairly easy to distinguish from the rougher, more grainy and rubbly brash characteristic of the Holywell Chalk. The New Pit Chalk is commonly quarried on a small scale.

Outcrop patterns and borehole evidence suggest that the New Pit Chalk could vary between 19 m and 46 m in thickness. Interpretation of borehole records suggests that this thickness variation is in part a consequence of intraformational erosion (Woods, 2001a). The New Pit Chalk is overlain conformably by the Lewes Chalk.

2.3.5 Lewes Chalk and the Chalk Rock

The Lewes Nodular Chalk Formation, in the middle part of the White Chalk Subgroup, crops out in the north and west of the area, typically forming steep ground at the top of the main escarpment. It is relatively resistant to erosion, forming the floor of the main valleys in the upper part of the Pang catchment, and of parts of some tributaries of the Lambourn.

The base of the Lewes Chalk is defined by the incoming of hard nodular chalk above the smooth white chalks of the New Pit Chalk (Bristow et al., 1997). This lithological change is diachronous on a regional scale, relative to both the biostratigraphy and the regionally-developed marker beds, such as the main marl seams (Mortimore et al., 2001). In this area it occurs between two to ten metres below the Chalk Rock, a member previously taken as the basal unit of the Upper Chalk (Jukes-Browne and Hill, 1904; Bromley and Gale, 1982).

The Lewes Chalk is typically composed of hard to very hard, white to creamy or yellowish white nodular chalks and chalkstones, with interbedded soft to hard gritty white chalks and common marl seams. Regular bands of nodular flint occur more commonly than in the underlying beds. An abundant and diverse molluscan fossil fauna can be found in some beds, including ammonites, bivalves and gastropods. Echinoids and brachiopods occur throughout and are also important to biostratigraphy. Low, but increasing, diversity of benthonic foraminiferal assemblages are present in the Lewes Chalk, and in the highest part *Verneuilinoides muensteri* and *Gavelinella pertusa* appear (in BGS13). Conversely, the long-ranging *Gavelinella tourainensis,* originating in the Cenomanian, is not recorded above this unit. Planktonic species present include *M. coronata,* first seen at the base of foraminiferal zone BGS12.

The Chalk Rock is a complex sequence of hardgrounds mineralised by glauconite or phosphate, each overlying a bed of chalkstone passing down into nodular chalk. Fragments of mineralised hardground can commonly be found in the soil on the lower part of the Lewes Chalk outcrop. However, it is likely that in the past the top and the base of the Chalk Rock have not been mapped consistently. Where the existing mapping of the Chalk Rock could be corroborated, or seemed reasonably accurate, it has been included in the 1:50 000 scale map which accompanies this report, in addition to the newly mapped boundary at the base of the Lewes Chalk. In the west of the area the Chalk Rock outcrop has been omitted.

The Chalk Rock has been described in detail at two localities within the Pang-Lambourn catchments (Fognam Farm Quarry [2978 7999] and Hackpen Hill, Sparsholt [349 845]) and at three other localities within the vicinity (Ogbourne St George [209 739], Ogbourne Maizey [180 716], and Harts Lock Wood [621 788]). At the type section at Ogbourne Maizey, and at Fognam Farm, the Chalk Rock is some 4.5 m thick, with five named hardgrounds and several subsidiary ones, grouped in three suites (Bromley and Gale, 1982; Mortimore et al., 2001). The lower hardgrounds fade out to the east. The Chalk Rock is 3.5 m in thickness at Banterwick Barn [5134 7750], in the east of the area, where three of the named hardgrounds are present. At Harts Lock Wood, just east of the River Thames, it is only 1.3 m thick and only two of the named hardgrounds are seen (Bromley and Gale, 1982).

The Lewes Chalk generally underlies a broad convex slope forming the top of the main chalk escarpment. The base is typically marked by a weak positive feature at the change from a uniform gradient on the New Pit Chalk to the convex slope above. The Lewes Chalk forms fairly voluminous, hard, gritty, nodular brash associated with nodular flints.

Outcrop patterns and borehole evidence suggest that the Lewes Chalk could vary between 10 m and 28 m in thickness. It is overlain conformably by the Seaford Chalk.

2.3.6 Seaford Chalk

The Seaford Chalk Formation, in the upper part of the White Chalk Subgroup, underlies most of the centre and south of the area, typically extending from the crest of the main escarpment down to where the chalk dip slope is covered by Palaeogene and Quaternary deposits.

The base of the Seaford Chalk is taken at the upward limit of nodularity and grittiness of the Lewes Chalk. This is gradational and can be difficult to locate in the field and in boreholes. The Stockbridge Rock Member, which occurs near the top of the Seaford Chalk, can be mapped in some places close to the south-western margin of the area.

The Seaford Chalk is composed mainly of soft to medium hard white chalk with common seams of small to very large flint nodules, and sporadic beds of semi-tabular flint. The flints commonly contain shell fragments, and in some cases echinoids. Carious (spongy-textured) flints are common near the base, but can also occur in the upper part of the Lewes Chalk. Otherwise, the flints are typically black to bluish-black, and mottled grey with a thin white cortex. Marl seams occur in the lowest Seaford Chalk but in general are rare. Phosphatic chalks and hardgrounds occur in the upper part of the Seaford Chalk near Boxford [4308 7195] (Jarvis and Woodroof, 1981), and might be more widespread.

Many beds within the Seaford Chalk contain macrofossils, of which inoceramid bivalves and echinoids are most significant biostratigraphically. For example, the lower part of the Seaford Chalk contains abundant fragments of the thick-shelled bivalves *Volviceramus* and *Platyceramus*, whilst the middle part contains thin-shelled, pinkish *Cladoceramus*; the echinoid *Conulus* is locally common at the top of the formation (Mortimore, 1986; Bristow et al., 1997). A more rapid increase in foraminiferal diversity is found in the Seaford Chalk, with the incoming of *Stensioeina granulata granulata* (in BGS14), *S. exsculpta exsculpta* (BGS15) and *Loxostomum eleyi* (BGS 16). Planktonic forms are less common compared to the Turonian, but long ranging species of *Marginotruncana, Dicarinella, Whiteinella* and *Heterohelix* are found, together with the first species of planispiral *Globigerinelloides*. The concurrent range of *Stensioeina granulata polonica* and *Lingulogavelinella arnagerensis* (foraminiferal zone BGS17) and the appearance of *Gavelinella stelligera* and *Gavelinella cristata* (foraminiferal zone BGS18) are characteristic of the upper part of the formation.

In the type area of Sussex, and other parts of southern England, the base of the Seaford Chalk is defined by Shoreham Marl 2, and coincides with the base of the *M. coranguinum* Zone (Mortimore, 1986; Bristow et al., 1997; Mortimore et al., 2001). Lithological, geophysical and biostratigraphical evidence from the Banterwick Barn Borehole [5134 7750], in the east of the area, shows that in the Berkshire Downs the base of the Seaford Chalk instead occurs some 10 m below the apparent correlative of Shoreham Marl 2, within the higher part of the underlying *M. cortestudinarium* Zone (Woods and Aldiss, in prep).

A bed of very hard, locally porcellanous, creamy-white chalk (the 'Stockbridge Rock') occurs in the topmost Seaford Chalk, about 5 m below the base of the Newhaven Chalk. It contains abundant sponge spicules, most commonly as moulds, together with some complete sponges. Its thickness is difficult to estimate (no exposures have been seen in the present area) but is probably about 1 m. The Stockbridge Rock occurs widely in Hampshire and Wiltshire but can be quite sporadic in its appearance

(Farrant, 1999, 2000). It occurs at about the level of Barrois' Sponge Bed and the Clandon Hardground of the North Downs (Robinson, 1986) and may equate with the Whitway Rock of the Newbury area (Sumbler, 1996).

In the old Hungerford Memoir, Osborne White (1907, p. 22) records a bed of 'very hard yellow chalk, from 3" to 18" thick [7.6 cm to 45 cm], and possessing a sharply-defined upper limit', which he thought to occur some 18 to 21 m below the top of the Seaford Chalk. It is not known if this refers to a different bed of hard chalk, lower in the succession than the Stockbridge Member, or if Osborne White's estimate was incorrect.

The Seaford Chalk typically forms the long 'dip slopes' behind the crest of the main chalk escarpment. The base can lie at a very weak negative feature, or at none at all. Brash is smooth and fine-grained, and tends to form small tablets. Flint nodules, some very large, are common and cultivated fields on the Seaford Chalk typically have piles of such flints at their margins. The Stockbridge Rock is associated with a slight positive topographic feature in places.

Outcrop patterns and borehole evidence suggest that the Seaford Chalk could vary between 55 m and 75 m in thickness. It is locally overlain conformably by the Newhaven Chalk, but more generally it is unconformably overlain by the Lambeth Group.

2.3.7 Newhaven Chalk

The Newhaven Chalk Formation, the youngest part of the White Chalk Subgroup present in Berkshire, crops out principally in four outliers in the south of the area. These outliers occupy ground standing slightly above the main chalk dip slope. They are largely covered by Palaeogene deposits. A more extensive outcrop of the Newhaven Chalk occurs within the axis of the London Basin. This occurs mainly to the south of the area here described but its northern limit is seen beneath the basal Palaeogene at Shaw [484 681], just north of Newbury (Treacher and Osborne White, 1906; Osborne White, 1907).

The Newhaven Chalk is composed mainly of soft to medium-hard, smooth white chalks with numerous marl seams and widely spaced flint bands. The marl seams normally vary between 20 mm and 70 mm in thickness but become much thinner or die out over syn-sedimentary positive tectonic features (Mortimore and Pomerol, 1987, 1991). Phosphatic chalks and hardgrounds occur in the Newhaven Chalk near Winterbourne [4477 7223] (Jarvis and Woodroof, 1981), and might be more widespread.

Many beds within the Newhaven Chalk contain macrofossils, of which crinoids and echinoids are most significant biostratigraphically. These fossils can be found in rock fragments in the soil (brash), as well as in exposed bedrock. Biostratigraphically, the Newhaven Chalk is co-extensive with the 'crinoid zones' (the Zones of *Uintacrinus socialis*, *Marsupites testudinarius* and *Uintacrinus anglicus*), together with most if not all of the *Offaster pilula* Zone. Note that in older accounts the three crinoid zones are treated together as a single '*Marsupites* Zone'. *Gavelinella cristata* rapidly increases in numbers to become the most dominant element of the benthonic foraminiferal community in the Newhaven Chalk. *Stensioeina granulata perfecta* and *Bolivinoides strigillatus* appear a little above the base of the formation, respectively in the 'mid' and late *U. socialis* macrofaunal zone. Planktonic foraminifera are of little biostratigraphical significance in this formation. However, just below the base of the Campanian, in the middle part of the Newhaven Chalk (*U. anglicus* macrofaunal zone), several species occur for the first time including *Rugoglobigerina pilula* and *Heterohelix striata*. The inception of *Bolivinoides culverensis* and extinction of *Stensioeina exsculpta exsculpta* characterises the basal part of foraminiferal Zone BGS19 (basal *O. pilula* macrofossil Zone).

A clay pit at Shaw [4837 6805] once exposed about 2.5 m thickness of chalk of the *Uintacrinus* Zone (Osborne White, 1907). The extent of the crinoid zones beneath Palaeogene cover east of Newbury is not known.

The base of the Newhaven Chalk is defined by the incoming of common marl seams above the flinty marl-free chalks of the Seaford Chalk (Bristow et al., 1997). In practice this is taken at the incoming of a particular assemblage of bioclastic debris (mainly comprising indeterminate crinoid brachials and thin-shelled oysters, but including calyx plates of *U. socialis*). These changes in the lithological assemblage commonly coincide with a negative break of slope (although this is exceedingly slight in some areas), assumed to mark a persistent marl seam. This break of slope is not always present, especially if the boundary occurs close to the base of the Palaeogene.

Outcrop patterns suggest that up to about 14 m of the Newhaven Chalk is present in the outliers around Boxford and Winterbourne. More than 40 m could be present in boreholes to the south of the area. The Newhaven Chalk is unconformably overlain by the Lambeth Group.

2.4 PALAEOGENE

2.4.1 Lambeth Group

The Lambeth Group, of Palaeocene age and the oldest Palaeogene unit present in the Berkshire Downs, crops out in the south-eastern third of the area. Together with the overlying formations, it forms an escarpment standing conspicuously above the main chalk dip slope. This escarpment tends to be wooded, in marked contrast to the open fields of typical chalk downland. There are several outliers of the Lambeth Group, but the largest outcrop continues south of the area into the axis of the London Basin.

Regionally, the Lambeth Group includes a thin basal unit, the Upnor Formation (previously known as the Bottom Bed), but in the western part of the London Basin is mostly made up of the Reading Formation (Ellison et al., 1994). It is not practical to differentiate the Upnor Formation from the Reading Formation except in exposed sections, and so on the map they are shown together. In the northern part of the outcrop in the present area, the Upnor Formation is apparently absent and the Reading Formation rests directly on either the Seaford Chalk or the Newhaven Chalk.

The Upnor Formation consists of highly glauconitic, green, blue and grey sands and clays. It contains large, irregular, glauconite-coated flint nodules and flint pebbles at the base, resting on a locally irregular, bored Chalk surface. It also contains a varied marine fauna. It is generally less than 1 m in thickness (Mathers and Smith, 2000) but some 2.2 m were observed in sections on the line of the A34(T) Newbury bypass (BGS unpublished records). Elsewhere in the area, the presence of the Upnor Formation can locally be demonstrated by the occurrence of glauconitic sandy clays ploughed up from the subsoil but as such material becomes more rarely seen northwards of about Northing 172, it is likely that the Upnor Formation has been overstepped in that direction by the Reading Formation.

The Reading Formation is made up predominantly of colour-mottled clays: mainly red and grey, but also purple, brown and orange. Beds of grey, buff, or orange-coloured, fine- to medium-grained sands are also present. These are commonly up to 2 m thick, but locally attain as much as 7 m. These sand beds occur at all levels but especially near the base: the sequence is laterally variable. The sand is locally cemented by silica, forming an intensely hard sandstone. Fragments of such sandstone commonly occur in soils and in some superficial deposits on the Chalk of the area: these fragments are known as sarsens. Fossil leaves, lignite and silicified wood also occur in the Reading Formation.

The Upnor Formation and parts of the overlying Reading Formation tend to be impervious, so that solution hollows occur at the margin of the Palaeogene outcrop. Springs can occur at the sand beds in the Reading Formation.

Outcrop patterns and borehole evidence suggest that the Lambeth Group varies between about 20 m and 30 m in thickness. It is conformably overlain by the London Clay Formation.

2.4.2 London Clay Formation

The London Clay Formation, of Eocene age, crops out in the south-east of the area. There are several small outliers of the London Clay, but the largest outcrop continues south of the area into the axis of the London Basin.

The London Clay is underlain by the Harwich Formation, previously recognised as its ‘Basement Bed’ (Ellison et al., 1994). In the Reading district, the Harwich Formation is less than 10 m in thickness. It has not been mapped separately from the London Clay (Mathers and Smith, 2000). The same practice is followed in this report, and on the accompanying map.

The Harwich Formation is up to 6 m in thickness in the east of the present area. It comprises a basal flint pebble bed overlain by highly glauconitic shelly sands and clayey silts. These are intensely burrowed, and locally cemented. The formation can appear intergradational with the Reading Formation where the latter is sandy. Springs occur at the Harwich Formation outcrop.

The London Clay comprises blue-grey silty clays and clayey silts with subordinate glauconitic sands and pebble beds in coarsening-upwards cycles, each with a basal pebble lag. The clay weathers to a rusty brown colour. Calcareous concretions and pyrite nodules occur. The London Clay contains a shelly marine fauna.

Outcrop patterns and borehole evidence suggest that the London Clay Formation could vary between about 20 m and 50 m in thickness, with a fairly abrupt westwards diminution occurring in the vicinity of Thatcham. It is conformably overlain by the Bagshot Formation.

2.4.3 Bagshot Formation

The Bagshot Formation, of Eocene age, crops out in a group of outliers in the extreme south-east of the area. It comprises the oldest part of the Bracklesham Group, and is the only component of that unit present in the area.

The Bagshot Formation is made up of fine-grained sands with subordinate thin lenses or beds of silt or clay. The sands are typically yellow-brown and grey in colour, varying to white or brownish-red. They are plane-bedded or cross-stratified, quartzose, micaceous and locally glauconitic. The base is marked by a discontinuous bed of black flint pebbles on a sharp, possibly erosive contact.

Springs occur at the base, and can occur at higher levels if there are clay beds.

Outcrop patterns and borehole evidence suggest that the Bagshot Formation ranges up to about 20 m in thickness. It is the youngest bedrock formation seen in the area.

3 Superficial geology of the Pang-Lambourn catchment

3.1 ARTIFICIAL DEPOSITS AND WORKED GROUND

3.1.1 Worked Ground

Two broad categories of Worked Ground are represented in the area: engineered cuttings and mineral workings.

Engineered cuttings are found on the lines of most major roads, and of railway lines. Disused railway lines lie between Didcot and Newbury (via Chilton, Hampstead Norreys and Shaw), and in the Lambourn Valley. The latter once had a branch line leading to RAF Welford.

Pits and quarries, mostly small and mostly disused, were opened for a variety of mineral commodities: chalk, flint, building stone, sand, gravel, clay and peat.

In addition to open workings, some chalk was extracted by underground working. This mode of working typically involved the sinking of a shaft (or 'chalk well') about 1 m to 1.5 m in diameter and 5 m to 20 m deep, and the excavation of inclined 'headings' or adits from the base of the shaft. This enabled fresh, unweathered chalk to be won for lime burning or for spreading on agricultural land to ameliorate clay-rich or acidic soils. Such shafts might be sunk into the Chalk through a thin cover of superficial deposits such as clay-with-flints, or of the Lambeth Group (Osborne White, 1907, p. 116). It is supposed that gradual subsidence at the site of such excavations, even after backfilling, would lead to the formation of a closed depression of similar appearance to a natural doline (Section 3.4).

3.1.2 Made Ground

Made Ground refers chiefly to engineered embankments on the main roads, and on railway lines. Considerable use of locally excavated material was made in the construction of screening embankments along the A34(T) Newbury bypass (Perry et al., 2000). Made ground also occurs within some archaeological sites.

3.1.3 Infilled Ground

Areas delineated as Infilled Ground are mostly either disused mineral workings or disused railway cuttings in which waste material has been deposited. The nature of the fill and the degree to which it has been compacted are generally unknown.

3.1.4 Landscaped Ground

Areas which are known to include Worked Ground or Made Ground or both, in some cases together with Infilled Ground, but where these categories cannot be reliably recognised or delineated, have been categorised as Landscaped Ground.

3.2 MASS MOVEMENT AND RESIDUAL DEPOSITS

3.2.1 Landslip

Several previously unrecorded landslips have been observed during the recent geological surveys in the area. These all occur in the south, on relatively steep slopes underlain by the sands and clays of the Reading Formation. They are presumably all associated with the emergence of water from minor perched aquifers within the Palaeogene sands. These landslips are generally of translational type. They typically underlie areas up to 150 m wide and 500 m long, marked by irregular, ill-drained hummocky ground.

3.2.2 Head

'Head' refers to superficial deposits formed by solifluction processes: mainly down-slope mass movement of unconsolidated materials under the prolonged influence of freezing and thawing in a periglacial environment, but including rain wash and soil creep in more temperate climatic conditions.

Head occurs on some slopes and in valley floors throughout the area. It tends to be more widespread on slopes facing east or north. It is assumed to have formed gradually during the successive Quaternary glacial periods, presumably most recently during the Devensian, and to be of fairly uniform age irrespective of topographic situation.

Head is very variable in composition depending on local sources of material and details of landscape evolution. It is typically composed of very stony, sandy and silty clays, or clayey gravels. It can be clast-supported or matrix-supported. It tends to include a large proportion of angular, frost-shattered flint gravel.

In much of the area head has been derived from the clay-with-flints and the Chalk, in many places together with sand and water-worn flints from river terrace deposits. These heads are composed of diamicton, more or less stony, but predominantly matrix-supported. In comparison with the clay-with-flints, this head has undergone lateral movement, and tends to be more sandy, with a greater proportion of shattered flints. It can be derived from (and overlie) clay-with-flints but it commonly includes admixed material from other deposits as well. It is locally separated from the clay-with-flints by a break of slope, but elsewhere a clear boundary cannot be recognised.

Head with a large proportion of material derived from river terrace deposits gives rise to conspicuously gravelly soils, but such head deposits lack the characteristic flat-topped landforms (Section 3.3.3).

Head composed of clayey sand, with little admixed gravel, occurs on parts of the Palaeogene outcrop. Such deposits can be difficult to distinguish with certainty from landslip. Head on the scarp face tends to have a large proportion of chalk fragments, together with broken flint and perhaps some clay.

Head which occurs in the steeper, upstream parts of dry valleys on the Chalk outcrop is assumed to be composed of a similar diamicton to that found on adjacent slopes. The downstream sections are expected to be underlain by more flinty deposits, perhaps including coarse, clast-supported gravels containing fragments of both flint and chalk. The near-surface layers of such a deposit can be expected to have been decalcified by the passage of water, leaving a flint gravel. 'Valley-bottom head' of this type is thought to pass imperceptibly downstream into river terrace deposits, as the influence of fluvial processes predominates over that of solifluction.

3.2.3 Clay-with-flints

Clay-with-flints occurs on interfluves within the Seaford Chalk outcrop. It is typically composed of orangish brown or reddish brown clays and sandy clays containing abundant matrix-supported flint nodules and pebbles. These clays are thought to be predominantly *remanié* deposits derived mainly from Palaeogene sequences and by dissolution of the Chalk. It is recognised that these deposits have been modified by periglacial processes but they are thought to have undergone little lateral movement compared with head. Thus the base of the clay-with-flints can be expected to correspond to the original basal Palaeogene transgressive surface. However, the contact with the underlying Chalk is typically of extremely irregular shape, as a consequence of dissolution by groundwater.

Three main types of flint are present in typical clay-with-flints, in variable proportions. These are: recognisable nodules of the same types found in the Chalk, although more or less broken; 'Tertiary pebbles', that is very well-rounded, subspherical flint pebbles derived from Palaeogene deposits, typically with crescentic chatter-marks, ranging up to cobble size; and angular shards of frost-shattered flint. The clay-with-flints often also includes fragments of hard sandstone (sarsen) and ironstone derived from Palaeogene deposits.

Clay-with-flints can be expected to pass laterally into undisturbed Palaeogene deposits with a complex intergradation, perhaps over a broad area. By way of simplifying this relationship, in places the clay-with-flints has been shown with a narrow overlap on the Reading Formation.

3.2.4 Sand in clay-with-flints

In the area between Hermitage, Chieveley, Beedon and Hampstead Norreys, the clay-with-flints appears to pass laterally into clean, medium to fine-grained sands, here classified as 'sand in clay-with-flints'.

The nearby outcrops of the Lambeth Group include relatively thick beds of sand. As mapped, these coincide with relatively upstanding ground, whereas the 'sand in clay-with-flints' forms a low-lying blanket over the Chalk. Otherwise, in the absence of exposures, this category of superficial deposit cannot be distinguished from the in situ Palaeogene sequence; indeed, part or all of what has been shown as 'sand in clay-with-flints' may comprise essentially undisturbed Lambeth Group sands.

3.3 ORGANIC AND FLUVIAL DEPOSITS

3.3.1 Peat

At Newbury and for some distance upstream, the flood-plain deposits of the River Lambourn and the River Kennet are dominated by peat. Osborne White (1907) notes that this is a black or dark-brown deposit consisting of decomposed moss, sedge, and bracken, with the leaves and branches of alder and other trees. It ranges in thickness to more than 4.5 m. During the 18th and 19th centuries, the peat near Newbury was extensively dug and burnt; the ash being used as fertiliser. In addition, much of the floodplain has been modified by drainage works, sluices and the like.

In addition, unmapped deposits of peat are known to be present within the alluvium. For example, site investigation boreholes on the line of the M4 demonstrated the presence of several metres of peat within the River Lambourn floodplain.

3.3.2 Alluvium

Alluvium comprises the predominantly fine-grained valley-floor deposits (including silt, clay, shell marl, peat and tufa) closely associated with modern streams, and underlying their flood plains. It can include gravel lenses and commonly has a basal gravel lag, or overlies gravelly river terrace deposits.

Alluvium can be expected to pass upstream into river terrace deposits (as in the Pang valley) or head.

3.3.3 River Terrace Deposits

River terrace deposits occur widely in the east and south of the area. They were laid down predominantly during periods of cold climate in the Quaternary. The older ones, dating from the Anglian and older Quaternary times, were deposited by rivers following somewhat different courses to the modern ones. These deposits occur at various levels on interfluves. Post-Anglian terraces follow present-day river valleys. The youngest, the First Terrace, was deposited in the floor of the modern valleys at a time of lower sea-level than at present. It is generally overlain by post-glacial alluvium and associated deposits including peat.

Occurrences of river terrace deposits in the east of the area, within the Reading district, have been classified according to the separate schemes in use for the Thames valley and the Kennett Valley (Table 2). Those occurring in the rest of the area remain undifferentiated.

The river terrace deposits typically comprise gravels and pebbly sands, commonly clayey. Flints (and clasts of other rock types) tend to show signs of being water-worn. These deposits can be expected to pass upstream into head.

The older terrace deposits have been extensively dissected by subsequent erosion of the river valleys to progressively lower levels. Those remnants which have escaped erosion will have undergone cryoturbation and solifluction during the periods of cold climate following their deposition. These processes led to a gradual degradation of the original landform as their component material is reworked into head, or into younger river terraces. In general, if a gravelly deposit retains a recognisable 'terrace' landform, with a flattish top and a base at a reasonably consistent level, it has been mapped as a 'terrace'. Otherwise similar gravelly deposits with no associated terrace landform have been mapped as head (Section 3.2.2).

Much information on the river terrace systems around Reading is given by Bridgland (1994), Gibbard (1982, 1985) and Mathers and Smith (2000).

3.4 DISSOLUTION HOLLOWS

Closed topographic depressions are common in parts of the south and east of the area, particularly close to where the Chalk is overlain by the Lambeth Group, or by clay-with-flints. The depressions occur both on the outcrops of the Chalk and of the overlying deposits.

These depressions are typically in the range 25 m to 50 m in diameter and from 1 m to 10 m deep, being generally either circular or oval in plan, and saucer or cone-shaped in vertical section. The amalgamation of contiguous hollows can lead to the formation of larger structures of more complex shape.

The largest and deepest of these structures occur at the base of the Lambeth Group, penetrating the top of the underlying Chalk. These act as sinks for minor streams draining the Palaeogene outcrop. However, most such depressions (including the smaller, shallower ones) have no afferent drainage channels, and many occur in otherwise fairly level ground on interfluves. In general, these are interpreted as dolines, or dissolution hollows, marking the site of gradual dissolution or collapse of the underlying chalk. Excavations which intersect such structures show they are typically infilled by clay-with-flints, perhaps with recognisable remnants of Palaeogene deposits.

Some dolines may have been enlarged by small-scale working for chalk, clay or sand. Indeed, some closed depressions shown as dolines on the accompanying map may instead mark the sites of 'chalk-mining' (Section 3.1.1).

4 Geological structure of the Pang-Lambourn catchment

4.1 STRUCTURAL SETTING

The project area is underlain at depth by Precambrian and Palaeozoic formations, including part of the coal-bearing Berkshire Carboniferous depositional basin (Allsop et al., 1982; Foster et al., 1989; Sumbler, 1996; Mathers and Smith, 2000). The area lies at the southern edge of the London Platform, part of the Variscan foreland, with the northern limit of late Carboniferous Variscan deformation in the extreme south. Within the Variscan foldbelt, deformation caused extensive north-vergent folding and thrusting of the Palaeozoic sequences, including the formation of east-west striking high-angle reverse faults or thrusts at depth in the vicinity of Newbury. North of the Variscan front, there was broad large-scale folding but the region was otherwise relatively little affected (Sumbler, 1996; Peace and Besly, 1997).

The area lies just north of the Wessex basin, a post-Variscan depositional basin that extends across central southern England and adjacent offshore areas. Faults on the northern margin of the basin are marked by monoclinal folds in the Chalk to the south of Newbury formed during Cenozoic structural inversion of the Wessex Basin (Hawkes et al., 1998; Underhill and Stoneley, 1998). The east-west trending axis of the synclinal London Basin, which also formed at this time, passes just south of Newbury. The Pang-Lambourn area thus lies on the northern limb of the London Basin syncline, near the western end of the basin.

4.2 BEDDING ORIENTATION

There are very few bedrock exposures anywhere in the area. Even if a reliable estimate of dip could be made at such an exposure, it would be only of local significance. Therefore the following observations of bedding orientation in the Chalk are based on a three-dimensional computer model (Figures 5 - 8). This model was created from lithostratigraphic interpretations of geophysical logs from approximately 60 boreholes (Figure 9). The derivation of lithostratigraphic interpretations of the Chalk from borehole logs of resistivity and natural gamma is described by Woods (2001a). These data were used to model surfaces representing the base of each of the Chalk formations, together with the base of the Palaeogene. Outcrop patterns from the previously published maps were used to control the intersection of these modelled geological surfaces with the digital terrain model representing the ground surface.

Structure contours for the surfaces representing the base of the Lewes Chalk, the base of the Holywell Chalk and the base of the West Melbury Chalk are shown in Figures 6, 7 and 8. The surface model for the base of the Lewes Chalk (Figure 6) is considered to give the best overall impression of the local structure, as it is based on a larger number of data points than the others. Moreover, identification of the Chalk Rock in borehole logs (either by the original drillers or in subsequent interpretations) is probably more reliable than for any other horizon in the Chalk.

The regional dip direction is generally towards the south-south-east (N155º). In the south-east of the area, this changes to a more southerly direction (N180º), normal to the axis of the London Basin syncline. The amount of regional dip generally varies between about 0.5º and 1º, locally increasing to as much as 2º. An east-west trending zone of very low and locally reversed dips occurs near the centre of the area, apparent from closed contours on the successive surfaces (Figures 6, 7, 8), and by the very gentle fold pair at about 13000 metres on Section 3, for example (Figure 10). This zone dies out to the east and, probably, to the west.

Various medium-scale and small-scale perturbations are superimposed on this overall pattern. Medium-scale variations are expressed by local changes in strike direction, reflecting offsets between adjoining sections of the surface. Within the resolution of the model, these offsets apparently persist through successive layers, indicating a series of north-west to south-east trending zones of displacement (Lines A to D on Figures 6, 7 and 8). The density of data available is insufficient to show whether these offsets reflect fault zones, or gentle monoclinal folds. No coincident faulting has been demonstrated at outcrop, and so gentle folding is the preferred interpretation. This is indicated between 20000 and 22000 metres on Section 4, for example (Figure 10).

Two of these zones (marked by Line A and Line D) appear to mark the limits of the zone of gentle east-west folding in the centre of the area, suggesting a constraining influence by underlying fault structures (Section 4.3).

The significance of the small-scale perturbations in the modelled surface is difficult to assess: they appear to reflect either local structures or changes in formation thickness which cannot be delineated from the available data.

One synclinal axis is shown on the map face. This trends east-north-east to west-south-west across the outliers of Newhaven Chalk between Boxford and Winterbourne. There is no apparent expression of this structure at the base of the Lewes Chalk.

4.3 FAULTING AND JOINTING

Few faults have been noted during geological surveying of the area. Those that are shown on the map trend either north-east to south-west or east-north-east to west-south-west. The larger ones downthrow to the south-east, by between 5 m and 10 m. However, detection of small- to medium-scale faulting in unexposed ground is not always possible, especially where (as in this area) the bedrock units are relatively thick and superficial cover is extensive. Although small faults would be apparent in exposed sections, they could remain undetected or equivocal even during detailed field survey of unexposed ground. Therefore faulting could be more common than apparent from the map.

It was suggested in the previous section that there is a series of very gentle north-west to south-east trending monoclinal folds in the Chalk of this area. Folds of this kind are likely to form above faults in the underlying formations, and to be marked by zones of enhanced fracturing within the Chalk. Such zones could include faults with displacements of up to, say, 5 m, which would be undetectable by field survey.

Tectonically controlled thickness variation within the Chalk is known from other areas of southern England (Mortimore and Pomerol, 1991), and might be found in the Berkshire Downs. Faulting in the pre-Cretaceous formations could have been active during Cretaceous sedimentation, so inducing local thickness variations. For example, recent mapping has shown a marked change in thickness in the Upper Greensand from about 9 m just west of Wantage to about 40 m just to the east of that town. This approximately coincides with a marked reduction or local disappearance in the glauconite sand at the top of the Upper Greensand. To the west of this line, the outcrop patterns in the Chalk change, reflecting marked changes in the topography: in general the Chalk escarpment becomes steeper. These changes might be controlled by faulting in a zone aligned with Line B on Figure 6, with downthrow to the north-east. The occurrence of phosphatic chalks and hardgrounds in the Chalk near Boxford and Winterbourne (Sections 2.3.6 and 2.3.7) might also reflect proximity to this structure.

To the north of the area, Line B is aligned with faults near Faringdon, which appear to have locally controlled the distribution of Lower Greensand strata (British Geological Survey, 1971; Ruffell, 1998), although these strata are preserved to the south-west of the fault zone, implying contemporary downthrow in that direction. The Berkshire Syncline, which preserves Carboniferous strata at depth beneath the Berkshire Downs, is elongated in a north-west to south-east direction (Allsop et al., 1982; Foster et al., 1989), possibly reflecting structural control by deep-seated fault zones.

It is assumed that linear valleys within the Chalk outcrop reflect zones of relatively dense jointing, although not necessarily accompanied by significant faulting. Identification of linear trends on digital terrain models of the area suggests there is a dominant fracture set oriented north-west to south-east. Fracture sets of this orientation appear to control the linear Lambourn valley, and linear valleys extending south-east from Chilton, Aldbourne and Yattendon, for example. Fracture systems of this orientation are widely developed in the Chalk of southern England (Bevan and Hancock, 1986). Subsidiary fracture sets in the Pang-Lambourn area are indicated by linear landscape elements oriented north-east to south-west and north-south.

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Figure 1: Location of the Pang-Lambourn area

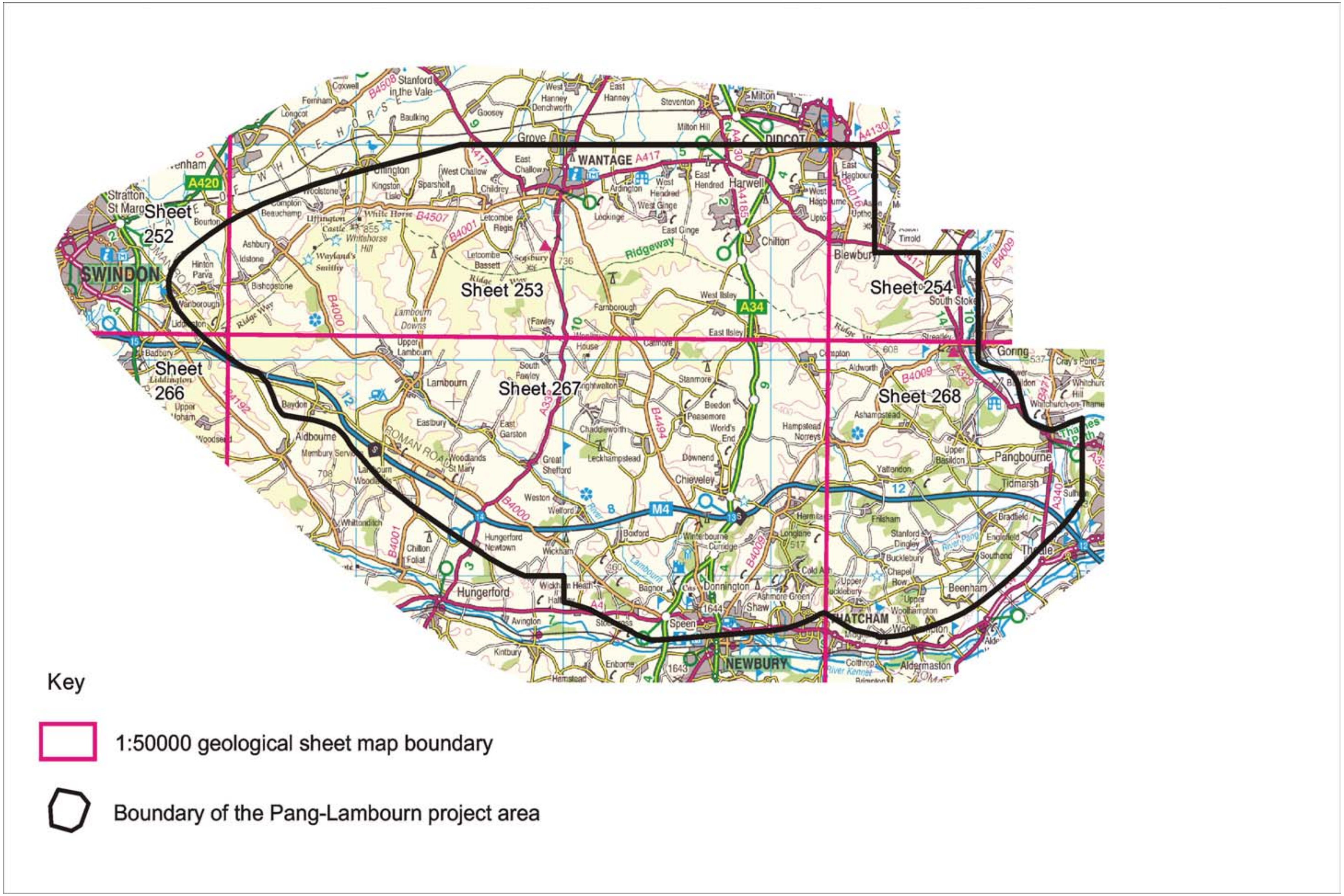


Figure 2: Topographic relief of the Berkshire Downs area

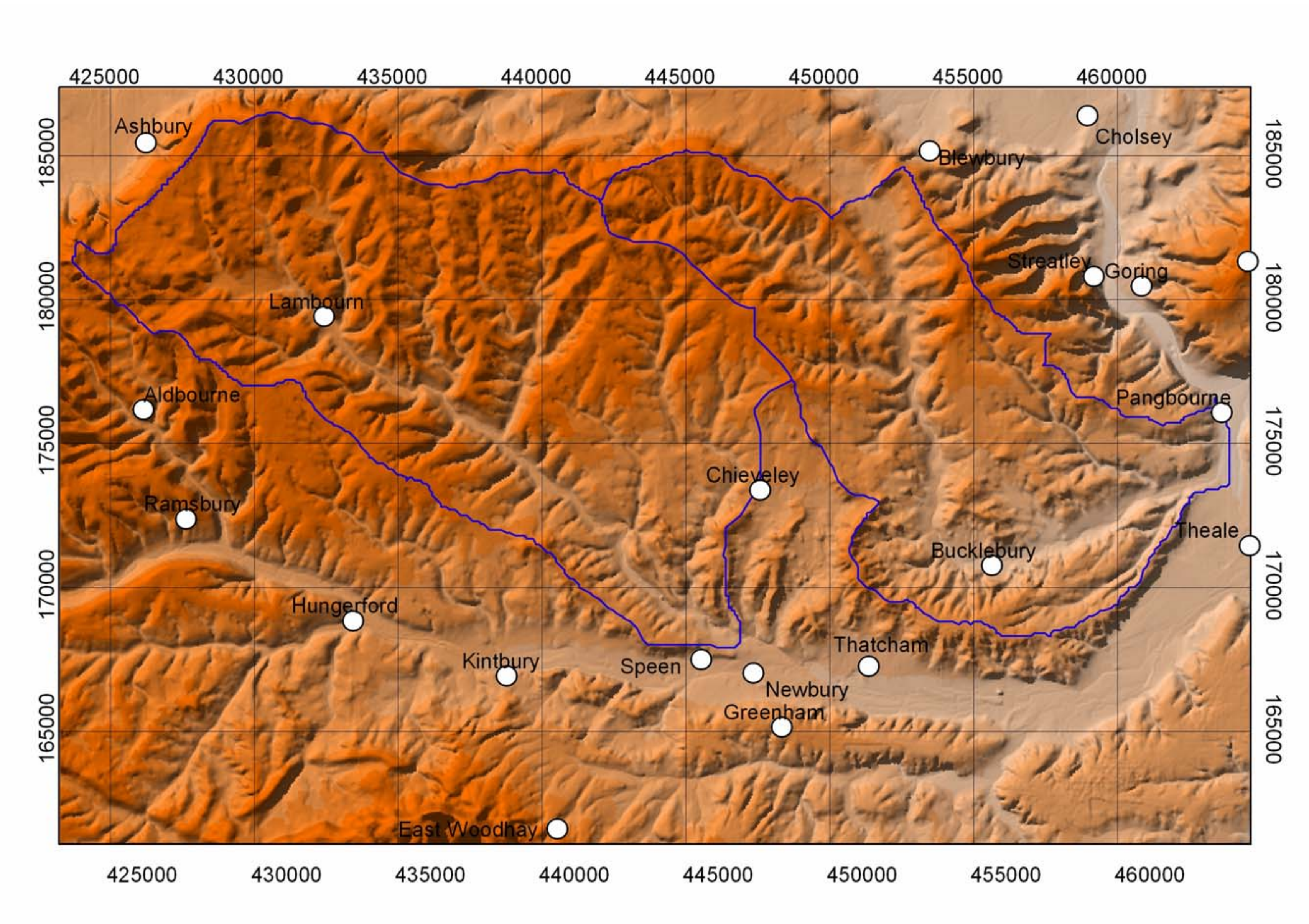


Figure 3: Solid geology of the Pang-Lambourn area

For Legend see page following Figure 4

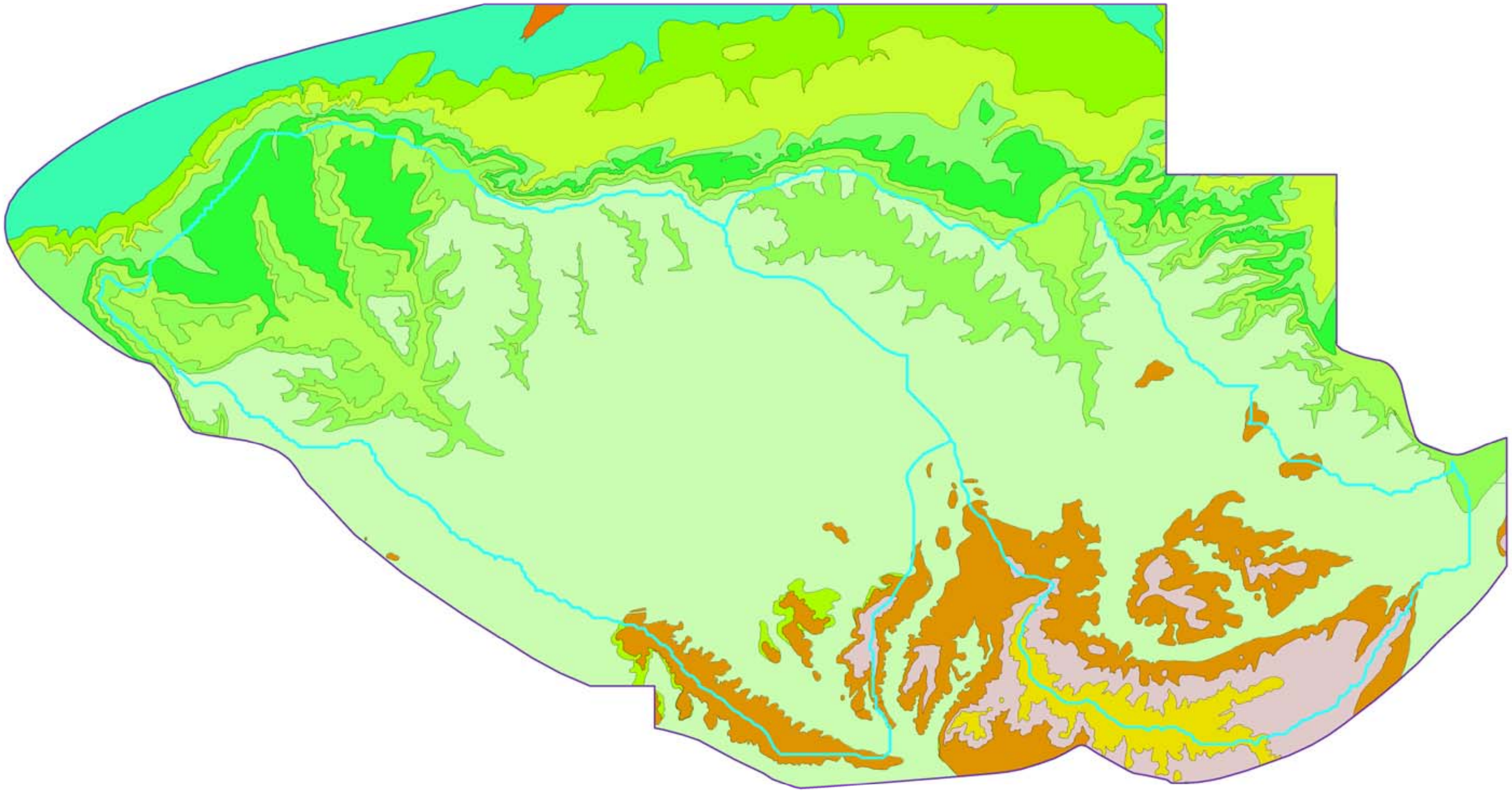
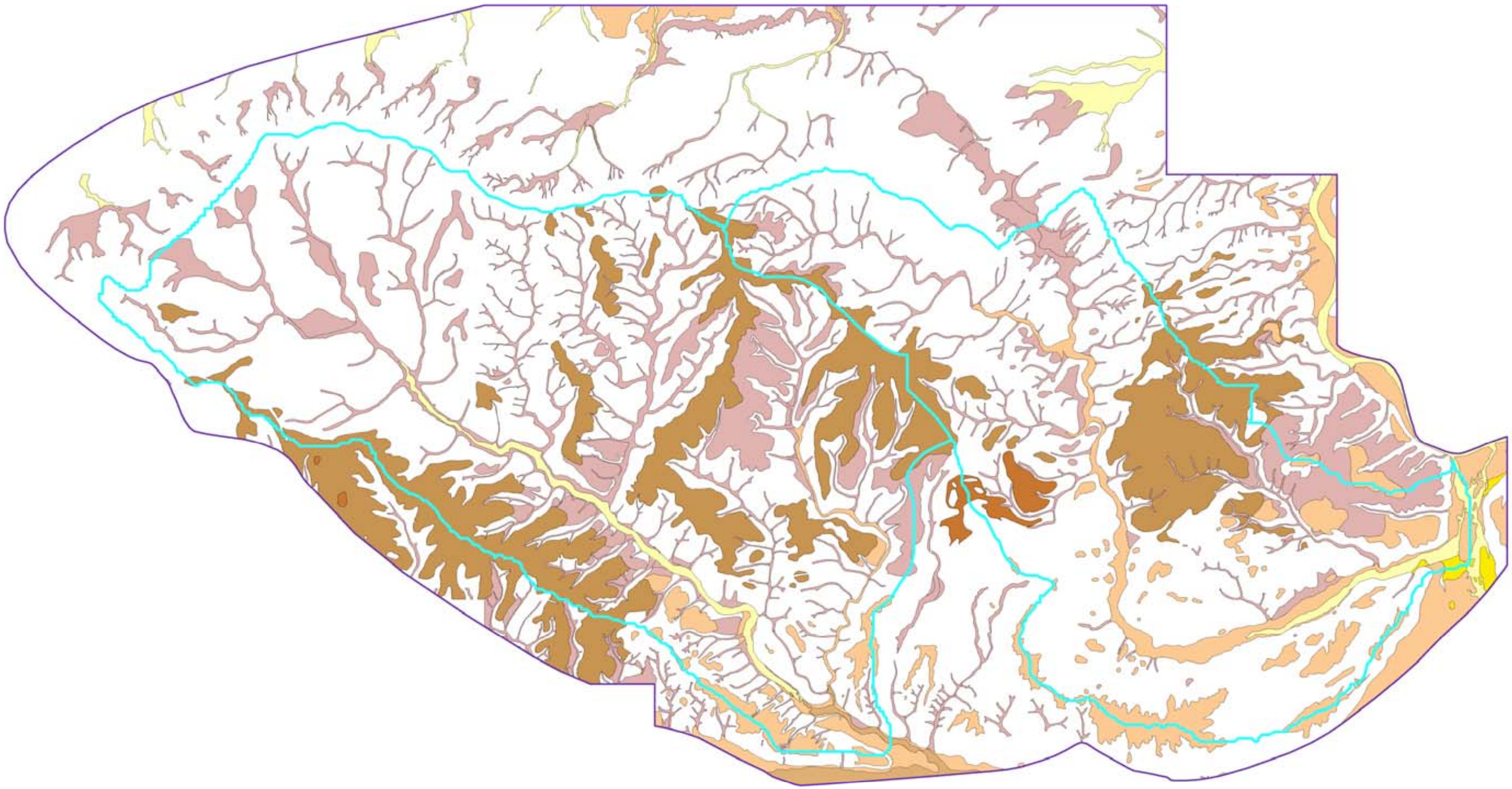


Figure 4: Superficial geology of the Pang-Lambourn area

For Legend see following page



Key to Figures 3 and 4

Figure 5: 3D perspective view of the Pang-Lambourn area

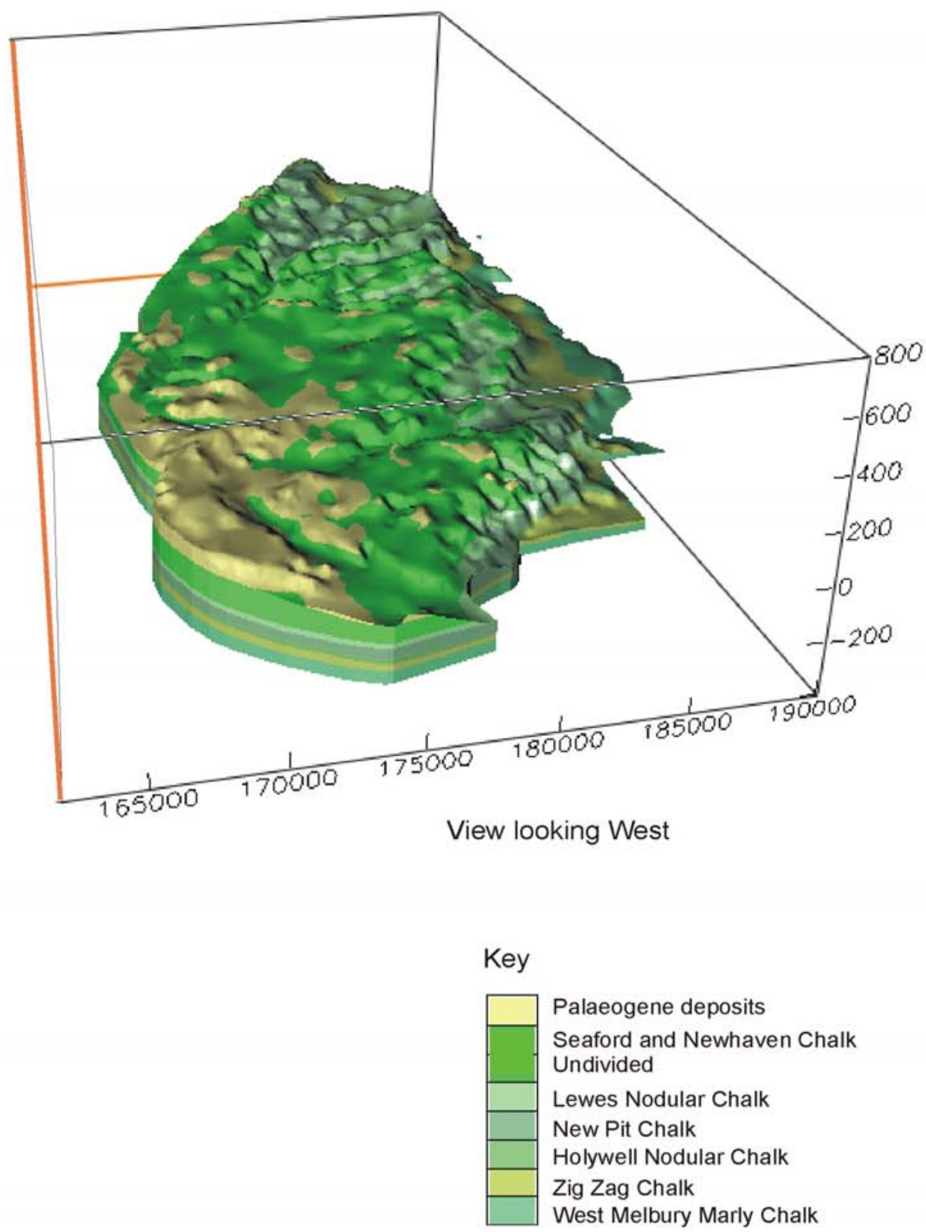


Figure 6: Structure contours on the base of the Lewes Chalk Formation

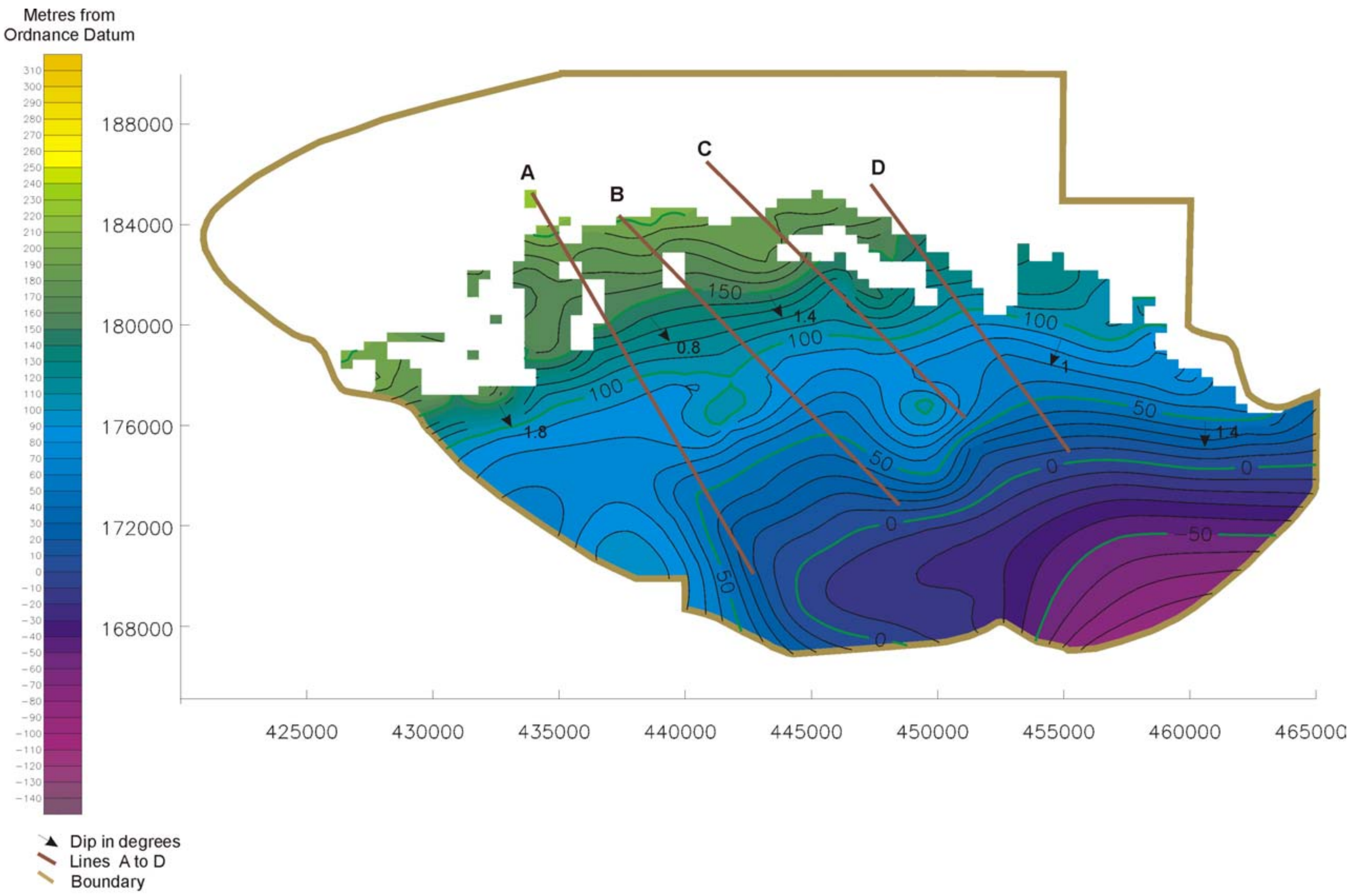


Figure 7: Structure contours on the base of the Holywell Chalk Formation

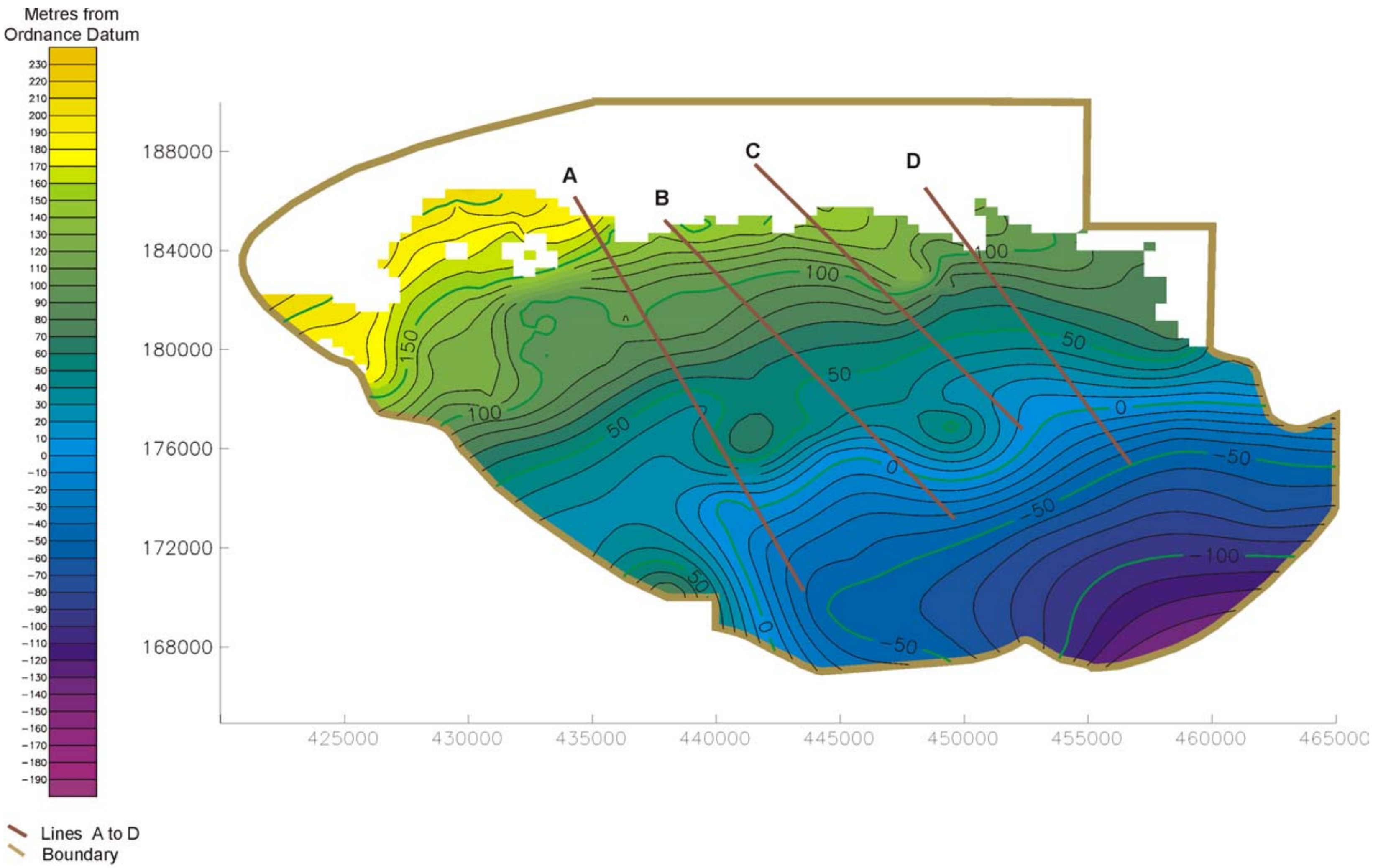


Figure 8: Structure contours on the base of the West Melbury Marly Chalk Formation

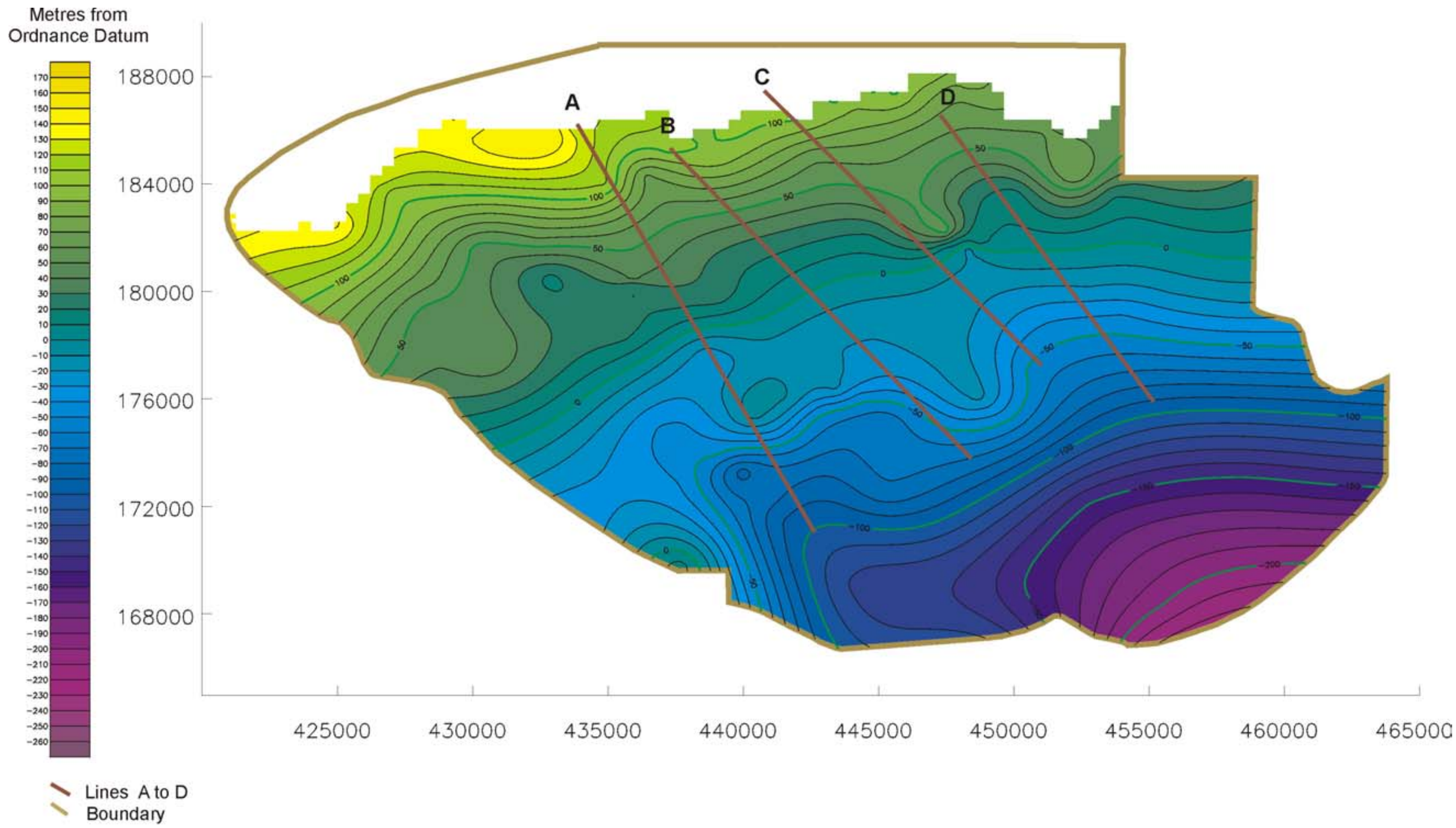


Figure 9: Distribution of boreholes and location of cross-sections

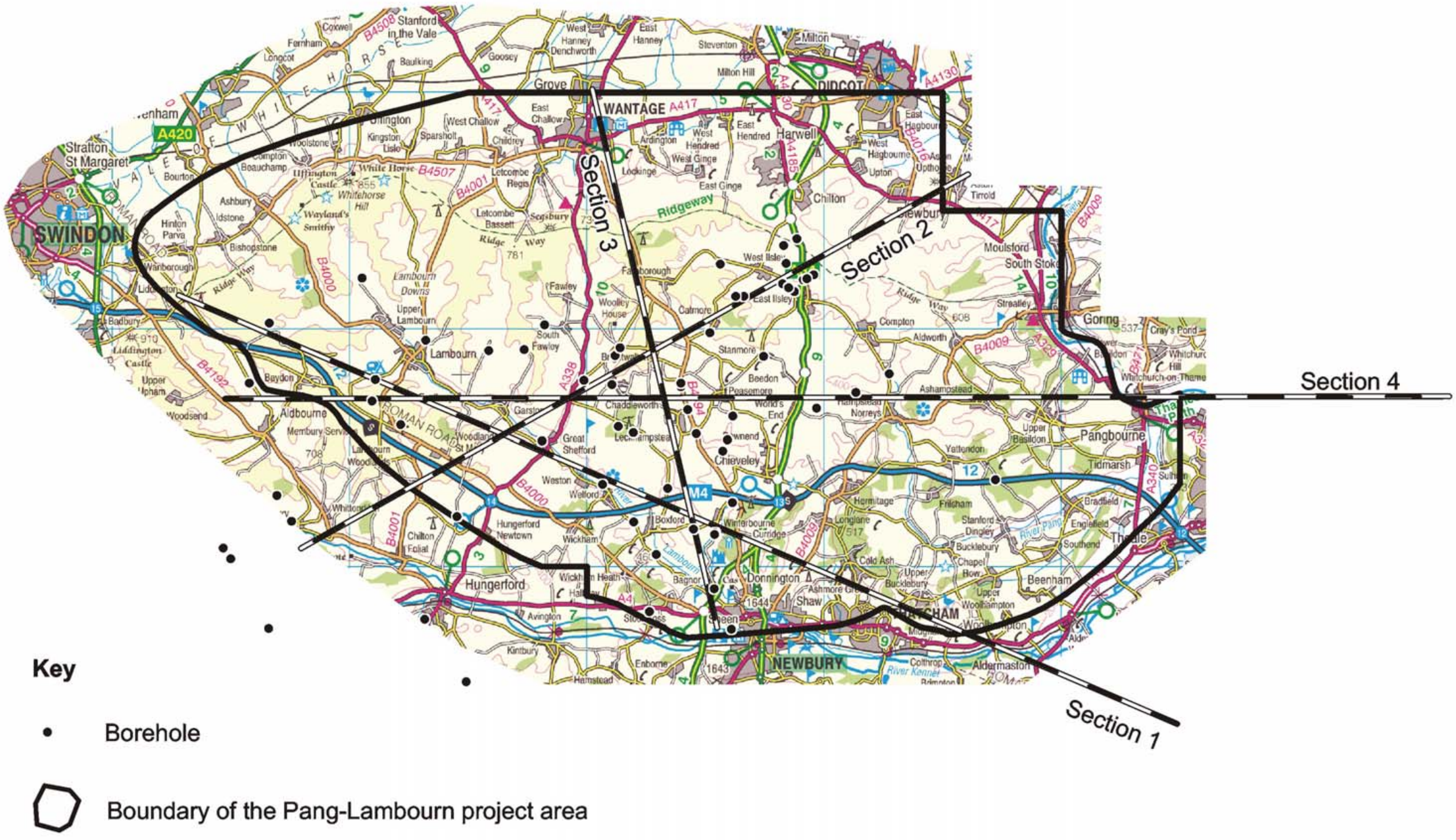
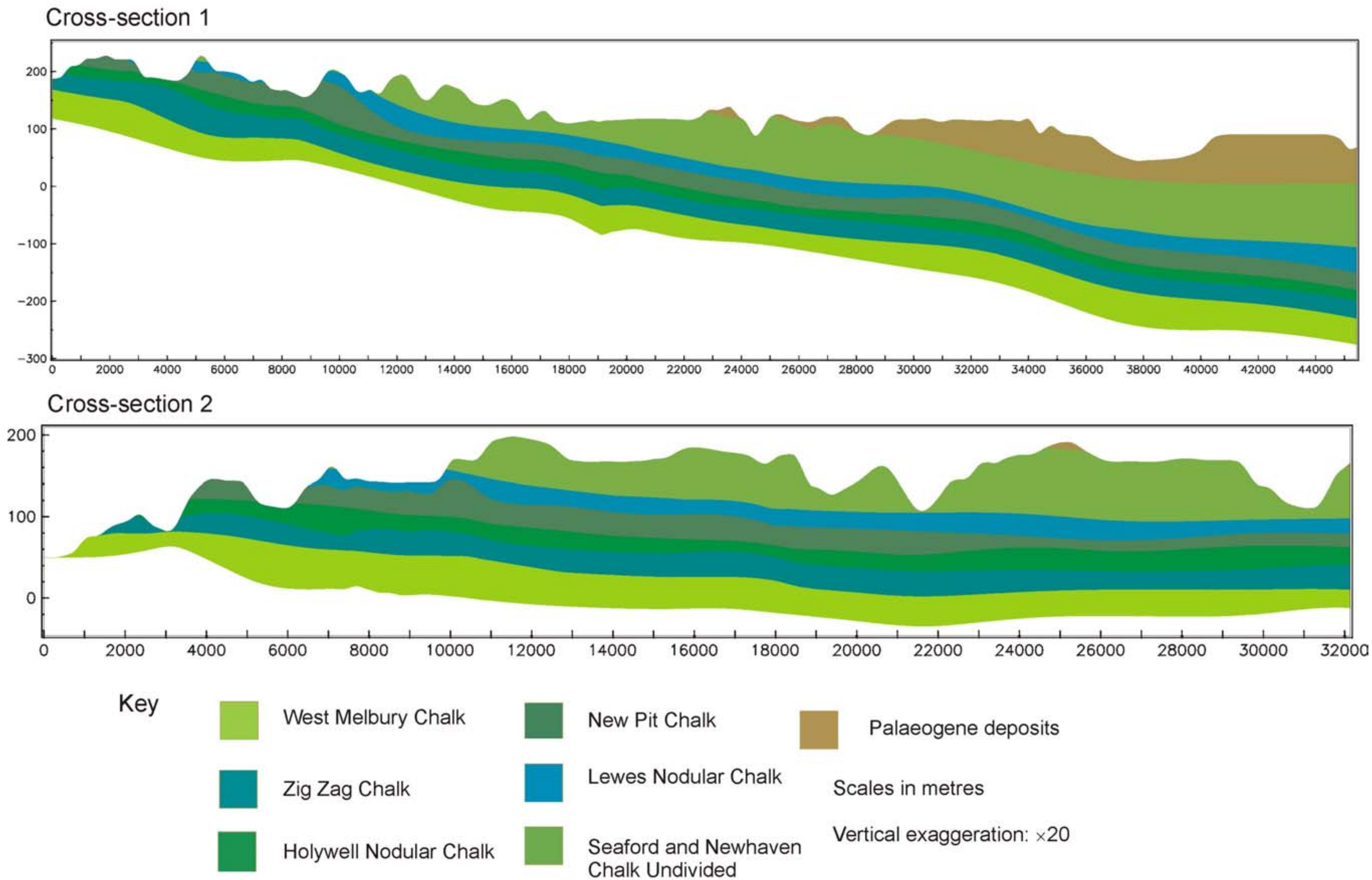
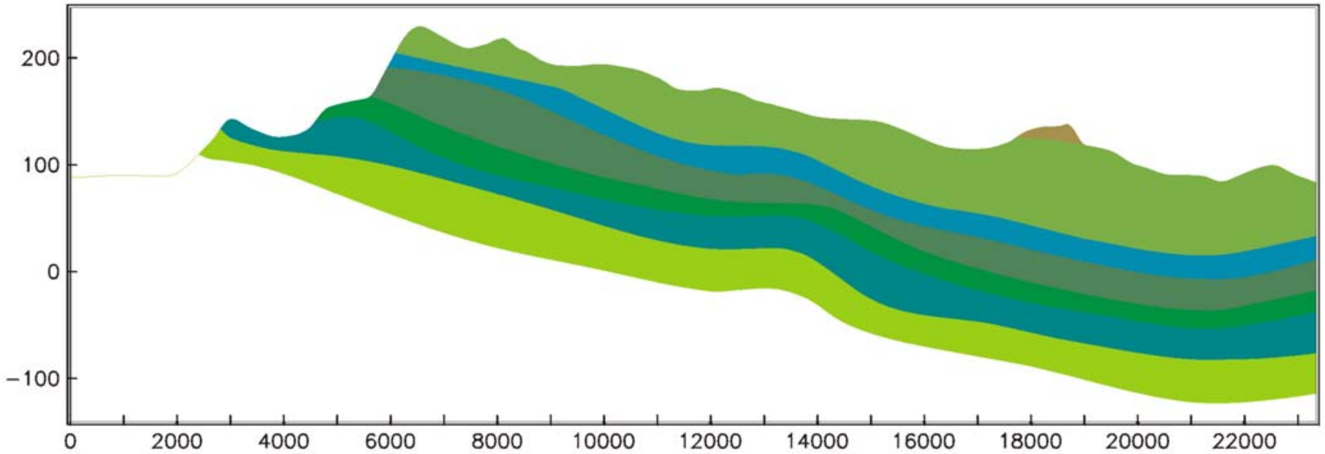


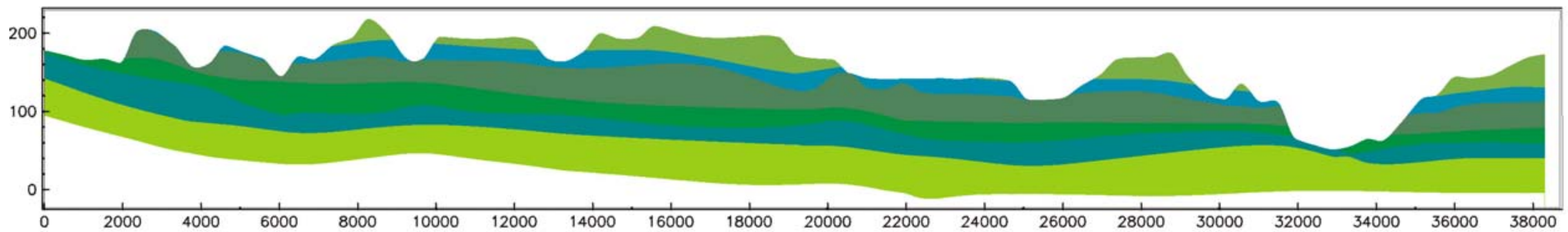
Figure 10: Cross-sections through the Pang-Lambourn area



Cross-section 3



Cross-section 4



Key

- West Melbury Chalk
- Zig Zag Chalk
- Holywell Nodular Chalk
- New Pit Chalk
- Lewes Nodular Chalk
- Seaford and Newhaven Chalk Undivided
- Palaeogene deposits

Scales in metres

Vertical exaggeration: ×20

Table 1: Correlation of biostratigraphical and lithostratigraphical classification schemes for the Chalk of southern England

Stage	Foraminiferal Zones* 1980 / 1977	Foraminiferal Zones* UKB	Foraminiferal Zones* BGS	Macrofossil Zones	Macrofossil Subzones
Campanian (pars)	B3 (pars) B2 B1	18 (pars) 17 16 15	21 20 19 18	*Belemnitella mucronata s.l.* (pars) *Gonioteuthis quadrata* *Offaster pilula*	'post *A. cretaceus* beds' *Applinocrinus cretaceus* *Hagenowia blackmorei* 'abundant *O. pilula*' *Echinocorys depressula*
Santonian	B1	15 14	18 17	*Uintacrinus anglicus* *Marsupites testudinarius* *Uintacrinus socialis*	
Coniacian		13 12 11	16 15 14 13	*Micraster coranguinum* *Micraster cortestudinarium*	
Turonian	1977	10 9	12 11 10 9 8	*Sternotaxis plana* *Terebratulina lata* *Mytiloides labiatus s.l.* *Neocardioceras juddii*	
Cenomanian U	14 13	8 7	8 7 6	*Metoicoceras geslinianum* *Calycoceras guerangeri*	
Cenomanian M	12 11ii 11i	6 5	5 4	*Acanthoceras jukesbrownei* *Acanthoceras rhotomagense* *Cunningtoniceras inerme*	*Turrilites acutus* *Turrilites costatus*
Cenomanian L	9 & 10 8 7	3 & 4 2 1	2 & 3 1 1i	*Mantelliceras dixoni* *Mantelliceras mantelli*	*Mantelliceras saxbii* *Sharpeiceras schlueteri* *Neostlingoceras carcitanense*
Upper Albian (pars)	6			*Stoliczkaia dispar*	*Arraphoceras briacensis* *M. (D.) perinflatum* *M. (M.) rostratum*

Stage	Traditional southern England subdivisions #	North Downs Robinson (1986)	South Downs Mortimore (1986)	Shaftesbury Bristow et al. (1995)	Southern England Bristow et al. (1997)	Southern England Rawson et al. (2001)
Campanian (pars)	Upper Chalk	Ramsgate Chalk Formation: Margate Member	Sussex White Chalk Formation: Portsdown Chalk Member Culver Chalk Member Newhaven Chalk Member	Upper Chalk: Spetisbury Ck Tarrant Chalk Blandford Chalk	Upper Chalk: Studland Chalk Portsdown Chalk Spetisbury Ck Tarrant Chalk Margate Chalk / ? Newhaven Chalk	White Chalk Subgroup: Portsdown Chalk Formation Culver Chalk Fm: Spetisbury C M; Tarrant Chalk Member Margate Chalk Member / ? Newhaven Chalk Formation
Santonian	Upper Chalk	Margate Member	Newhaven Chalk Member	Blandford Chalk	Margate Chalk / Newhaven Chalk	Margate Chalk Member / Newhaven Chalk Formation
Coniacian	Upper Chalk	Broadstairs Member St Margarets Member	Seaford Chalk Member Lewes Chalk Member	Blandford Chalk Lewes Chalk	Seaford Chalk Lewes Nodular Chalk	Seaford Chalk Formation Lewes Nodular Chalk Formation
Turonian	Upper Chalk: Top Rock Chalk Rock Middle Chalk: Spurious Chalk Rock Melbourn Rock	St Margarets Member Dover Chalk Fm: Akers Steps Mem Aycliff Member Shakespeare Cliff Member	Lewes Chalk Member Ranscombe Ck: New Pit Beds Holywell Beds (U, M, L) Melbourn Rk	Lewes Chalk Middle Chalk: New Pit Chalk Holywell Chalk	Lewes Nodular Chalk Middle Chalk: New Pit Chalk Holywell Nodular Chalk	Lewes Nodular Chalk Formation New Pit Chalk Formation Holywell Nodular Chalk Formation
Cenomanian U	Plenus Marls Lower Chalk: Grey Chalk	Plenus Marls Fm Abbots Cliff Fm: Capel-le-Ferne Member Hay Cliff Member	(Plenus Marls) Lower Chalk	(Plenus Marls) Lower Chalk: Zig Zag Chalk	(Plenus Marls) Lower Chalk: Zig Zag Chalk	(Plenus Marls Member) Grey Chalk Subgroup: Zig Zag Chalk Formation
Cenomanian M	Grey Chalk Chalk Marl	East Wear Bay Chalk Fm	Lower Chalk	Zig Zag Chalk West Melbury Chalk	Zig Zag Chalk West Melbury Marly Chalk	Zig Zag Chalk Formation West Melbury Marly Chalk Formation
Cenomanian L	Chalk Marl Glauconitic Marl	East Wear Bay Chalk Fm Glauconitic Marl	Glauconitic Marl	West Melbury Chalk UGS: Melbury Sst	West Melbury Marly Chalk Glauconitic Marl	West Melbury Marly Chalk Formation (Glauconitic Marl Member)
Upper Albian (pars)	Upper Greensand or Gault	Gault	Upper Greensand or Gault	Boyne Hollow Chert	Upper Greensand or Gault	Upper Greensand or Gault

#Traditional Chalk subdivisions after Jukes-Browne and Hill (1903, 1904, for example). UGS = Upper Greensand; *s.l.* = *sensu lato*. **Not to scale**
***Foraminiferal zones after Carter and Hart (1977), Swiecicki (1980), Hart et al. (1989) (UKB zones) and Wilkinson (2000) (BGS zones).**

Table 2: Classification of River Terrace Deposits in the Pang-Lambourn catchment

Age	Order	Kennet valley	Thames valley
Pre-Anglian	Tenth		Westland Green Gravel
	Ninth		Beaconsfield Gravel
	Eighth		Gerrards Cross Gravel
Anglian	Seventh	Beenham Stocks Gravel	Winter Hill Gravel
	Sixth	Silchester Gravel	Black Park Gravel
Post-Anglian/ Pre-Devensian	Fifth		
	Fourth		
	Third	Thatcham Gravel	Taplow Gravel
Devensian/ Holocene	Second	Beenham Grange Gravel	Kempton Park Gravel
	First		

Terraces not named are not present or have not yet been differentiated.

Correlations after Mathers and Smith (2000).