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Geology of the Poole-Bournemouth area
Part of 1:50 000 Sheet 329 (Bournemouth)
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with an account of the hydrogeology
by R.A.Monkhouse
Palaeontological contributions by R.Harland,
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Geology of the Poole-Bournemouth area

Geological report for DOE: Land Use Planning
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CORRECTION : Owing to error in pagination this report contains no page 30

POOLE-BOURNEMOUTH

EXECUTIVE SUMMARY

This report summarises the results of the three phases of a three year project to investigate the geology of the Poole-Bournemouth area in Dorset, funded by the Department of the Environment.

Prior to the commencement of the project, no adequate 1:10,000 scale geological maps of the Poole-Bournemouth area were available. The district has important sand resources, currently being extensively quarried on Canford heath, Beacon Hill and Henbury. Clay has been worked in many areas for bricks, tiles and ceramics, but apart from clays dug for unglazed floor tiles near Corfe Mullen, clay extraction is now principally from the Wareham area to the west. Most of the areas suitable for potential mineral extraction lie close to the urban conurbation, and conflict could arise between the need for further mineral extraction and housing.

The objective of the Poole-Bournemouth contract was to provide detailed 1:10,000 scale geological maps as a basis for effective and safe planning of urban and industrial development, and for safeguarding mineral and water resources.

The work consisted of a field survey of 270km^2 by three staff over a 3-year period.

A database was established using BGS holdings, greatly augmented by information gained from trial bores and pits undertaken by various geotechnical firms and local councils and confidential borehole records from commercial companies. The

data were collated and evaluated and entered into the BGS geoscience data base.

Ten 1:10,000 sheets (SZ 09 NW, NE, SW, SE; SZ 19 NW, NE, SW, SE; SY 99 NE and SE) and parts of four others (SY 99 NW, SW; SZ 08 NW and SU 00 SE) were surveyed during the three years of the project, and reports have been produced each year for each phase of the project (Freshney, Bristow and Williams, 1984; 1985, and Bristow and Freshney, 1986). This present report should be read in conjunction with the above maps. The earlier reports contain more detail than the this summary report.

The area surveyed consists of a ridge of high ground extending from Lytchett Matravers in the west, where it rises to about 90m O.D, in an arc across Canford Heath to the coast. The River Stour and its north-bank tributaries, the Allen, Moors River and River Avon, flow eastwards and south-eastwards across the northern part of the district to enter the sea at Christchurch Harbour. The southern part of the district is bounded by Poole Harbour in the west, and Poole Bay in the centre and east. The varied drift and solid deposits, combined with the general low relief, give rise to a gently undulating topography with no pronounced physical features, apart from St. Catherine's Hill and Hengistbury Head in the east. Most of the district is urban, with areas of agriculture mainly in the north-east, but with smaller tracts in the north and north-west.

The oldest formation to crop out is the Upper Chalk in the north-west. The Tertiary strata commence with a distinctive red-bed sequence, the Reading Formation. This is succeeded by an alternating sequence of clays and sands that comprise principally the London Clay, Poole Formation, Branksome Sand and Boscombe Sand. Younger formations crop out in the east, but occupy relatively small areas and are not important economically. The most extensive of the drift deposits include Head, River Terrace Deposits, which form an important potential resource of sand and gravel, and Alluvium.

The geological structure of the district is simple. The Solid formations have a gentle dip of about 1°SE. Locally, the dip direction is modified by gentle folding. One fault, the Christchurch Fault with a downthrow of about 30m W, has been recognized.

MINERAL RESOURCES

Ceramic clays

The Upton Heath area lies in the current Ball Clay Consultation area (see Highley, 1975), but ball clay has not been worked from the heath. Until 1978, ball clay was dug from a pit in the Poole Formation south-west of Lytchett Minster. Near Corfe Mullen, clay of the Reading Formation is worked for unglazed floor tiles. Apart from these occurrences, there is a strong possibility that ceramic clays of a quality suitable for tile manufacture may occur elsewhere.

Brick and pipe clay

Although several companies exploited the clays of the Poole Formation for bricks and pipes from large pits on the fringe of Poole until the 1960s and 70s, all extraction has ceased. Much of the clay outcrop is now sterilized by urban development, but areas of potentially workable clay still exist between the northern side of Holes Bay and Upton Heath, and on either side of the Sherford River.

Sand

The Poole Formation and Branksome Sand are exploited for construction sand (i.e. building, asphalt and concreting sands) from large pits on Canford Heath and at Henbury Plantation. Sand/lime bricks are made from sand of the Poole Formation at Beacon Hill.

The Poole Formation sands and Branksome Sand, therefore, form a large and important resource, but it is rapidly being worked out and sterilized by urban development.

Silica sand

Some of the Poole Formation sands may be of sufficient purity to be used for silica sand, but they have only been exploited on a limited scale, mainly because there is no local market for it. Further work is necessary to evaluate the potential resource of silica sand, and it should not be discounted by planning authorities.

Sand and gravel

Much of the Poole-Bournemouth area is underlain by sand and gravel of the river terrace deposits, but large areas have already been sterilised beneath housing. Currently, there is only one working gravel pit near Knighton. large potential resources exist in the Avon valley north of the railway line.

Hydrocarbons

The area covered by this report is adjacent to Wytch Farm, the most important onshore oilfield in the United Kingdom. Seismic surveys have been carried out in the Poole-Bournemouth area, and test drilling took place in 1986 at Hurn and Bransgore, but the results of this drilling have not yet been released.

GROUND STABILITY

Slope stability and bedrock physical properties

Some of the slopes on clay outcrops of the Reading Formation show evidence of landslip. Such areas are outlined on the geological maps where identified. The slips, which appear to be of the shallow translational type, are developed on slopes of 10° or less, whereas slopes developed on mixed sand/clay sequence in the London Clay and on the Poole Formation appear to be stable as steep as 25°.

The Tertiary sands are usually compact, poorly graded, well draining and can have high compressive strengths. In general, they provide adequate foundations for most small to medium-sized structures, although interbedded clays of variable thickness may, in places, alter these overall characteristics.

The in-situ strength of the Tertiary clays is related to their natural moisture content. They vary tremendously in plasticity, shear strength and cohesion within any one unit and detailed site investigations are necessary to determine their physical parameters.

The Head deposits are a heterogeneous group of superficial material accumulated by a process of mass movement downslope under cold climatic conditions. Present day hill-wash has also added to these deposits. Their composition reflects that of the upslope source material, and may consist of a mixture of clay, silt, sand or gravel. It is therefore important, if any major development of a site is planned, that the thickness and extent of any Head be determined by a ground investigation.

Areas of Made Ground (fill) may be split into two main categories: one where disused sand, clay, and other pits have been back-filled with various materials, and the second where materials have been dumped on an original land-surface. Areas of Made Ground are depicted on the maps where they have been identified, with the exception of some road and railway embankments which are obvious to any observer. Made Ground may be unstable because of differential compaction. This can be especially acute where a structure spans the junction between the Made Ground and the adjacent undisturbed bedrock.

Underground workings

Clay was worked in underground workings at Hamworthy, Corfe Mullen and Beacon Hill. Care must be taken in proposed developments in these areas, and also elsewhere, where extraction may have taken place, but has gone unrecorded.

Solution-collapse hollows

Numerous solution-collapse hollows have been mapped on Tertiary strata which overlie Chalk at shallow depth in the Lytchett Matravers area. They do not always have a surface expression, but they may be located by geophysical and remote sensing methods.

GROUNDWATER

The groundwater resources of the district have not been actively investigated as part of the project, although a review of existing data by R. Monkhouse is included in this and the earlier reports. The hydrogeological maps covering the Chalk and associated minor aquifers of Wessex, and that of Hampshire and Isle of Wight, both published by BGS in 1979, include the project area.

The Chalk, Poole Formation, and the combined Branksome Sand and Boscombe Sand are all potential aquifers, but have been little exploited within the district. Care must be taken to ensure that no polluting agency is sited in areas where there is a risk of polluting an aquifer, particularly sandy aquifers which potentially are the most important in the Poole-Bournemouth area.

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INTRODUCTION

The original geological survey of the area, comprising Sheets SY 99, SZ 09, SZ 19 and parts of sheets SZ 08 NW and SU 00 SE, was made by H W Bristow and J Trimmer at the one-inch to one mile scale (1:63 360) and was published on Old Series Geological Sheets 15 and 16 in 1856 and 1855 respectively. The drift deposits were not represented on these maps. Clement Reid resurveyed the area on the six-inch to one mile scale (1:10 560) in 1893-1895 and his results were incorporated in New Series One-Inch Geological Sheet 329 (Bournemouth), published in 1895 in both Solid and Drift editions, and in the accompanying memoir (Reid, 1898). A second edition of this memoir by H J O White was published in 1917. White re-examined much of the ground, but the published maps remained unaltered. In 1976 the Bournemouth (329) Sheet was republished without revision at 1:50 000 scale. In 1983 the Institute of Geological Sciences (now the British Geological Survey) was commissioned by the Department of the Environment (contract PECD7/1/0103-149/82) to provide new 1:10 000 geological maps of the Poole-Bournemouth area. The contract comprised the survey of ten 1:10 000 sheets, and parts of four others (Figure 1), over three years, to form a basis for the planning of urban and industrial development, and the safeguarding of mineral and water resources. The first phase of the contract was completed in 1983 and the results were incorporated in the four 1:10 000 sheets which comprise SZ 19, published in 1984, and the accompanying Open File Report by Freshney, Bristow and Williams (1984). During 1984 the second

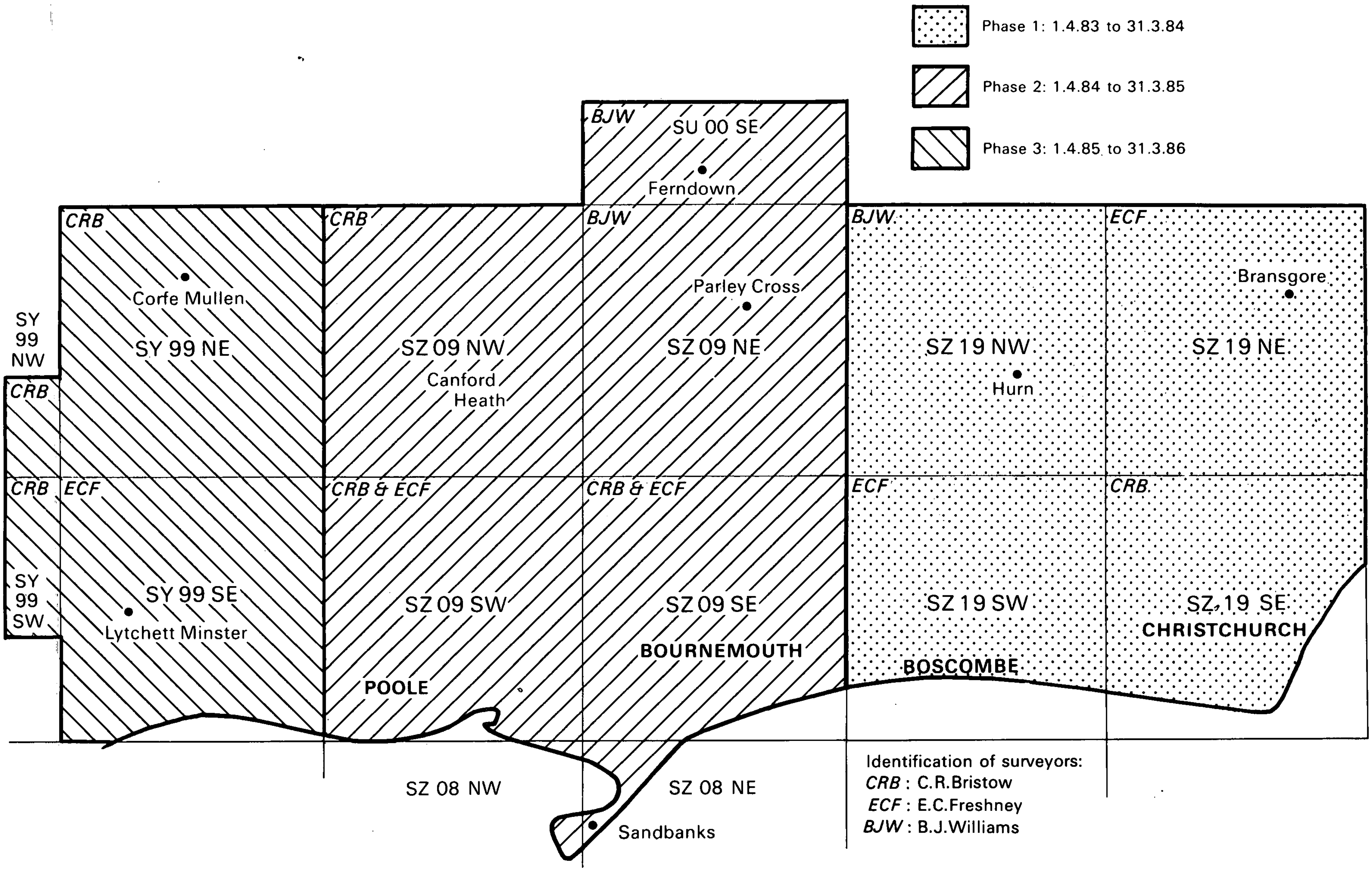

Fig. 1. Index map showing the area covered by the Poole-Bournemouth project and this report, the dates of survey and initials of the surveyors

phase of the contract was completed and the four constituent quadrants comprising SZ 09 and parts of sheets SZ 08 NW and SU 00 SE were published in 1985, together with an Open File Report (Freshney, Bristow and Williams, 1985). Mapping of the final phase of the contract, consisting of SY 99 NE and SE and parts of SY 99 NW and SW was carried out in 1985, and the results published the following year (Bristow and Freshney, 1986).

Dr R Harland, Mr M.J.Hughes, Mr D K Graham and Mr. C.J.Wood have provided palaeontological reports respectively on dinoflagellates, foraminifera and molluscs collected during the survey. The account of the hydrogeology has been compiled from reports by R A Monkhouse.

The authors thank Bournemouth, Poole and Wimborne borough councils, and Dorset and Hampshire County Councils and their officers for their co-operation in providing borehole and other sub-surface information from their records. In particular, Bournemouth Borough Council have generously allowed us to use the cliffs sections constructed by Mr R Agar, the former Deputy Borough Engineer. We also thank E.C.C. Ball Clays Ltd for permission to use data from their Beacon Hill Borehole. Thanks are also due to numerous landowners for access to their ground both for mapping and test drilling.

The area surveyed is dominated by the River Stour which flows eastwards and then south-eastwards across it to empty into Christchurch Bay just east of Christchurch, where it is joined by the River Avon (Fig.2). The watershed between the Stour and the rivers to the south, crosses the district in an arc from Lytchett

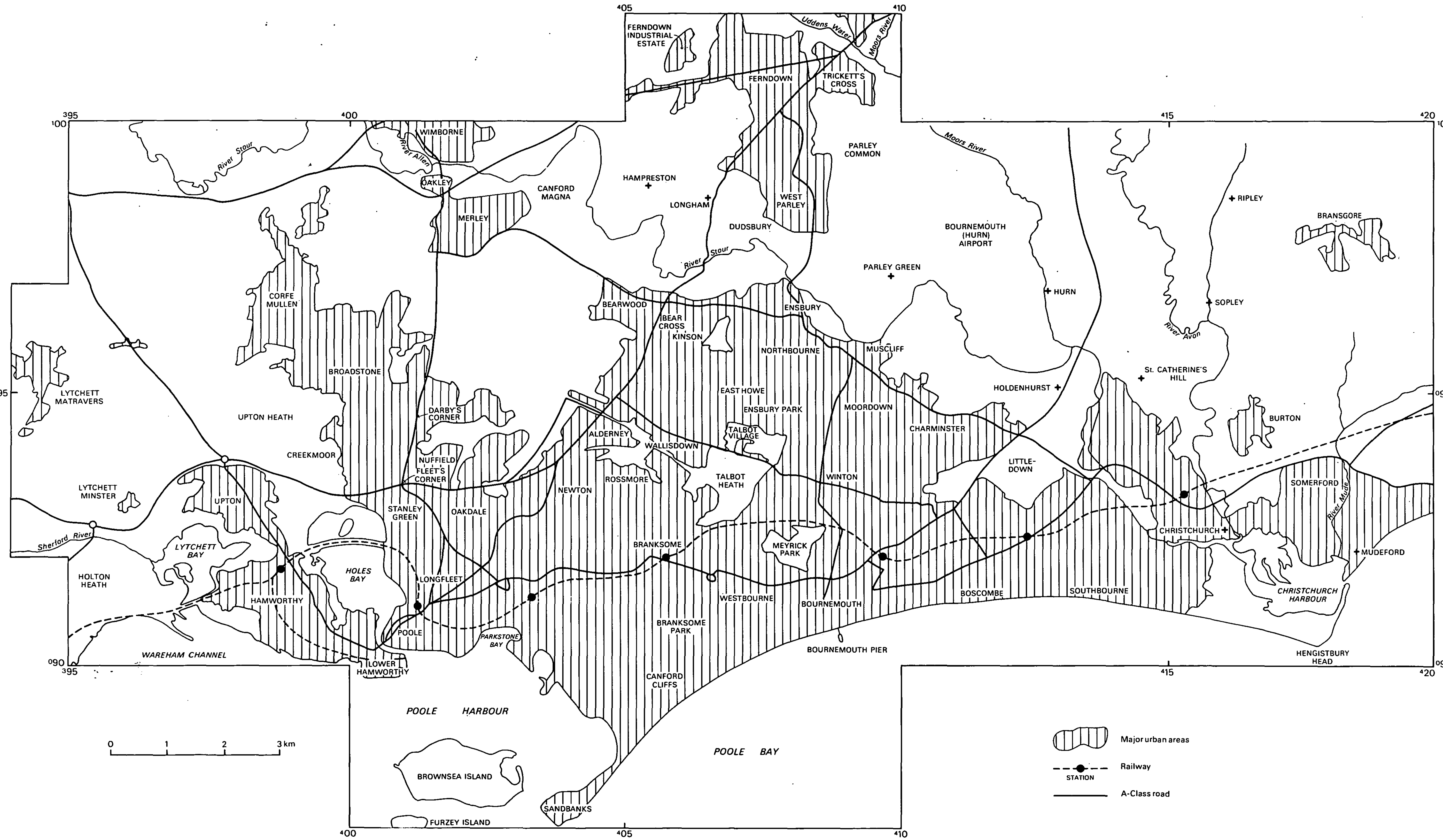

Fig. 2 Location map showing major urban areas and main communication routes in the Bournemouth-Poole-Wimbourne area

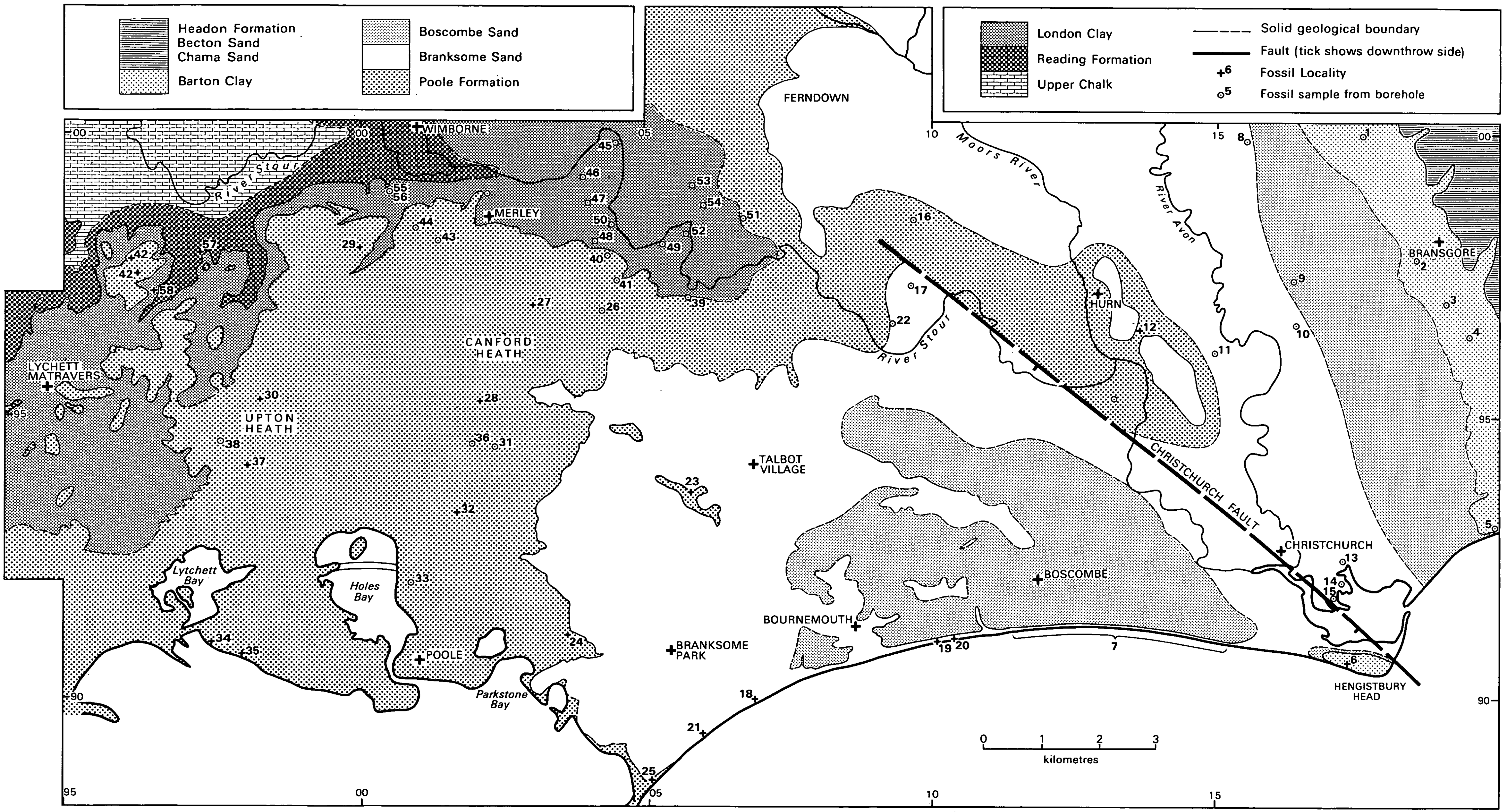

Fig.3 Sketch map of the Solid geology of the Poole-Bournemouth area with the sites of fossil localities (see also Table 2)

Matravers in the west, where it rises to about 90m O.D, across Canford Heath at about 65m O.D, to the Boscombe area.

The centre of the district is dominated by the urban conurbation of Poole-Bournemouth-Christchurch. The north-eastern part of the area, and the western part, west of Corfe Mullen and Upton, are rural with a network of small villages set in mixed arable and pasture farmland.

Most of the area is underlain by Palaeogene strata, but Cretaceous Chalk crops out, or has a subdrift crop, in the north-west. The older Palaeogene strata, Reading Formation, London Clay and Poole Formation, that crop out in the west (Fig.3), are dominantly clayey in contrast to the overlying Branksome and Boscombe sands exposed in the eastern portion of the district. The succeeding Barton Clay and higher strata have only a limited outcrop in the east.

The evolution of the nomenclature of the Palaeogene rocks of the district is shown in Fig.4. The generalised stratigraphy of the Palaeogene strata, together with the dinoflagellatecysts zones, the Bournemouth 'Formation' of Plint (1983b) and the London Clay lithological divisions of King (1981) are shown in Figs. 5 and 6.

About 50% of the area surveyed has a covering of drift deposits. These are chiefly river terrace deposits, consisting of sand and gravel of potential economic importance. The floodplains of the rivers are floored by alluvium forming rich pasture land.

The geological succession of the district is shown in Table 1. Estimated thicknesses are given in metres, where known.

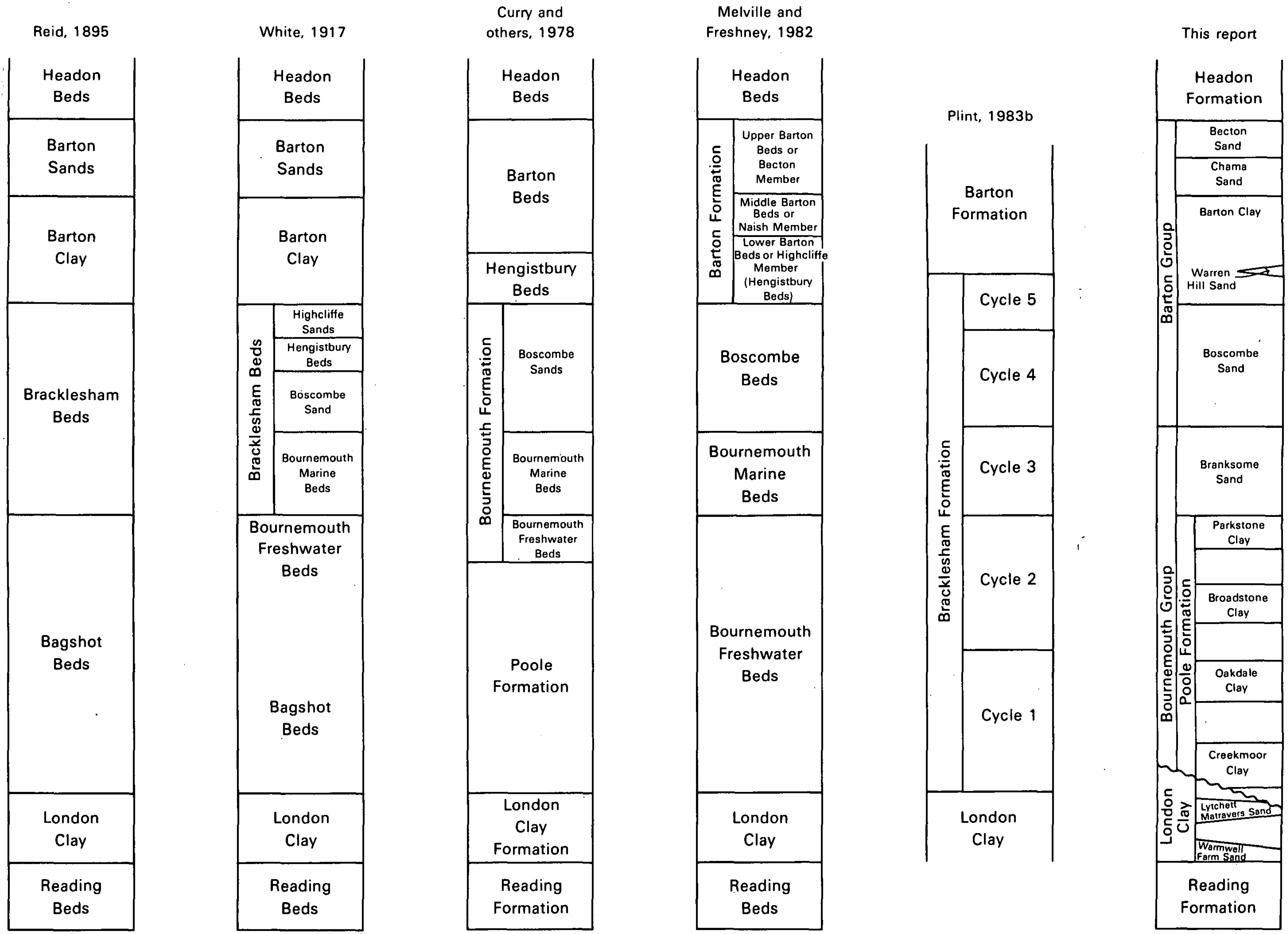

Fig. 4 Selected stages in the evolution of the nomenclature of the Palaeogene rocks of the district

Table 1. Geological succession

DRIFT DEPOSITS

Quaternary
- Landslip
- Blown Sand
- Older Blown Sand
- Peat
- Alluvium
- River Terrace Deposits, Sands and Gravels
- River Terrace Deposits, Loam
- Marine Beach Deposits
- Estuarine Alluvium
- Storm Gravel Beach Deposits
- Head

SOLID GEOLOGY

System	Group	Formation	Member	Thickness
		Headon Formation		16
	Barton Group	Becton Sand		7
		Chama Sand		5
		Barton Clay		60
			Warren Hill Sand	0-10
		Boscombe Sand		c20
Palaeogene	Bournemouth Group	Branksome Sand		c65
		Poole Formation	Parkstone Clay	0 to 22
			Sand	8 to 13
			Broadstone Clay	0 to 19
			Sand	2 to 10
			Haymoor Bottom Clay	0 to 3
			Sand	6 to 17
			Oakdale Clay	0 to 54
			Sand	5 to 30
			Creekmoor Clay	0 to 27
			Sand	5 to 30
		London Clay	Christchurh Member (proved in boreholes in the east)	40 to 60
			Clay	0 to 5
			Lytchett Matravers Sand (western outcrops)	0 to 6
			Clay	10 to 20
			Warmwell Farm Sand (western outcrops)	0 to 15
		Reading Formation		12 to 30
Cretaceous		Upper Chalk		50 proved

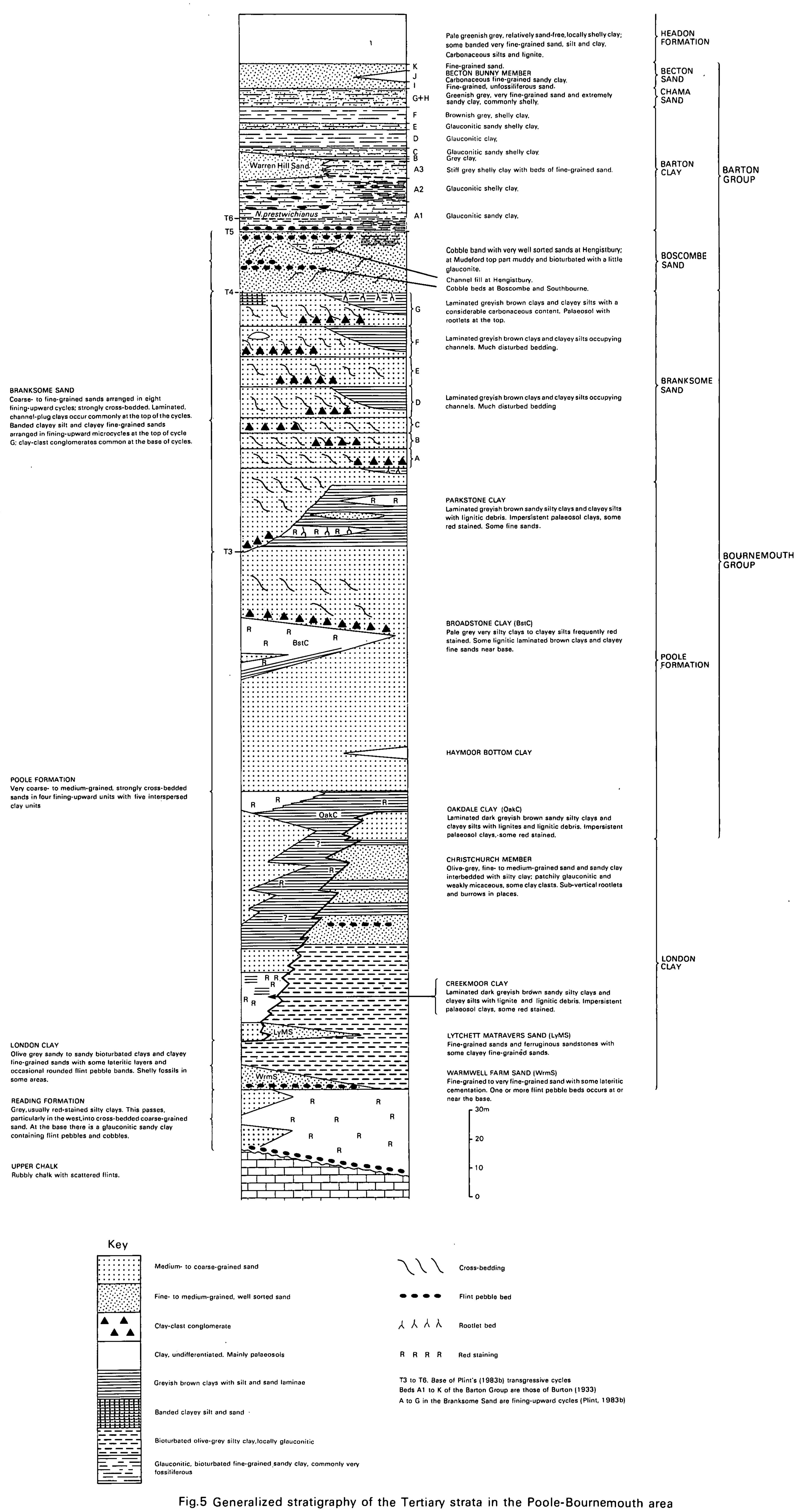

Fig.5 Generalized stratigraphy of the Tertiary strata in the Poole-Bournemouth area

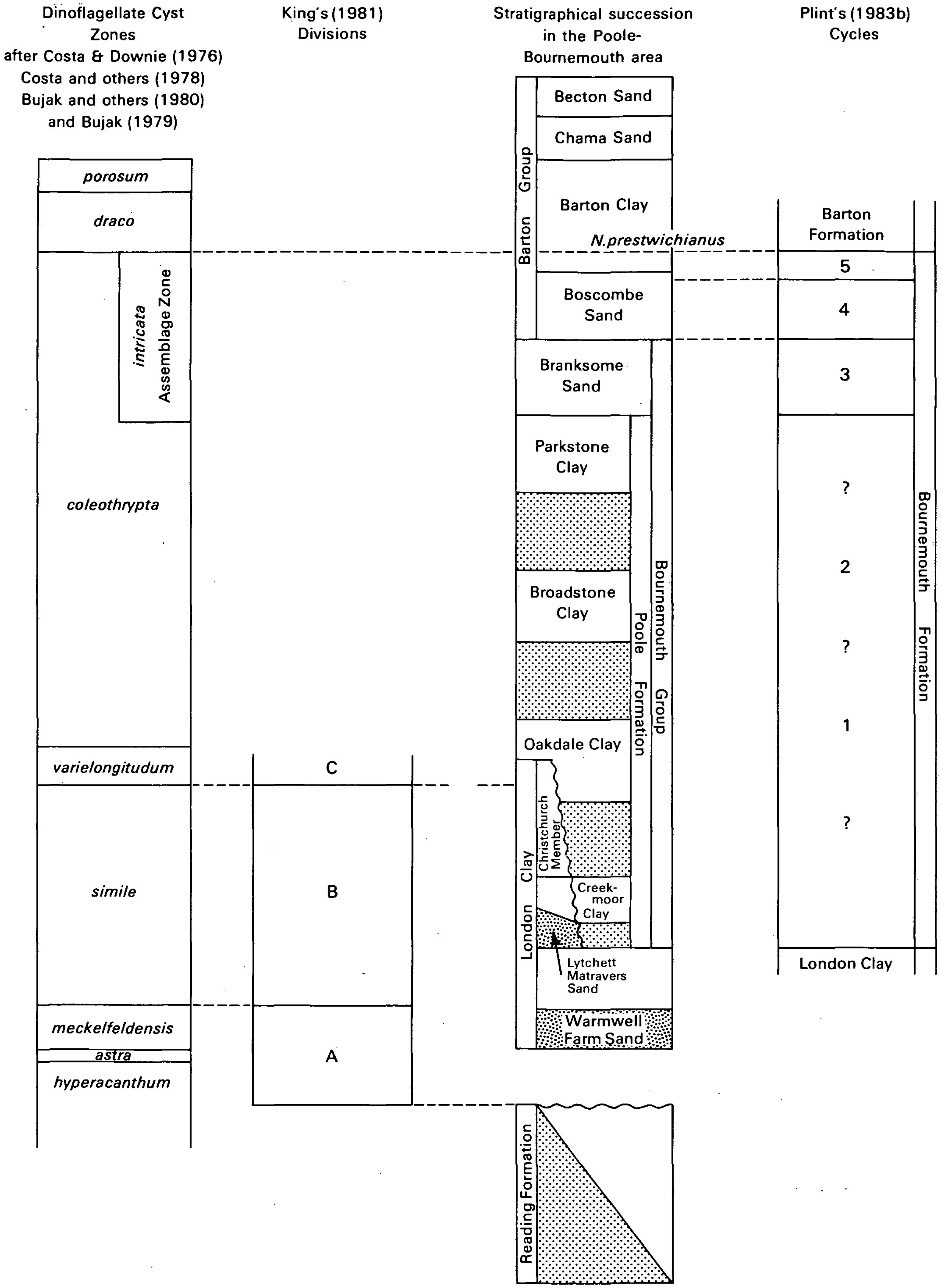

Fig. 6 Generalized stratigraphy of the Palaeogene strata of the Poole-Bournemouth area with the dinoflagellate cyst zones, Bournemouth "Formation" cycles of Plint (1983b) and the London Clay lithological divisions of King (1981)

The grain-size parameters used throughout this report are those defined by Folk and Ward (1957). These parameters are widely used by sedimentologists because they enable rapid comparisons to be made between different types of sand and gravels, but they have yet to find general acceptance with geotechnical engineers.

ϕ (phi unit) ....1/Log grain size in millimetres e.g. 2mm= -1ϕ; 16mm = -4ϕ; 0.25 mm = 2ϕ.

$$\text{Mean Size (Mz)} = \frac{\phi16+\phi50+\phi84}{3}$$

where $\phi16$ is the grain size (in ϕ) at 16 wt% cumulative grain-size curve.

Sorting (Inclusive Graphic Standard Deviation of Folk and Ward) =

$$\frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$$

The lower the sorting value, the better sorted the sample. Most sedmiments have values between 0.35ϕ and 4.0ϕ.

Skewness (Inclusive Graphic Skewness of Folk and Ward) =

$$\frac{\phi16+\phi84-2(\phi50)}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2(\phi50)}{2(\phi95-\phi5)}$$

For a perfectly symmetrical grain-size distribution curve skewness = 0. Samples with a relative preponderance of finer grains have positive skewness values, those with a greater relative preponderancy of coarser grains have negative Skewness values. The absolute mathematical limits for skewness are -1.00 to +1.00, but few sediments lie outside the range -0.80 to + 0.80.

2. SOLID GEOLOGY

CRETACEOUS

UPPER CHALK

Chalk occurs at depth under the whole of the district, but crops out only in the north-west near Combe Almer [SY 95 98] and north of the River Stour. It is present beneath the alluvium and river terrace deposits of the Stour Valley to about 1km W of Wimborne. There is a general south-eastward fall across the whole district in the Chalk surface of between 0.5^{o} and 1^{o}. At Christchurch in the east, the Chalk surface is at 245m below O.D, at Holton in the south it is at 125m below O.D.

Only poor exposures of weathered rubbly chalk with scattered flints are present in the district; most drillers' logs record 'Chalk and flint', or 'soft, crumbly or putty chalk with flints'. Palaeontological data from outside the district indicates that the Chalk belongs to the <u>Belemnitella</u> <u>mucronata</u> Zone of the Upper Chalk (White, 1917).

The maximum thickness of Chalk recorded in the district is 191m near the Corfe Mullen Pumping Station [SY9705 9845][1]. At Shapwick [ST 9429 0135], just beyond the northern border of the district, 341m of Chalk were proved beneath river terrace deposits, of which 225m belongs to the Upper Chalk. To this can be added about 60m of Upper Chalk which occurs at outcrop to give it a total thickness of about 285m.

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1 Grid References are prefixed by SZ unless otherwise stated.

PALAEOGENE

READING FORMATION

The Reading Formation underlies much of the district, but crops out, or has a sub-drift crop, only in the north-west between Lytchett Matravers [SY940 960] and Lambs Green [000 990]. Three small inliers occur in the bottom of valleys south and south-east of Lytchett Matravers.

The Reading Formation is dominantly a clay, with sand at the base and locally throughout the deposit. Both the clays and the sands probably have a combined maximum thickness at outcrop of 20m. In the Beacon Hill Borehole [SY9761 9446], the Reading Formation is about 11m thick; at Knapp Mill, Christchurch [1544 9380] it is 30m thick.

The basal bed consists of a lithologically distinctive, glauconitic sand or sandy clay with glauconite-coated flint pebbles and cobbles. Characteristically, and particularly in the east, the overlying clay is brick-red, mottled red and grey, and mottled red, yellow and grey. Locally, and especially in the higher strata in the west, the clays are silty and mottled orange and grey and are similar to clays in the London Clay. Beds of fine- to coarse-grained, locally cross-bedded sands are also common in the west of the district. These sands may be developed both at the base [SY945 970] and at the top [SY9545 9745] of the Reading Formation. In places [SY951 972 and 955 980], the whole of the formation is represented by sand. Apart from the basal bed, no pebbles have been found within the sands of the district.

Grain-size analyses of samples from the district are included in Figs. 8 and 9. Buurman (1980), from his work on the

Isle of Wight, concluded that the Reading Formation formed in a fluvio-marine environment in which periods of sedimentation and emergence alternated. Soil formed during the emergent phases in a climate with a fairly high annual temperature and a dry season.

LONDON CLAY

London Clay occurs at depth over most of the Bournemouth region, but crops out only in the west around Lytchett Matravers and Lytchett Minster and north-eastwards to Lambs Green, south of Wimborne Minster. East of Wimborne, it is present along the Stour Valley beneath alluvium and river terrace deposits as far as Longham [07 98]. In boreholes to the south, the London Clay has been proved at Holton Heath [SY9557 9087], Beacon Hill [SY9761 9446], the old Dolphin Brewery, Poole [009 905], Knapp Mill, Christchurch [1544 9380] and in the Christchurch Borehole [2002 9301] just beyond the present district (Fig.7).

Over much of the outcrop, the London Clay comprises an alternating sequence of well sorted, fine-grained sand (Figs.8 and 9) and olive-grey bioturbated silty clay. Pebble beds are commonly developed in the basal sand. Two sand members at outcrop in the west have been named, the Warmwell Farm Sand at the base, and the Lytchett Matravers Sand towards the top. At two localities near Lytchett Heath [SY964 945] in the south, clay of London Clay lithology has been recognized beneath the Warmwell Farm Sand. In the absence of boreholes, the extent of this lower clay, which has only been recognised in this inlier, is unknown. In the central tract, from about 2.5km SW of Wimborne to 7km ESE

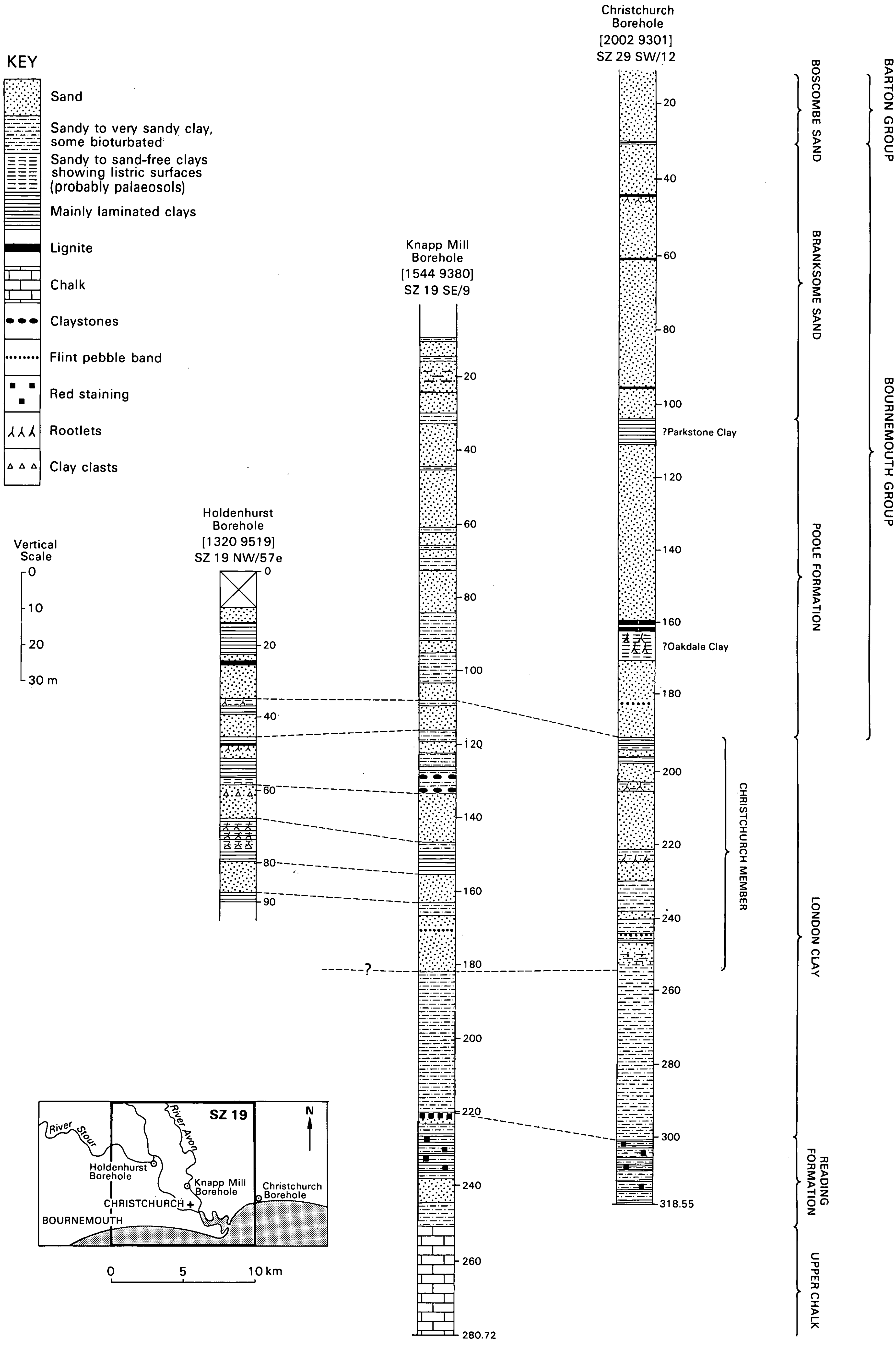


Fig. 7 Comparison of the Tertiary sequences proved in the Christchurch, Knapp Mill and Holdenhurst boreholes

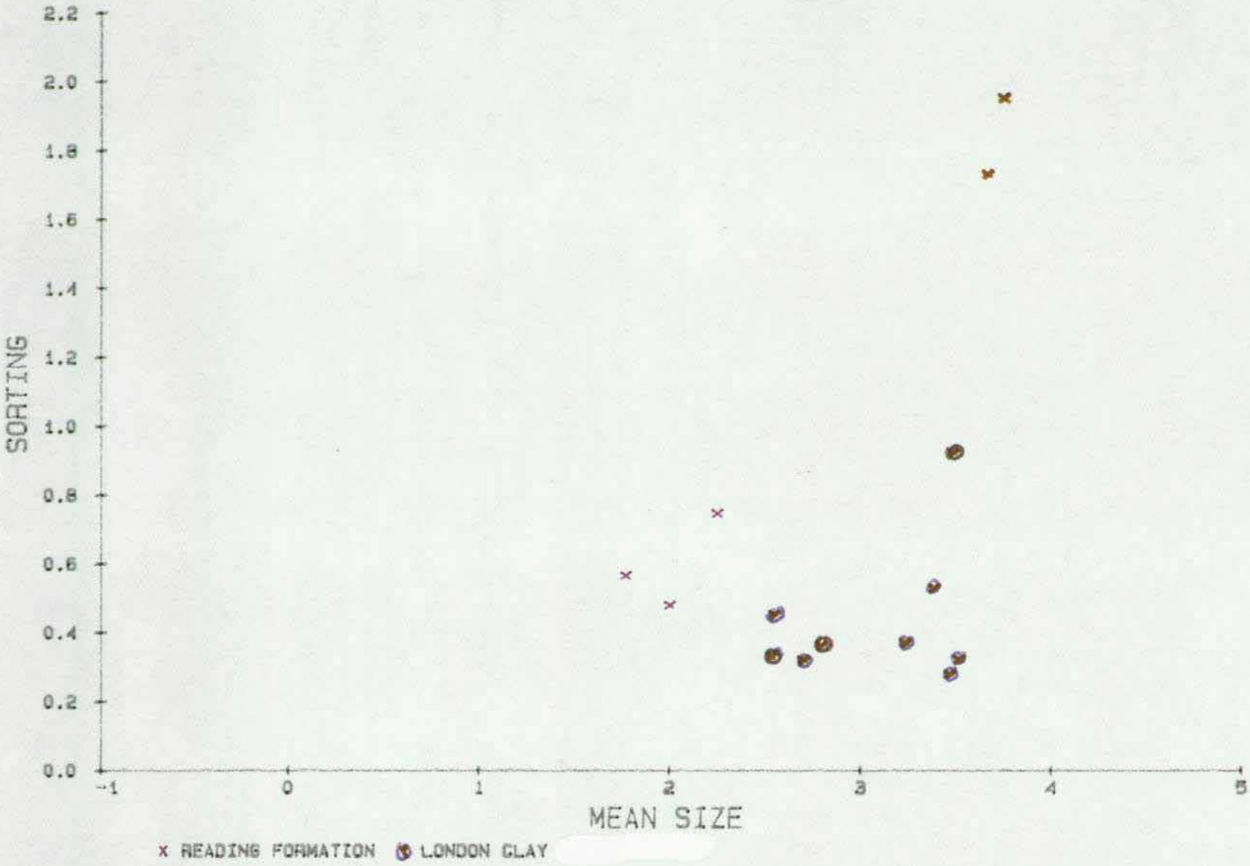


FIG.8 SCATTER PLOT OF MEAN SIZE/SORTING FOR SANDS OF THE READING FORMATION AND LONDON CLAY IN THE POOLE-BOURNEMOUTH AREA

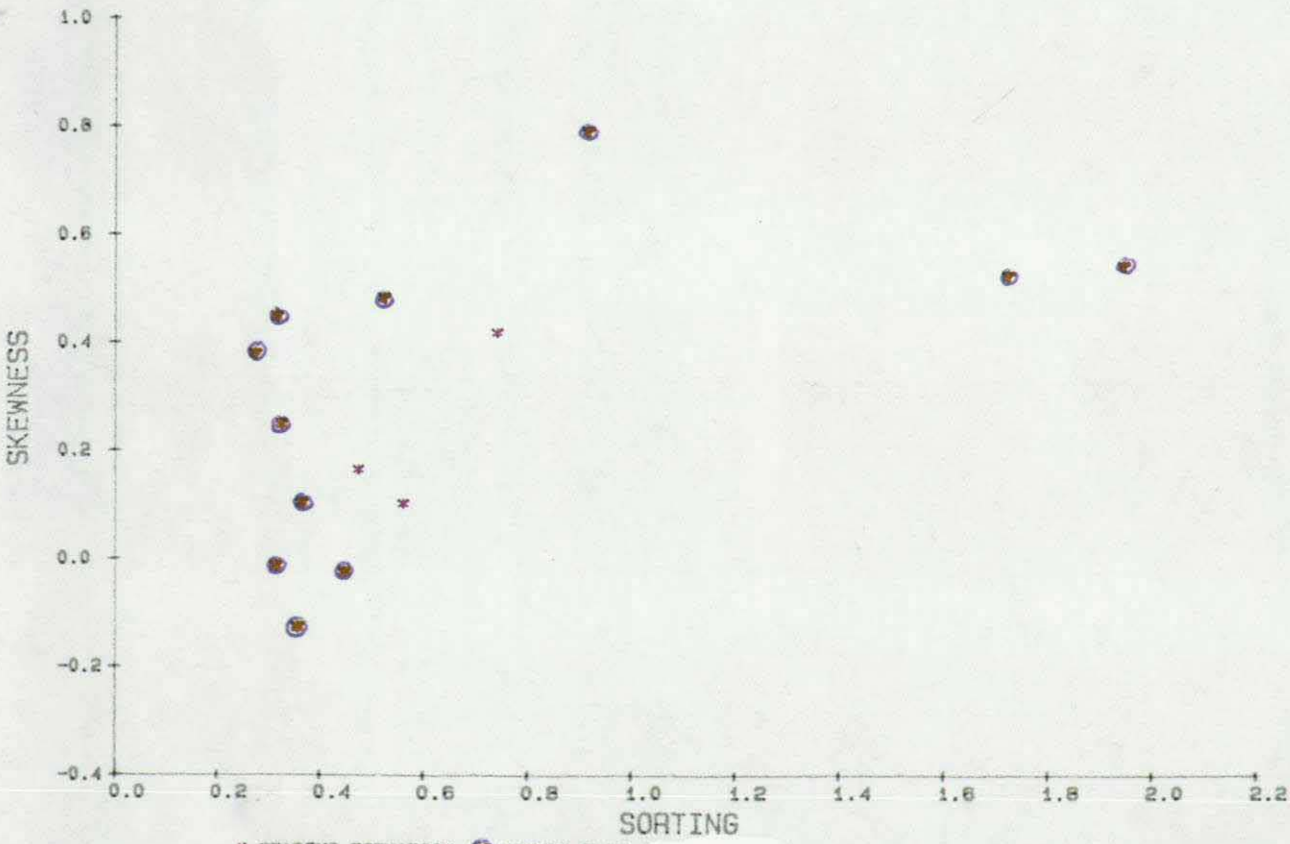


FIG.9 SCATTER PLOT OF SORTING/SKEWNESS FOR SANDS OF THE READING FORMATION AND LONDON CLAY IN THE POOLE-BOURNEMOUTH AREA

of the town, the London Clay is not divisible into members. At depth in the east, a younger unit, about 40m thick, of glauconitic silty and micaceous sand, with interbeds of clayey silt and silty clay has been named the Christchurch Member (Freshney, Bristow and Williams, 1984). South-east of Lytchett Matravers, the upper part of the London Clay passes eastwards into the lower part of the Poole Formation (Bristow and Freshney, 1986).

By reference to Fig.6, it can be seen that the London Clay of the Poole-Bournemouth area is represented by three (out of five) transgressive/regressive cycles, which can be recognized throughout much of the Hampshire and London basins (King, 1981, fig.45). Ideally, each coarsening-upward cycle commences with a thin pebble, or glauconitic bed, which is succeeded by clays that pass up in into fine-grained sands, or laminated/interbedded sediments.

The London Clay maintains a uniform thickness of about 20m in the west, but there is some local variation in thickness due to overstep by the Poole Formation. In the Oakley to Ashington [005 983] area, the London Clay is estimated to be about 12m thick. In the Lytchett Minster area, it is about 30m thick. In the Beacon Hill Borehole [9761 9446], where younger strata are preserved at depth, the London Clay is up to 40m thick (Bristow and Freshney, 1986). In the Canford Magna area, the thickness is calculated to be about 30 to 35m (Freshney, Bristow and Williams, 1985). In the east of the district, the London Clay is about 110m thick, but there it contains the 40-m thick Christchurch Member (Fig.7).

Undivided London Clay

The following borehole [0171 9868] is representative of the London Clay in the Wimborne area where the London Clay cannot be divided into mappable members:

	Thickness (m)	Depth (m)
River Terrace Deposits	3.80	3.80
LONDON CLAY		
Sand, fine-grained, silty, mottled orange and light brown (0.20m proved)	0.20	4.00
Silt, clayey, fine-grained sandy, firm, grey	1.00	5.00
Clay, silty, thinly bedded, scattered siltstones, grey, firm to very stiff	1.80	6.80
Silt, clayey, fine-grained sandy, grey	2.20	9.00
Clay, silty with siltstone, fine-grained sandy, thinly laminated, grey, very stiff	1.75	10.75
Silt, fine-grained sandy, grey	0.25	11.00
Silt, clayey, with fine-grained sand laminae, firm to stiff	1.00	12.00
Sand, fine-grained, silty	2.00	14.00
Sand, very fine-grained, silty with 0.1m bands of soft, thinly laminated, light grey very silty clay	4.20	18.20
Silt, clayey, fine-grained sandy with fine-grained sand laminae, shelly, very stiff, fissured	2.30	20.50

In the Canford Magna area, beds of coarse-grained sand up to 6m thick, and coarse-grained, glauconitic sandy clay were encountered in several boreholes (Freshney, Bristow and Williams, 1985).

Clay beneath the Warmwell Farm Sand

At the northern end [SY9589 9532] of the Lytchett Heath inlier, grey-brown micaceous fine-grained sandy clay was augered in the bottom of a valley. At the second locality [SY9647 9450], lower down the valley, olive-grey, extremely silty clay with glauconite was encountered.

Warmwell Farm Sand

The base of the London Clay is well marked in the north near Corfe Mullen, Wimborne and Canford Magna by a highly glauconitic, clayey, locally shelly, pebbly sand up to 2m thick. This sand, which is probably the lateral equivalent of the Warmwell Farm Sand, is not separately represented on the maps. The base is well shown by a section [SY9736 9766] in the Knoll Manor clay pit:

	Thickness (m)
Clay, and fine-grained sand, poorly exposed	c.4.0
Sand, clayey, highly glauconitic	0.6
Pebble bed of small (generally less than 2cm) well-rounded flints, shelly with common *Turritella* and bivalves - locally lateritically cemented. Spring at base	0.1
READING FORMATION	
Clay, mottled red and grey	2.0+

In the west, neither shelly nor strongly glauconitic beds have been recognised, but pebble beds, developed at more than one level, occur within the basal fine-grained sand which may be up to 6m thick. This sand, the Warmwell Farm Sand (Bristow and Freshney, 1986), is well developed in the tract south-west from Henbury Plantation [SY966 980]. The member takes its name from the exposures in the lanes and banks near Warmwell Farm [949 964].

The sands, which are commonly well sorted and symmetrical to negatively skewed, vary from very fine to fine grained, but can be locally clayey (Figs.8 and 9). Pebble beds composed of very well rounded black flints occur at at least two levels. White (1917) recorded the presence of quartz pebbles. Most pebbles are between 1 and 2 cm across, but some reach 10cm. The pebble beds vary from stringers of scattered pebbles to matrix- supported pebble beds up to 0.6m thick; most beds are less than 10cm thick.

An exposure [SY9645 9702] in the old Henbury Plantation Pit provides a typical section in the Warmwell Farm Sand, and reveals the junction of this sand with the overlying clay:

	Thickness (m)
Clay, silty, mottled orange and grey; a clay-clast breccia with one rounded flint pebble, up to 0.1m thick in a clay matrix at the base. Locally, where there are lateritic nodules at the base, moulds of *Turritella* and the bivalve ?*Dosiniopsis bellovacina* occur.	c0.8
WARMWELL FARM SAND	
Sand, very fine-grained, buff-orange, with thin clay layers up to 2cm thick. This sand is irregular and is either channelled into, or is strongly affected by dewatering structures. At one point, a flame of sandy clay passes up from bed below, through the fine-grained sand, but stops beneath the overlying clay.	0 to 0.8
Sand, fine-grained, clayey, thinly bedded; pronounced lateritic layer, 1 to 2cm thick, between 0.1 and 0.25m above base; irregular clay bed, 1 to 2cm thick above the laterite. At about 0.3m above the laterite, there is an impersistent pebble bed, varying from single small pebbles (1cm diameter) to an 0.6m thick bed with pebbles up to 0.8cm maximum diameter; locally the pebble bed is cemented by laterite to form an indurated pebble bed. Local thin inter-beds, 1 to 2cm thick, of fine-grained sand.	c1.0
Sand, fine-grained, buff, with some lateritic sand, 1m exposed, but probably continues to bottom of pit 2m lower.	c3+

The Warmwell Farm Sand almost everywhere forms a prominent scarp, up to 6m high, generally with powerful springs issuing from its base. At outcrop, the sand is up to 6m thick, but in the Holton Heath borehole [SY9548 9087] in the south, it is about

15m thick.

Clay above the Warmwell Farm Sand

The Warmwell Farm Sand is succeeded by up to 8m of silty and sandy clays with clayey fine- to very fine-grained silty sands; locally, mainly at the top of the succession, slightly coarser-grained sands occur. The sandier parts of the succession probably lie at the top of coarsening-upward sequences of which the London Clay usually consists. At the surface, the clay weathers mottled orange and grey. Locally, mottled red, yellow and grey clays have been augered. A characteristic feature of the member inthe west, is an abundance of hard ferruginous cemented layers (?laterites). They form many 1 to 2cm-thick hard brown brittle beds. At the base of the clays, a breccia of tabular siltstone and fine-grained sandstone with scattered rounded flints, up to 10cm thick, is locally present. A typical section [SY9550 9614] in this deposit is as follows:

	Thickness (m)
Clay, sandy, mottled orange and grey, with scattered well rounded flint pebbles (up to 15mm diameter) in the basal 5cm	0.6
Sand, very fine-grained, mottled orange and grey	0.1
Sand, very fine-grained, buff	0.1
Breccia of tabular and angular ferruginous siltstone and fine-grained sandstone; one rounded flint pebble	0.1
WARMWELL FARM SAND	
Sand, fine-grained, buff-brown	0.2+

Fossils have been found at one locality [SY9645 9702] in laterite nodules at the base of the clay.

Lytchett Matravers Sand

This is named after the village of Lytchett Matravers near to which there are extensive outcrops of fine-grained sand similar to the Warmwell Farm Sand; they are commonly ferruginously cemented and are locally hard enough to have been worked as building stone (White, 1917, pp.16-17). No pebble bed has been noted in this sand. The sand forms extensive flats around Lytchett Matravers and has a sharp feature break, locally associated with springs, at its lower boundary. The maximum thickness is about 6m.

Northwards, the Lytchett Matravers Sand either dies out as a mappable unit, or is cut out beneath the unconformable Poole Formation.

Clay above the Lytchett Matravers Sand

The clay overlying the Lytchett Matravers Sand is similar to the lower clay. It has been worked for bricks and pipes near Lytchett Matravers. It probably has a maximum thickness of 10m.

The bioturbated clays of the London Clay east of Lytchett Minster appear to pass eastward into laminated carbonaceous clays with palaeosols of the Creekmoor Clay of the Poole Formation.

Christchurch Member

This consists mainly of fine-grained silty, commonly glauconitic and micaceous sand interbedded with yellowish brown often carbonaceous colour-banded and laminated sand and silt. Claystone concretions and scattered black flint pebbles also occur in places. Palaeosols with or without rootlet beds are common. The type sequence is the strata between the depths of 191 and 231.5m in the Christchurch Borehole. It is also well developed in boreholes sunk by Wessex Water Authority at Holdenhurst [132 953] and in the Knapp Mill Borehole, Christchurch [1544 9380] (see Fig.7). Comparable beds are seen at Alum Bay in the Isle of Wight between Prestwich's (1846) Beds 7 and 13, and it is probably present in the E.C.C. Ball Clay Co.'s borehole at Beacon Hill between 28m and 41m. The geophysical logs of oil wells at Wytch Farm also suggest the presence of the Christchurch Member.

Biostratigraphy

Dinoflagellate cyst floras have been collected from 21 localities of the London Clay (see Figure 3 and Table 2), and range in age from the ?*meckelfeldensis* to *varielongitudum* zones of Costa and Downie (1976). In addition, foraminifera were found in 4 samples, and molluscs at two localities. By reference to Figure 6 it can be seen that these zones correspond to divisions A - C of King (1981, fig.45).

The fossil evidence for dating the named members of the London Clay is sparse. It is probable (see below) that the Warmwell Farm Sand belongs to Division A (?A3) (*meckelfeldensis* Zone), and the overlying clay and Lytchett Matravers Sand to Division B (*simile* Zone); the highest clay may fall within Division C (*varielongitudum* Zone). In the Lambs Green area [SY996 988], where the London Clay is undivided, two samples from a glauconitic sandy clay at the base of the London Clay (Localities 55 and 56 on Fig.3 and Table 2) yielded dinoflagellates possibly assignable to the *hyperacanthum* Zone, but more probably to the _meckelfeldensis_ zone (see below); these include _Apectodinium paniculatum_ (Costa and Downie) Lentin and Williams, _A.quinquelatum_ (Williams and Downie) Costa and Downie, _Cordosphaeridium gracile_ (Eisenack) Davey and Williams and _Homotryblium tenuispinosum_ Davey and Williams. This association of dinoflagellates is, however, facies controlled and may be indicative of a nearshore environment of deposition at any time in the Early Eocene. It is not unequivocal evidence for the _hyperacanthum_ Zone. In the Knoll Manor Clay Pit (Locality 57), 3km WSW of Lambs Green, there is a rich molluscan fauna associated with much glauconite and well rounded black flint pebbles, at the base of the London Clay. The fauna is rich in numbers, but low in species; it includes: _Ditrupa plana_ (J. Sowerby), _Rotularia bognoriensis_ (Mantell), _Ancistrosyrinx_ aff. _revoluta_ (Deshayes), _Epitonium sp_, _Euspira glaucinoides_ (J. Sowerby), _Turritella_ cf. _interposita_ Deshayes, _Caestocorbula sp_, _Callista (Microcallista) proxima_ Deshayes, _Corbula sp_?, _Dosiniopsis bellovacina_ (Deshayes), _Glycymeris brevirostris_ (J.de C. Sowerby), _Nemocardium plumsteadianum_ (J. Sowerby), _Nucula sp_., _Orthocardium_ cf. _subporulosum_ (Deshayes) and _Striatolamia striata_ (Winkler), of which the commonest fossils are _T._ cf. _interposita_ and _G. brevirostris_. On general considerations they are thought to be indicative of Division A, possibly A3 (_meckelfeldensis_ dinoflagellate Zone) (Wood, in Bristow and Freshney, 1986). A single specimen of the facies-controlled dino-flagellate _Apectodinium_ sp. from a clay above the basal bed is indicative of an Early Eocene nearshore environment of deposition. Bioturbated

No	Locality	Grid ref	Stratal Unit	Fossil Group	Zone
1.	Whistler's Copse	SZ 1752 9975	Barton Clay	Dinoflagellates	porosum, or slightly younger
2	Bransgore	SZ 1853 9766	Barton Clay	Dinoflagellates	porosum [or intricata]
3	Godwinscroft	SZ 1905 9685	Barton Clay	Dinoflagellates	non-diagnostic
4	Allensworth Wood	SZ 1952 9627	Barton Clay	Dinoflagellates	laticinctum or younger
5	Christchurch Bh.	SZ 2002 9301	Barton-London Clay	Dinoflagellates	porosum to simile
6	Hengistbury Head	SZ	Barton Clay - Boscombe Sand	Dinoflagellates	draco to intricata Ass.Zone
7	Bournemouth cliffs	SZ	Boscombe -Branksome Sand	Dinoflagellates	coleothrypta (intricata Ass. Zone)
8	Anna Lane	SZ 1550 9964	Branksome Sand	Dinoflagellates	non-diagnostic
9	Clapcott's Farm	SZ 1632 9723	Branksome Sand	Dinoflagellates	non-diagnostic
10	nr. Winkton	SZ 1637 9644	Branksome Sand	Dinoflagellates	non-diagnostic
11	Dudmoor Farm	SZ 1494 9593	Branksome Sand	Dinoflagellates	non-diagnostic
12	Blackwater Hall Bridge	SZ 1396 9641	Branksome Sand	Dinoflagellates	Early Eocene
13	Stanpit 1	SZ 1715 9235	Branksome Sand	Dinoflagellates	Early Eocene
14	Stanpit 2	SZ 1697 9212	Branksome Sand	Dinoflagellates	Early Eocene
15	Stanpit 3	SZ 1700 9168	Branksome Sand	Dinoflagellates	Early Eocene
16	Barnes Farm	SZ 0965 9830	Branksome Sand	Dinoflagellates	non-diagnostic
17	Parley Court	SZ 0962 9715	Branksome Sand	Dinoflagellates	non-diagnostic
18	Branksome Dene	SZ 069 899	Branksome Sand	Dinoflagellates	coleothrypta or younger
19	Eastcliff	SZ 1000 9100	Branksome Sand	Dinoflagellates	coleothrypta (intricata Ass. Zone)
20	Eastcliff	SZ 1025 9106	Branksome Sand	Dinoflagellates	coleothrypta (intricata Ass. Zone)
21	Canford Cliff	SZ 0606 8931	Branksome Sand	Dinoflagellates	coleothrypta or younger
22	Parley Court No.1	SZ 0928 9649	Parkstone Clay	Dinoflagellates	coleothrypta or younger
23	Rossmore	SZ 0582 9355	Parkstone Clay	Dinoflagellates	coleothrypta or younger
24	Parkstone	SZ 0388 9104	Parkstone Clay	Dinoflagellates	non-diagnostic
25	"Sandbanks"	SZ 051 8841	Parkstone Clay	Macroflora	non-age diagnostic
26	Canford Magna 8	SZ 0429 9668	Broadstone Clay	Dinoflagellates	Early Eocene
27	Canford Heath	SZ 0305 9670	Broadstone Clay	Dinoflagellates	non-age diagnostic
28	Canford Heath (S)	SZ 0208 9508	Broadstone Clay	Dinoflagellates	non-diagnostic
29	Ashington	SZ 0004 9787	Broadstone Clay	Dinoflagellates	coleothrypta or younger
30	Beacon Hill	SZ 9834 9523	Broadstone Clay	Dinoflagellates	coleothrypta or younger
31	Canford Heath	SZ 0248 9430	Oakdale Clay	Dinoflagellates	coleothrypta or younger
32	Oakdale	SZ 0246 9453	Oakdale Clay	Dinoflagellates	coleothrypta or younger
33	Sterte Bh.	SZ 0095 9200	Oakdale Clay	Dinoflagellates	coleothrypta or younger
34	Rockley Sands	SY 9737 9090 9739 9108	Oakdale Clay	Dinoflagellates	coleothrypta or younger
35	Lake	SY 979 907	Oakdale Clay	Macroflora	non-age diagnostic
36	Marley Tile	SZ 0195 9438	Oakdale-Creekmoor Clay	Dinoflagellates	simile or younger
37	Upton Heath	SY 9809 9400	Creekmoor Clay	Dinoflagellates	non-diagnostic
38	Beacon Hill Bh.	SY 9761 9446	London Clay	Dinoflagellates	varielongitudum-hyperacanthum
39	Canford Magna 7	SZ 0578 9694	London Clay	Dinoflagellates	?varielongitudum or younger
40	Canford Magna 4	SZ 0439 9769	London Clay	Dinoflagellates Foraminifera	simile or younger non-diagnostic

No	Locality	Grid ref.	Stratal Unit	Fossil Group	Zone
41	Canford Magna 5	SZ 0443 9729	London Clay	Dinoflagellates	simile or younger
42	Henbury Pit	SY 9631 9732 9613 9766	London Clay(top)	Dinoflagellates	simile or younger
43	Higher Merley 1	SZ 0139 9792	London Clay(top)	Dinoflagellates	meckelfeldensis or younger
44	Higher Merley 2	SZ 0098 9823	London Clay(top)	Dinoflagellates	meckelfeldensis or younger
45	Knighton	SZ 0447 9965	London Clay	Dinoflagellates Foraminifera	meckelfeldensis or younger ~~Divisions B and~~ C of King (1981)
46	Canford Magna 1	SZ 0400 9908	London Clay	Dinoflagellates	Late Palaeocene/Early Eocene
47	Canford Magna 2	SZ 0406 9859	London Clay	Dinoflagellates	Early Eocene
48	Canford Magna 3	SZ 0425 9797	London Clay	Dinoflagellates Foraminifera	Early Eocene non-diagnostic
49	Canford Magna 6	SZ 0535 9789	London Clay	Dinoflagellates Foraminifera	Late Palaeocene/Early Eocene c. base of Division B of King(1981)
50	Knighton Farm	SZ 0445 9821	London Clay	Dinoflagellates	Early Ecocene
51	Canford Magna 9	SZ 0670 9802	London Clay	Dinoflagellates	hyperacanthum or older/ -Early Eocene
52	Canford Magna 10	SZ 0511 9952	London Clay	Dinoflagellates	" "
53	Canford Magna 11	SZ 0593 9882	London Clay	Dinoflagellates	" "
54	Canford Magna 12	SZ 0501 9860	London Clay	Dinoflagellates	" "
55	Merley 1	SZ 0055 9870	London Clay (base)	Dinoflagellates	" "
56	Merley 2	SZ 0050 9887	London Clay(base)	Dinoflagellates	" "
57	Knoll Manor	SY 9742 9770	London Clay (base)	Dinoflagellates Molluscs	" " ?Division A of King (1981)
58	Henbury Plantation	SY 9645 9703	London Clay (base)	Molluscs	?Division A of King (1981)

grey silty clays at an unknown height above the base of the London Clay from four boreholes (localities 51-54) in the Knighton area all yielded facies-controlled floras similar to those of Lambs Green and probably indicate an Early Eocene age rather than the *hyperacanthum* Zone. In the Beacon Hill Borehole (Locality 38), where the *hyperacanthum* Zone appears to be present, it is about 17m thick. *Hyperacanthum* Zone sediments elsewhere in the Hampshire Basin fall within King's Division A1.

At the top of the Warmwell Farm Sand in the Henbury Plantation Pit (Locality 58), patchily developed ferruginous concretions have yielded a few specimens of *Turritella* sp. and the bivalve cf. *Dosciniopsis bellovocina*. The sparse fauna is similar to that from the Knoll Manor Pit, and a Division A, possibly A3 (*meckelfeldensis* Zone), assignment is suggested for the Warmwell Farm Sand. There is no unequivocal evidence (see below) for strata above the Warmwell Farm Sand, or above the basement bed where the Warmwell Farm Sand is absent, of *meckelfeldensis* Zone age at outcrop. Elsewhere in the Hampshire Basin *meckelfeldensis* floras are associated with Division A2 and A3.

In the Beacon Hill Borehole (Locality 38), the *meckelfeldensis* Zone is about 9m thick.

At three localities (Nos.43-45) farther east, dinoflagellates indicative of either the *meckelfeldensis* or a younger zone have been obtained from bioturbated silty clays at an unknown height above the base of London Clay. The London

Clay at localities 43 and 45, contains members of the Apectodinium homomorphum plexus (Harland, 1979) together with Wetzeliella meckelfeldensis Gocht; at Locality 44 the same flora was found, together with Homotryblium tenuispinosum. The sparse assemblages indicate a near-shore marine, or even lagoonal, environment of deposition. Despite the presence of the zone fossil, a younger zone is not impossible and indeed is indicated by the foraminifera (Freshney, Bristow and Williams, 1985, p.18) which are consistent with Division B (ie simile Zone) or C (ie. varielongitudum Zone). Therefore, putting the evidence of the two fossil groups together, the samples from these three localities probably belong to the simile Zone.

One other locality (No.49) where a chronologically important fauna occurs is in the Canford Magna No.6 borehole. There, the foraminifera (see Freshney, Bristow and Williams, 1985, p.20) suggests a stratigraphical level at about the Planktonic Datum of Wright (1972), within Division B (ie simile Zone) of King (1981).

In the Canford Magna No.4 Borehole (Locality 40), the dinoflagellate cysts Homotryblium abbreviatum Eaton, H. tenuispinosum Davey and Williams, members of the Apectodinium plexus and Dracodinium simile (Eisenack) Costa and Downie, all consistent with a simile Zone assignment, were found in grey bioturbated silty clays that were overlain by a clayey, coarse-grained sand. This sand, which also occurs in the Canford Magna boreholes 1-3 (localities 46-48), may be the coarse top of the Division B cycle, but more probably represents local channel-fill deposits. Unfortunately no age diagnostic dinoflagellates were found in the samples from the last three localities. A *simile* Zone flora was recovered in the Canford Magna No.5 Borehole (Locality No.41).

In the Henbury Pit (Locality 42), the local top of the clay unit between the Warmwell Farm Sand and the Lytchett Matravers Sand is of *simile* Zone age, and therefore corresponds to part of Division B.

In the Christchurch Borehole (Locality 5), strata of *simile* Zone age have a minimum thickness of 8m.

The Lytchett Matravers Sand is probably the coarse-grained top to the Division B cycle of sedimentation.

In the Beacon Hill Borehole (Locality 38), the 4.5-m of strata at the top of the London Clay yielded *Wetzeliella lunaris* Gocht probably indicative of the *varielongitudum* Zone. Beneath it, 2.1m of fine-grained sand, possibly the Lytchett Matravers Sand, contain dinoflagellates of *simile* Zone age. In the Canford Magna No.7 Borehole (Locality 39), where the London Clay is not divided into members, the uppermost clay sampled, at a depth of 16m, yielded *Wetzeliella lunaris*, again a possible indication of the *varielongitudum* Zone. Underlying samples down to 20m contained *Homotryblium abbreviatum* and *H. tenuispinosum* suggesting lagoonal conditions within the *simile* Zone.

In the Christchurch Borehole (Locality 5), the *varielongitudum* Zone may be 76m thick and spans the whole of the Christchurch Member, 40m thick, at the top of London Clay, and about 37m of the clay below.

The *varielongitudum* Zone is the youngest zone of the London Clay in this part of the Hampshire Basin.

BOURNEMOUTH GROUP

In an earlier report (Freshney, Bristow and Williams 1984), the provisional term Bournemouth Formation was used for the predominantly arenaceous strata that lie between the London Clay and Barton Clay in the Bournemouth - Christchurch area. It was divided into a lower Branksome Sand (member) and an upper Boscombe Sand (member) which were regarded as probable part lateral equivalents of the Poole and Bournemouth formations of Curry and others (1978). As mapping progressed into the Poole area, it became clear that there were deposits between the London Clay and the Branksome Sand forming a lithologically distinct unit which approximates to the Poole Formation of Curry and others (1978). It also became clear that the Boscombe Sand is a marine deposit that passes eastwards into the Barton Clay of the central part of the Hampshire Basin. The term Bournemouth Group was, therefore, introduced (Freshney, Bristow and Williams, 1985) to comprise the lower Poole Formation and the upper Branksome Sand Formation (Figure 6). The group is roughly equivalent to the Bagshot Beds of One Inch Geological Sheet 329 (Bournemouth), first published in 1895. The Boscombe Sand is now regarded as the basal formation of the Barton Group (Figs 5 and 6).

POOLE FORMATION

The term Poole Formation was introduced by Curry and others (1978, pp.21-22, Table 1) for a sequence of sands and clays above the London Clay, and defined to include the Redend Sandstone, the Pipeclay Series, and the Agglestone Grit of Arkell (1947). The top of the Formation was taken at the base of the Bournemouth

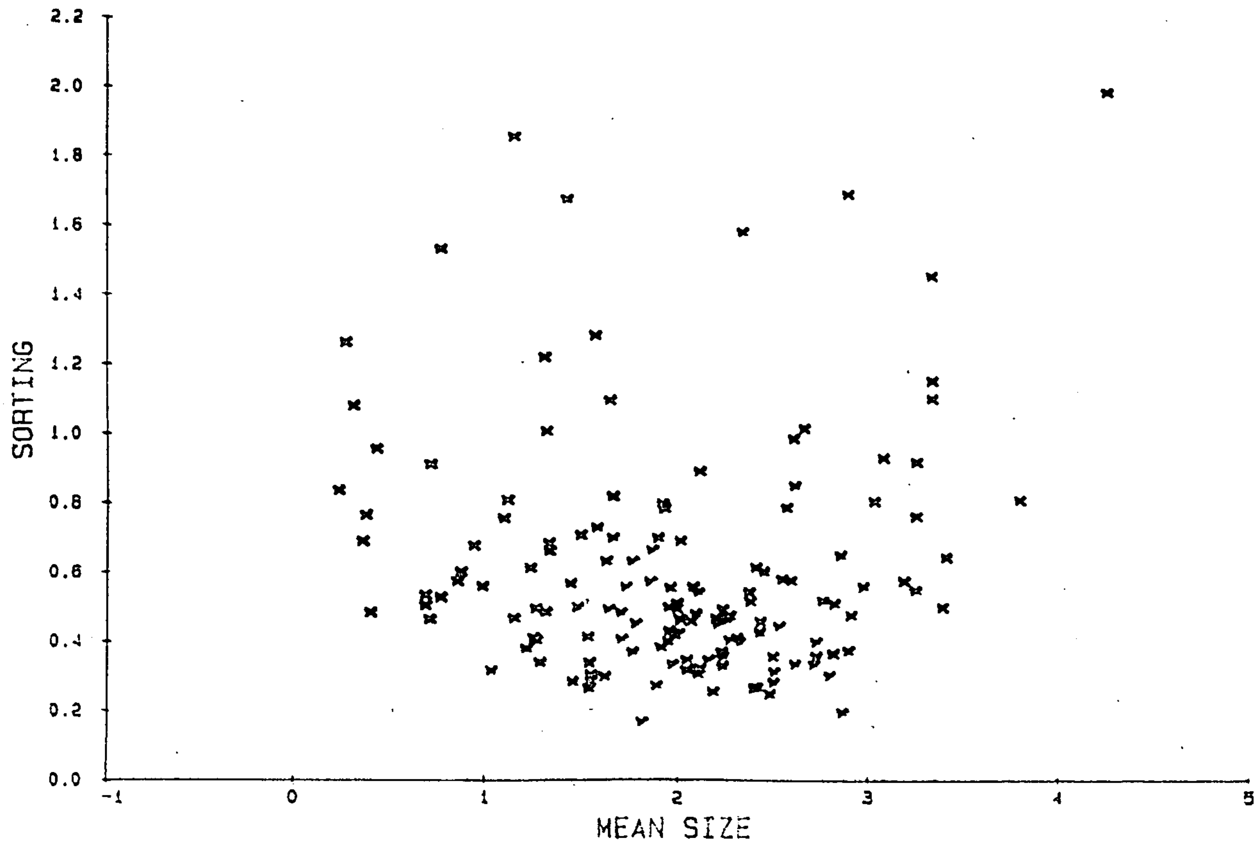
Freshwater Beds (the Branksome Sand of this account). The Poole Formation is equivalent to the 'Lower Bagshot' of Gardner (1877) and 'Lower or Pipe-clay Division' of White (1917).

Within the present area, the Poole Formation consists of an alternating sequence of fine- to very coarse-grained, locally pebbly, cross-bedded sands, and pale grey to dark brown, carbonaceous and lignitic, commonly laminated, locally red-stained, clays and silty clays, five of which have been named as members (Freshney, Bristow and Williams, 1985). The clays have been extensively worked for bricks, tiles and pottery. The sands generally are thicker than the clays and occupy just over half of the outcrop area.

The sands range in Mean Grain Size from 0.3 to 4.0ϕ with an average of about 2ϕ; the sorting ranges from 0.2 to 1.8ϕ, but with an average of about 0.4ϕ (Figs.10 and 11). The lower part of the Poole Formation, below the Oakdale Clay, consists dominantly of fining-upward sequences of poorly sorted, positively skewed (average 0.25, see figs. 10 and 11) sands. Some of the finer grained sands, particularly those above the Oakdale Clay, are well sorted and negatively skewed. Sands of this latter type occur throughout the district, but are commonest in the finer grained parts of the succession in the Christchurch Borehole.

Cross-bedding measurements (Fig.12) indicate sediment transport dominantly from the west and south.

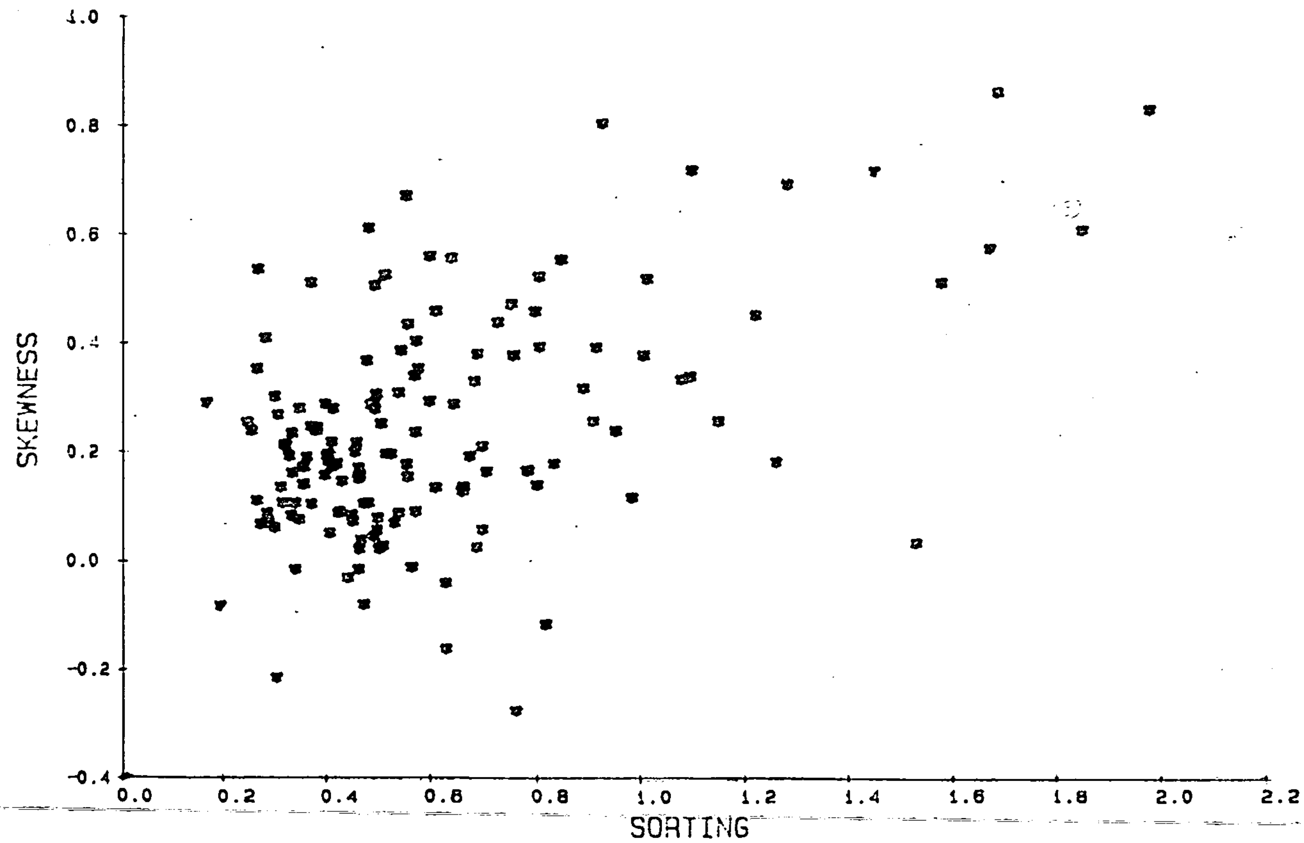
The formation crops out in an arc from Poole in the south, to Ferndown in the north (Fig. 3). It increases in thickness southwards and probably eastwards within the district. It is



x POOLE FORMATION

POOLE FORMATION- POOLE/BOURNEMOUTH AREA

Fig. 10



■ POOLE FORMATION

POOLE FORMATION- POOLE/BOURNEMOUTH AREA

Fig. 11

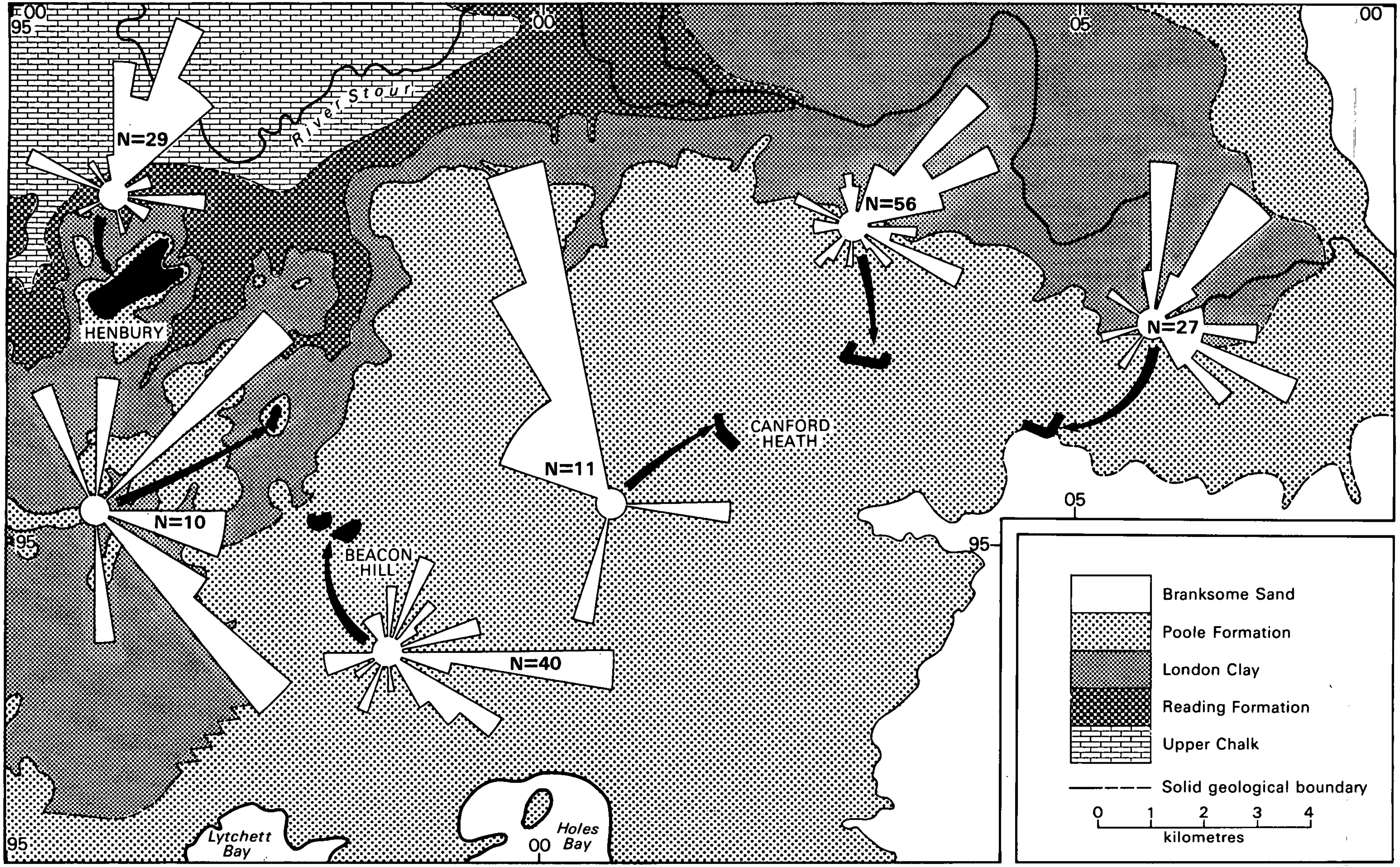


Fig.12 Current rose diagrams for sands of the Poole Formation

about 30m thick around Merley[015 983], about 40m in the Knighton area, and is calculated to be about 160m thick near Poole.

Between Merley and Stapehill [SU 055 005], the junction with the London Clay is taken at the base of a dominantly coarse-grained sand. In the Poole area, the base has been tentatively identified only in boreholes. The most complete sequence occurs in the southern part of the district, where the following units have been recognised:

Parkstone Clay
Sand
Broadstone Clay
Sand
Haymoor Bottom Clay (only locally developed)
Sand
Oakdale Clay
Sand
Creekmoor Clay
Sand (proved in boreholes only)
LONDON CLAY

In the north, only the Broadstone and Parkstone clays are developed, though a clay locally present below the Broadstone Clay around Uddens Plantation [SU 056 016], may correlate with one of the lower clays of the Poole area.

Since the Creekmoor Clay, which is of simile Zone age, passes laterally into the London Clay in the Lytchett Minster area, and as there are no signs of any signiificant breaks in sedimentation until at least the Broadstone Clay, it is evident that the Poole Formation is equivalent to the upper part of the London Clay of the eastern part of the Hampshire Basin. The strata below the Oakdale Clay probably correlate with the intertidal laminated clay and sand of the Wittering Formation in the eastern part of the Hampshire Basin. The strata above the

Oakdale Clay probably correlate with the glauconitic sands of the Earnley Formation.

Plint (1983b) divided his Bracklesham Formation (equivalent to the Poole Formation, Branksome Sand and Boscombe Sand of the present authors) into five sedimentary cycles, the bases of which are marked by a transgressive horizon. His Cycles 4 and 5 correspond to the bases of the Boscombe Sand and Barton Clay respectively, thus leaving three cycles within the Poole Formation. The evidence for the five cycles is based largely on the more marine sequence exposed on the Isle of Wight, which Plint correlated with five sedimentary cycles in what he regarded as dominantly fluvial sediments (of the Poole Formation, ?and the Branksome Sand) in the Wareham area. However, it is evident from the recent work in the Poole-Bournemouth area that all five cycles near Wareham must pre-date Plint's T4 transgression of the Isle of Wight (ie.the base of the Boscombe Sand).

In the Poole area, the Creekmoor, Oakdale, Broadstone and Parkstone clays correspond in lithology to the 'pure clay' facies of Plint (1983b) which he thought were lacustrine clays formed during periods of rising sea-level. From the sparse dinoflagellates recovered from several samples from each of them, part of these clay sediments were laid down in environments with a marine, possibly nearshore, influence. Thus the sea-level rises envisaged by Plint were more extensive than he thought. The clay units must correspond to transgressive phases and are not simply the results of lacustrine ponding because of a higher sea level.

In the following account, the sequence is subdivided into a number of couplets comprising an unnamed sand and an overlying named clay member. For convenience, the descriptive headings take their names from the clay within each couplet; the sands are included in each account.

Creekmoor Clay

The Creekmoor Clay has a wide outcrop in the Creekmoor and Upton areas [000 935], where it was formerly extensively worked for brickmaking; it is thought to underlie much of Holes Bay [00 92]. The "Unnamed clay" of an earlier report (Freshney, Bristow and Williams, 1985) is now known to be the Creekmoor Clay. The sand of the Creekmoor Clay couplet is known only from boreholes.

At outcrop, the clay is characteristically off-white to pale grey, red-stained and mottled. In boreholes, dark brown carbonaceous clays, laminated light grey and brown silty clays and clayey fine-grained laminated sand, all with common listric surfaces, have been recorded.

The full thickness of the clay/sand couplet has only been proved in the southern part of the district. It varies from 30 to over 45m; within this, the clay/sand thicknesses shows marked variations. In three boreholes [009 905; 0137 9040 and 0157 9037], clay thicknesses were 9.7, 16.1 and 32.9m respectively, and the sand 15.8, 14.9 and 10m respectively. Elsewhere, incomplete thicknesses of 13.4m [0110 9336], and 16.7m [0063 9132] of clay have been proved, and complete thicknesses of 15.2m [0110 9336] and 12.2m [0101 9181] of sand.

The following sequence taken from the driller's log of the old Dolphin Brewery well [009 905], Poole may be regarded as a representative section through the Creekmoor Clay:

	Thickness (m)	Depth (m)
Sand of the Oakdale Clay couplet		
Sand, dark grey	15.24	59.13
Creekmoor Clay couplet		
Clay, sandy, light coloured	4.57	63.70
Clay, mottled red	3.05	66.75
Clay, black, loamy, peaty and sandy	1.52	68.27
Claystone	0.31	68.58
Clay mottled	4.88	73.46
Sand, sharp, blowing (sic), light coloured	2.44	75.90
Sand, sharp, blowing, dark	3.13	78.03
Sand, sharp, blowing, light	0.91	78.94
Clay, black	0.92	79.86
Sand, sharp, blowing light grey	9.44	89.30
London Clay	12.20	101.50

<u>Oakdale Clay</u>

The Oakdale Clay and underlying sand extend in an arc from Holton Heath through Hamworthy, across the southern part of Poole Harbour, Oakdale, part of Canford Heath, Creekmoor [005 942] and Upton Heath. Part of the "Creekmoor" Clay of an earlier report (Freshney, Bristow and Williams, 1985) is now known to be the lower leaf of the divided Oakdale Clay.

Oakdale has been chosen as the type locality because several cored site-investigation boreholes were drilled into the clay there. One of these [0217 9323], which penetrated the full thickness of the clay and part of the underlying sand, is reproduced below:

	Thickness (m)	Depth (m)
Sand (of the Broadstone Clay couplet)	8.6	8.6
Oakdale Clay couplet		
Clay, silty, grey, very stiff, fissured	5.0	13.6
Lignite	1.5	15.1
Clay, silty, grey, very stiff to hard, fissured	7.9	23.0
Sand, grey, very dense	2.0	25.0

Elsewhere, the clay is commonly carbonaceous and laminated; red staining occurs locally. In places, one type of clay may pass laterally into the other. In several site investigation boreholes, polished, striated shear planes are recorded. At Poole [around 012 910], and Upton Heath [SY985 945], a lenticular sand up to 30m thick is present within the clay. It is the lower clay of the divided Oakdale Clay which was initially regarded as part of the Creekmoor Clay (Freshney, Bristow and Williams, 1985). The sand of the couplet varies from fine to very coarse grained, and is locally pebbly; the sorting ranges from very well sorted to moderately sorted. A sand bed within the clay [at 0243 9448] is also very well sorted. Excellent sections of the sand of the Oakdale Clay couplet can be seen in the old Marley Tile Pit [020 940] Poole (see Freshney, Bristow and Williams, 1985, pp.36-37, pl.1).

At Poole Hospital [0180 9140], the clay and sand thicknesses for the undivided Oakdale Clay couplet are 10.4m and 16.1m respectively. Under Canford Heath [around 022 942], the clay is only about 2 to 3m thick. North-westwards from there [0141 9482], the clay is 12.6m thick and rests on more than 30m of coarse-grained sand.

A clay at a depth of 1.9m in the BGS Marley Tile Borehole [0195 9438] is probably the basal part of the Oakdale Clay; it yielded the zonal index of the <u>simile</u> dinoflagellate Zone.

The Oakdale Clay is represented by a fining-upward sequence between the depths of 158 and 171m in the Christchurch Borehole. It contains a structureless clay at the top, with laminated clay and clayey fine-grained sands lower down. An extensive rootlet network is developed.

<u>Haymoor Bottom Clay</u>

The Haymoor Bottom Clay has an outcrop length of about 1.4km on low ground at Haymoor Bottom on Canford Heath [026 947 to 030 940]. Much of the outcrop is hidden by river terrace deposits, head and made ground. In the type area, the Haymoor Bottom Clay consists of hard grey silty clay.

A lenticular clay (which may correlate with the Haymoor Bottom Clay) extends from Uddens Plantation [SU 059 019] eastwards into a northward-draining valley [SU 063 015]. It has a maximum thickness of about 8m. The clay is fairly stiff, grey, locally mottled reddish brown, usually finely laminated with thin pale silty and sandy interbeds. The beds below the clay consist of at least 9.5m of fine- to medium-grained sand with thin clayey beds.

<u>Broadstone Clay</u>

Broadstone Clay takes its name from Broadstone [005 957] where the clay was worked for brickmaking [0085 9575] (White, 1917), and where it has been proved in several boreholes [around 004 954]. This is the most laterally persistent of the clays in the Poole Formation. In the north, the outcrop is impersistent between Bedborough Farm [SU053 020] and Dudsbury. From Dudsbury there is a continuous outcrop through Bearwood [045 966], Broadstone, Canford Heath [003 047] to just south of Oakdale Cemetry [025 925], beyond which the clay can no longer be recognised. An outlier of the sand of the couplet occurs at Hamworthy.

The clay varies from a pale grey silty clay, through homogeneous medium grey silty clay, to laminated, lignitic, silty and fine-grained sandy clay. The underlying sand varies from a silty, very fine- to very coarse-grained, commonly cross-bedded, sand, with medium-grained sand the dominant lithology.

Excavations [0218 9324 and 0215 9331] for the Oakdale underpass revealed the following composite section at the junction of the Broadstone Clay and the underlying sand, and may be regarded as typical of this couplet:

	Thickness (m)
Clay, reddish brown, sandy and silty, with silty sand partings; layers of sand near the base range up to medium-grained	1.5+
Sand, coarse-grained to pebbly, cross-bedded grey, white rotten flint grains common; some lamination picked out by pebble bands and thin carbonaceous layers	4.0+
Unexposed	?
Sand, coarse-grained, orange to dark brown with some fine gravel; well banded and laminated	over 1.1
Sand, clayey, coarse- to very coarse-grained, orange	0.2
Sand, clayey, fine-grained, yellowish orange, with streaky lamination; some blocky clasts of pale grey, extremely sandy clay to clayey fine-grained sand; carbonaceous layers about 1m down; grain size becomes medium, and the colour becomes brown downwards; strong marcasite stain near base. Water weeping from base which is sharp	2.0

OAKDALE CLAY

Clay, sticky, soft, pale grey; carbonaceous material ?rootlets; occasional masses of black to dark reddish brown, highly lignitic clay 0.3m across; some siderite nodules 2.0

Parkstone Clay

The clay outcrop extends from Poole Head [050 884], in an arc through Parkstone, to the north of Alderney [040 950]. North and north-west of Alderney and eastwards from Canford Heath, the Parkstone Clay is cut out by the Branksome Sand. The clay reappears in the Stour valley and has a continuous outcrop as far north as Ferndown, where it is again cut out; it re-emerges in the valley of Uddens Water. An outlier of Parkstone Clay caps Hill View, west of Broadstone.

The clay has been proved at shallow depth along Bourne Bottom [047 945 to 063 935] and crops out in the parallel valley south-west of Bourne Bottom [around 058 933] where clay was formerly worked in large pits. Clay was seen by Reid (MS map 1894) beneath the electricity station [0596 9254] at Branksome, and proved in one deep borehole [098 917] at Bournemouth.

The type area of this clay is Parkstone [036 910], Poole, where the clay was formerly extensively dug for pottery and tiles. Most of the pits have now been filled, but poor exposures remain at some localities [e.g. 0365 9097 and 0369 9133]. The section at the former locality (Freshney, Bristow and Williams, 1985) commenced in a sand within the clay; the lowest 3.5m of this sand, and the underlying clay, more than 15.2m thick, were proved in the BGS Homark Borehole [0364 9096] as follows:

	Thickness (m)	Depth (m)
Made Ground		
Sand, gravel, clayey, organic	2.0	2.0
Parkstone Clay		
Sand, black, slightly clayey, medium- to fine-grained, waterlogged	1.5	3.5
Sand, very fine-grained to silt with much fine- to medium-grained sand below 5m, dark greyish brown, clayey; some fine lignitic debris	2.0	5.5
Clay, medium grey with some marcasite staining and listric surfaces (possible seatearth)	8.0	13.5
Clay, grey to greyish brown and brown, streaky,	0.5	14.0
plastic, sticky with some marcasite staining; stronger brown colour with greater silt content 18 to 18.5m; below 18.5m dominantly a greyish brown plastic clay with only a small silt content	6.7	20.7

The sequence exposed in the pit, and that proved in the borehole, can be regarded as the type sequence for the Parkstone Clay.

In general in the type area, Parkstone Clay comprises a lower bluish grey, plastic ball clay (as proved in the Homark Borehole) and an upper, lignitic, commonly laminated, clay. The upper lignitic, laminated clay can be seen in poor sections [0365 9127 and 0390 9104] north and north-east of the Homark Borehole.

The lower sand of the couplet, which may be up to 30m thick, varies from silty and fine grained, to very coarse grained and pebbly, with medium to coarse the commonest grain size. Some beds are graded, and fine upwards from fine gravel; elsewhere, impersistent clay breccias with clay clasts up to 10cm occur (Freshney, Bristow and Williams 1985, pp.52-63; Bristow and Freshney, 1986,p.54; pl3). This sand is well exposed in the old pit on the north-west side of Canford Heath [030 968]. Cross bedding is common and indicates two principal current directions: one from the WSW and the other from the SE (Fig. 12). Most of the sand is moderately sorted, with some medium-grained sands being well sorted and some of the finer grained sands poorly sorted (Figs. 10 and 11).

The Parkstone Clay thickness varies. In the type area, the maximum recorded thickness is 16m [0342 9064]. At Newton [032 938], an incomplete 17m was proved in a well [032 938] in the old brickworks; the clay is absent about 1.5km N, having been cut out beneath the Branksome Sand. At Rossmore, thicknesses range from 6.5m [0707 9163] to 14.9m [058 931]; at Bournemouth, it is 17m thick [098 917], and farther north, in the Parley No.2 [SU 1020 0015], outside the present district, and No.1 [0928 9649] boreholes it is 5.5m and 14.43m thick respectively.

Biostratigraphy

Within the district, a rich flora, indicating a tropical environment of deposition, has been obtained from the Oakdale [SY979 907] and Parkstone clays [052 886] by Chandler (1962b, pp. 11-13; 1963, pp.8-10). No age can be deduced from it.

Fourteen samples of clay from the Creekmoor, Oakdale, Broadstone and Parkstone Clay members of the Poole Formation have yielded dinoflagellates. With two exceptions (Locality, 36), all had coleothrypta Zone (Costa and Downie, 1976) floras. The exceptions, the basal Oakdale Clay and the top of the Creekmoor Clay, had simile Zone floras. Unfortunately it has not been possible to divide the Zone into the Assemblage Zones of Bujak and others (1980), although it is known that the overlying Branksome Sand falls within the intricatum Assemblage Zone (see Fig.6). The presence of Homotryblium abbreviatum from the Broadstone Clay in the Canford Magna No.8 Borehole (Locality 26) may indicate the abbreviatum Assemblage Zone within the coleothrypta Zone, but it is long-ranging species and no importance can be attached to one specimen in isolation.

The Creekmoor Clay has only yielded diagnostic dinoflagellates from one locality (No. 36). There, members of the Apectodinium homomorphum plexus together with Dracodinium simile, the zone fossil of the simile Zone, were obtained. From Locality 37 on Upton Heath an assemblage indicative of a nearshore environment of Early to Middle Eocene age was found.

The basal Oakdale Clay at Locality 36 also yielded a simile Zone flora. All other samples from the Oakdale Clay had either undiagnostic floras (Locality 35), or coleothrypta floras (localities 31-34). At Locality 31 on Canford Heath, the index species Kisselovia coleothyrpta (Williams and Downie) Lentin and Williams was recovered; the poor flora probably indicates a nearshore environment of deposition. Similarly at the Oakdale Underpass (Locality 32), the sparse flora indicates an inner neritic environment of deposition within the coleothrypta Zone. One sample from the Sterte Borehole (Locality 33) also contained the eponymous zone fossil which, together with the other dinoflagellates, suggests again a nearshore environment of deposition with little marine influence. At Rockley Sands (Locality 34) members of the Apectodinium homomorphum plexus and K.cf.coleothrypta again indicate the coleothrypta Zone and a nearshore environment of deposition. A rich, but non-age diagnostic, macroflora was obtained by Chandler (1962b) from the Oakdale Clay of the foreshore at Lake.

Three samples of the Broadstone Clay (localities 26,29,30) yielded coleothrypta Zone floras, and two (localities 27 and 28) had undiagnostic floras. At Ashington (Locality 29) and Beacon Hill (Locality 30) single specimens of *K. coleothrypta* were obtained. An additional sample at Beacon Hill contained a single specimen of *Wetzeliella* cf. *articulata* Eisenack indicative only of a general Early to Middle Eocene age.

Two samples (localities 22 and 23) of the Parkstone Clay had coleothrypta floras. In the Parley Court No.1 Borehole (Locality 22) the zonal index species was obtained, whilst in the Parley Court No.2 Borehole (just outside the present study area), *Areosphaeridium dictyostilum* (Menendes) Sarjeant and *Wetzeliella horrida* Jan du Chene and Chateauneuf, both indicative of coleothrypta Zone, and laticinctum or younger Assemblage Zone, were obtained. At Rossmore (Locality 23), a sparse coleothrypta flora indicative of a nearshore palaeo-environment was recovered. A rich, but non-age diagnostic macroflora, was found in the Parkstone Clay by Chandler (1963) on the east side of Poole Harbour.

BRANKSOME SAND

The formation crops out in a 5-km wide arc between Ferndown in the north, through Parley and under the northern part of Bournemouth, and the Branksome area of Poole in the south. It is well exposed in cliff sections from Bournemouth Pier westwards to Canford Cliffs, though cliff protection schemes are steadily reducing the exposure(Fig.13).

The name Branksome Sand, after Branksome Chine, was introduced by Freshney, Bristow and Williams (1984) as the lower member of the Bournemouth Formation. In a later work (1985) these authors modified the terminology and regarded the Branksome Sand as the upper formation of the Bournemouth Group (see Fig.4).

In the Christchurch Borehole [2002 9301], the Branksome Sand is 71m thick; in a well [098 917] at Bournemouth the total thickness of the Branksome Sand is 70m.

The base of the formation is taken at a transgressive erosion surface that is marked by a sudden upward coarsening of sediment from either Parkstone Clay into Branksome Sand or, where the Parkstone Clay is absent, from the underlying fine-grained sand. Locally, the basal beds are fine-grained, well sorted, and commonly red stained; in the Alderney area, they are channeled into the Parkstone Clay and are ferruginously cemented at their base.

The bulk of the Branksome Sand consists of sand of various grain sizes arranged in eight fining-upward cycles of which the upper seven were lettered A to G in ascending order by Plint (1983b).

At the western end, between Sandbanks and Branksome Dene Chine, the cliffs expose mainly sand ranging from fine to very coarse grained and comprising the lowest five fining-upward cycles. Figure 15 shows the general arrangement of Plint's (1983b) fining-upward cycles on the cliffs between Sandbanks and east of Bournemouth Pier. One of the clay-rich units exposed in the cliffs (Freshney, Bristow and Williams, 1985, fig.12) shows great lateral variability in its ratio of clay to sand layers, being clayey near its western end at Branksome Dene Chine and becoming progressively less so eastwards. The bedding also changes from cm-scale lamination at the western end, to dm-scale and larger bedding eastwards. The section shows much disturbed bedding and rotational slump structures close to the channel margins. Cycle D sands appear to have cut down into the clayey unit.

The sands at the bases of the higher cycles include fine gravel. Impersistent beds of clay-clast conglomerate occur locally at the bases of the main and some subsidiary cycles. The cycles usually pass up to fine-grained sand or silt; pale grey kaolinite-rich silty clays ('pipe-clays') commonly form impersistent beds at the tops of the cycles. Evidence of fossil soils (palaeosols) are present in some of these clays; elsewhere, these horizons have been removed by erosion at the base of the overlying cycle. Cycle G is poorly exposed and may not be a separate cycle, but a finer grained, eastern equivalent of Cycle F. East of Bournemouth Pier, Cycle G consists of fine-grained sands and clays (Fig.13).

The sands are commonly strongly planar cross bedded in sets up to 2m thick. The distribution of cross-bedding for selected horizons in the Branksome Sand is shown by Freshney, Bristow and Williams, 1985, fig.7). These distributions, which are thought to be coincident with the directions of current flow, show great variability between the various units in the Branksome Sand. In the Alderney area, several sand-filled channels cut into the top of the Parkstone Clay have a N-S orientation with cross-bedding indicative of current flow from the north. Convoluted bedding is common in the Branksome Sand; it was probably formed by the rapid dewatering of saturated, poorly compacted sediment.

Brown clay interlaminated with silt and clayey very fine-grained sand occurs impersistently as fluviatile channel plugs (Plint, 1983a) at several levels in the Branksome Sand. They are laterally highly variable and range from laminated carbonaceous brown clays to clayey fine-grained sands. The bedding within these plugs is irregular with slump structures locally common. The tops and bottoms of the plugs are well-defined, but the margins are not. The plugs occur at or near the top of the fining-upward cycles (Figure 5) and seem to be most common at the top of Plint's Cycles C,D,F, and G; one occurs at the top of a largely unexposed unnamed cycle that underlies A. Plint (1983b) recorded channels ranging from 90m to 170m wide, and from 6 to 18m thick in Bournemouth cliffs. Inland exposures are rare, but boreholes indicate similar clay bodies at the same stratigraphical levels. The clays are commonly highly lignitic and much plant material has been recorded in them (Chandler, 1962a; 1963).

Interbedded and interlaminated clay, silt and fine-grained sand also occurs at the top of the Branksome Sand in the more easterly exposures of Cycle G. These beds contain marine molluscs and were called the Bournemouth Marine Beds by Gardner (1879). They consist of thin and rhythmically bedded fine-grained clayey sand and silty clay with common carbonaceous and rootlet beds, and bi-directionally cross-bedded sands containing the trace fossil Ophiomorpha (Plint, 1983b). Ord (1914) reported lignite logs, some bored by Teredo, in the sands. A persistent

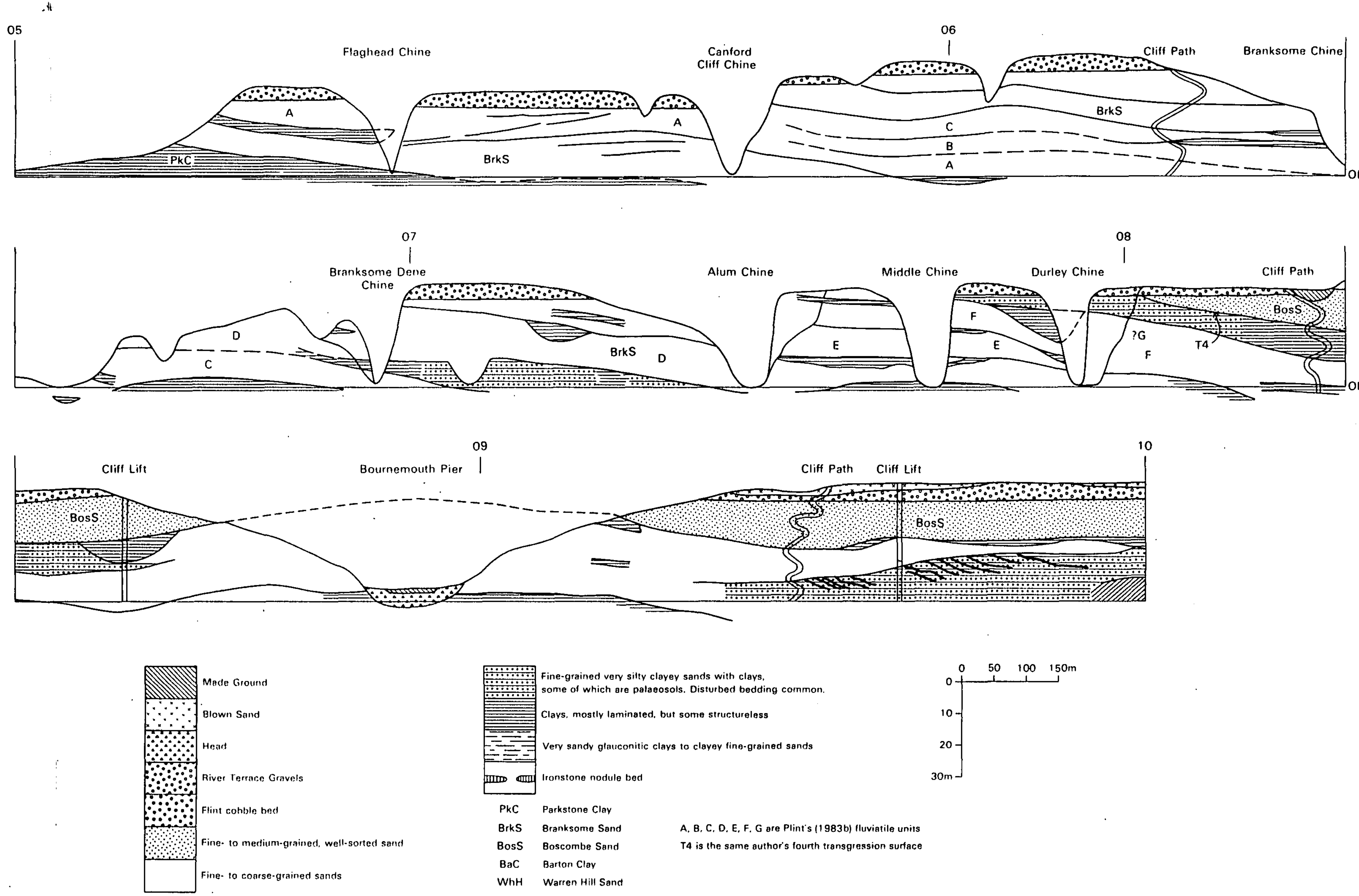


Fig. 13. Cliff section between Sandbanks and East Cliff, Bournemouth showing the arrangement of the various formations.

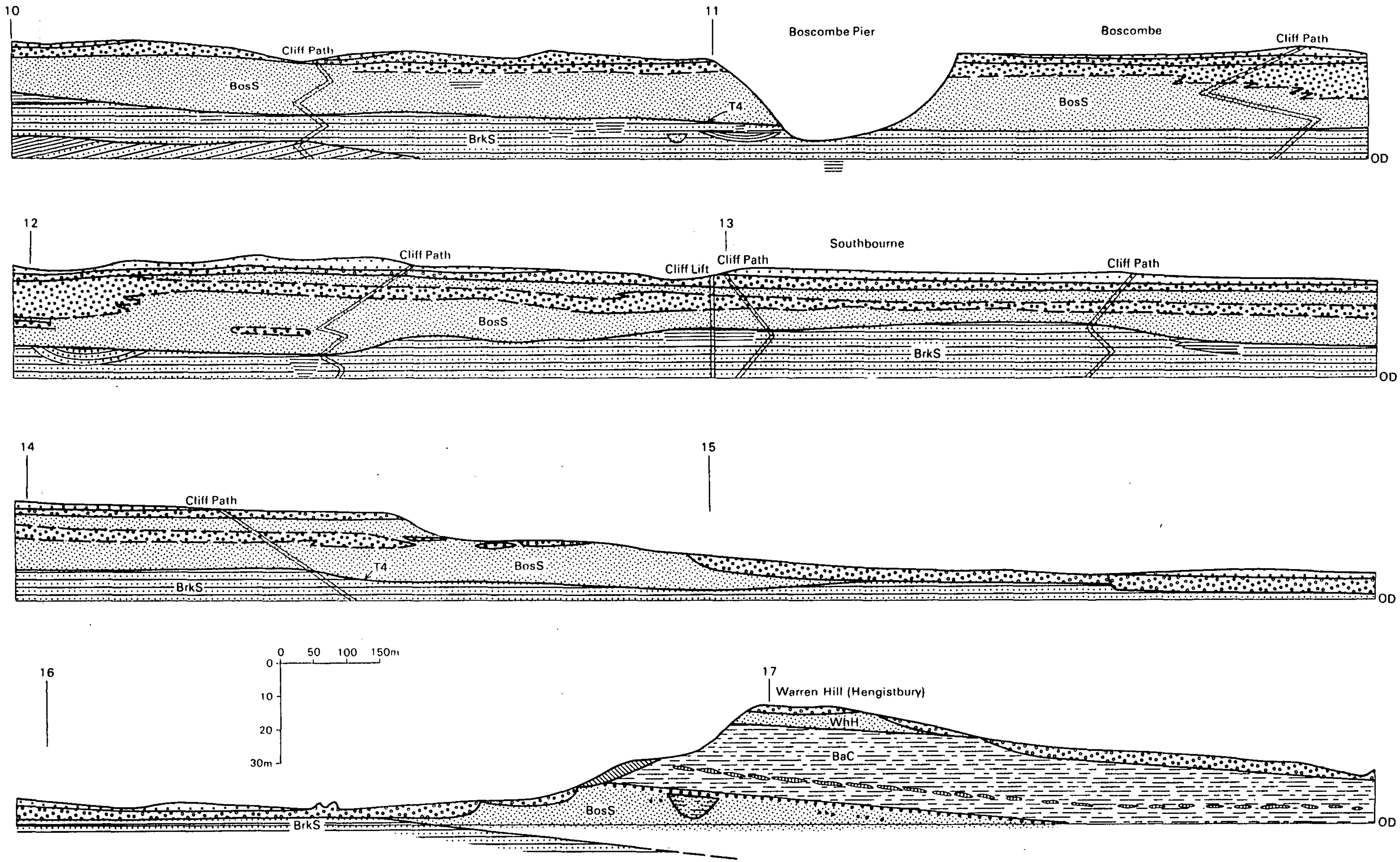
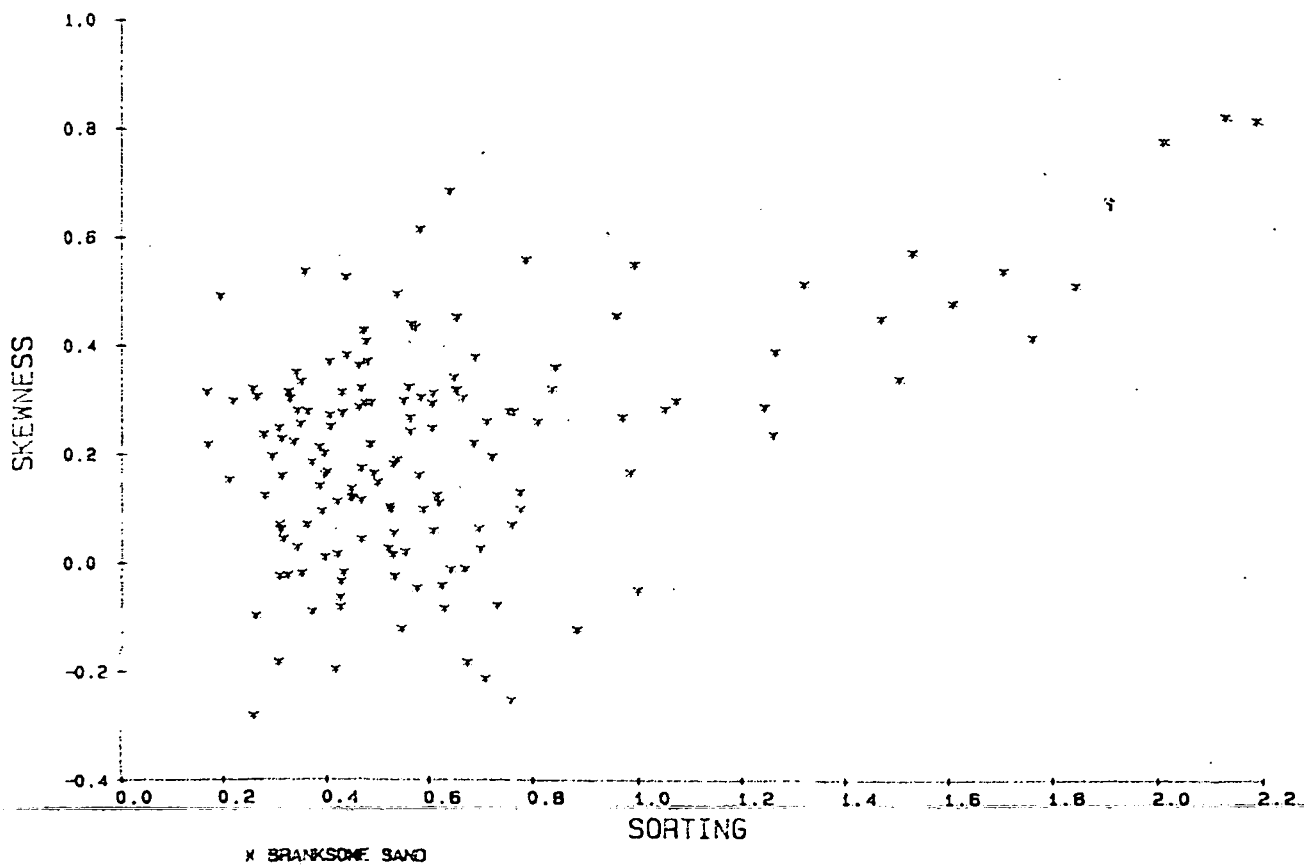


Fig. 14. Cliff section between East Cliff, Bournemouth and Warren Hill, Hengistbury showing the arrangement of the various formations. (Key to ornament etc. on Fig. 13).

BRANKSOME SAND- POOLE/BOURNEMOUTH AREA

Fig.15



BRANKSOME SAND- POOLE/BOURNEMOUTH AREA

Fig.16

laminated clay with a bleached palaeosol at the top occurs locally at the top of Cycle G. This clay gives rise to a perched water table and a pronounced spring-line in the cliffs.

The sands of the Branksome Sand consists mainly of quartz, with some flint grains which are particularly obvious in the coarser grained sands. The grains are sub-angular to sub-rounded, the very coarse grains being rather angular. The mean grain size ranges between 0.330 (800um) and 3.20 (108 um) with an average of 1.980 (253 um) (Figure 15). A wide range of sorting is present from very well sorted (0.170) to poorly sorted (2.20), with an average of 0.65. The skewness also has a wide range (-0.22 to 0.8) and an average of 0.23 (Fig. 16).

Biostratigraphy

Age-significant dinoflagellates were obtained from the Branksome Sand only in the Bournemouth cliff sections(Fig.3). Samples from all ten inland localities (No.8-17) had sparse non-age diagnostic floras. The floras from the cliffs have been reported on by Costa and others (1976). Additonal samples collected by the authors, and also by R.V.Melville lower down in the sequence, are mentioned here for the first time. The oldest sample was from Canford Cliff (Locality 21). It contained only a poor dinoflagellate flora, but did include the index species of the *coleothrypta* Zone; a nearshore environment of deposition is indicated. Farther east, at Branksome Dene (Locality 18) a few specimens of *K. coleothrypta* were also obtained. About 400m ENE of Eastcliff (Locality 19), a brown carbonaceous clay yielded *Glaphyrocysta undulata* (Eaton) Stovis and Evitt and

Cordosphaeridium funiculatum Mergenroth. The presence of *Glaphyrocysta intricata* (Eaton) Stovis and Evitt and *G. vicina* (Eaton) Stovis and Evitt from a sample near the Toft Zigzag (Locality 20) indicate the *intricata* Assemblage Zone. The coastal section eastwards from about this last point to Southbourne also yielded *intricatum* Assemblage Zone floras)Costa and others, 1976).

The shelly marine fauna recorded by Gardner (1879) in Cycle G does not have any biostratigraphical significance, but may represent a chronostratigraphical event. The fauna includes species of the gastropods *Calyptraea, Phorus, Natica* and *Cerithium* and the bivalves *Arca, Modiola, Ostrea* and *Tellina*.

BARTON GROUP

The Barton Group includes four formations, the Boscombe Sand, Barton Clay, Chama Sand and Becton Sand. The Barton Clay locally contains a sand member, the Warren Hill Sand, whose outcrop is limited to Hengistbury Head (Freshney, Bristow and Williams, 1984). The Group comprises a number of upward-coarsening cycles, representing marine transgressions and regressions, some of which terminate in shore-face or beach barrier sands.

BOSCOMBE SAND

Boscombe Sand underlies much of Bournemouth between Meyrick Park and Southbourne. It is well exposed along much of the cliffs in these areas. The outcrop is broken by Christchurch Harbour; the beds form an outlier at Hengistbury Head and then reappear in the cliffs at Highcliffe, the so-called Highcliffe Sands, where they dip eastwards beneath the Barton Clay. From Mudeford on the coast, northwards to North Ripley the sand is extensively drift covered.

In the Christchurch Borehole, the Boscombe Sand is 20m thick.

The base of the Boscombe Sand is taken at a sharp lithological change from laminated carbonaceous brown clays (Branksome Sand) to fine- to medium-grained, wellsorted sands. At localities where the highest bed of the Branksome Sand is a sand, the boundary is taken at an erosion surface, marked by contrasting sedimentary and grain-size features in the sands, that was regarded as a marine transgression surface (T4) by Plint(1983b).

The Boscombe Sand comprises two main bedding forms in the present district: marine, medium-grained, plane-laminated with a few planar cross-bedded sands with pebble and cobble beds occur in the lower part of the formation, and estuarine bi-directional cross-bedded sands in the upper part. The sands are mainly well sorted and fine to medium grained.

The pebble and cobble beds are well displayed in the cliffs between Boscombe and Southbourne (Freshney, Bristow and Williams, 1984). Good sections in the Boscombe Sand occur on Hengistbury Head. Locally, bituminous sands up to 2.5m thick are present. A section through a channel containing these bituminous sands is given in Freshney, Bristow and Williams (1984, fig. 7). The origin of this bituminous sand and its subsequent disruption is described in detail by Plint (1983c).

At Friars Cliff [197 928], Plint (1983b, fig.9) described three upward-coarsening, mouth-bar sequences, each about 5 to 6 metres thick. Each unit consists of an upward gradation from intensely bioturbated dark brown, sandy and silty clay, rich in plant debris, through silty sand into fine-grained, clean, faintly parallel-laminated sand. This last is overlain by cross-bedded, fine- to medium-grained sand containing layers of mud pellets. A structureless sand at the top of the Boscombe Sand in this area appears to have lost its original depositional features through quicksand action. Buff sand with ball-and-pillow structures is also seen in this locality. Most of the balls are between 0.5 and 1m, but some are up to 4m in diameter. Large-scale dewatering structures penetrate 4m of beds in this vicinity.

At the western end of the Hengistbury Head, an impersistent layer, up to 1.25m thick, of well sorted fine-grained sand with cobble beds at the top and bottom occurs at the top of the Boscombe Sand. These deposits probably represent a return to shoreface conditions, the cobbles having been derived from a storm beach.

At Hengistbury and Mudeford, the uppermost part of the Boscombe Sand contains upward-coarsening, carbonaceous, silty, bioturbated sands, and remobilised muddy sands (slurry beds) containing clasts of bituminous sand. These deposits were regarded by Plint(1983c) as estuary mouth bar sands and estuary channel plugs respectively.

Thin (1 to 100mm) pale grey to cream, silty clay seams (pipe-clay) are fairly common throughout the district.

The sands of the Boscombe Sand consist mainly of quartz grains, but at some levels flint grains are common. The Mean Grain Size varies between 1.0Ø(500um) and 3.5Ø(88um) with an average of 2.2Ø(218um). The sorting ranges between 0.18Ø and 1.7Ø with an average of 0.42Ø and the skewness between +0.7Ø and -0.5Ø with an average of +0.10. Some samples, notably those from the top of the Boscombe Sand at Hengistbury Head, have a sorting average of 0.3ϕ and a skewness average of −0.4ϕ. Scatter plots of mean size/sorting, and sorting/skewness are shown on Figs. 17 and 18.

Biostratigraphy

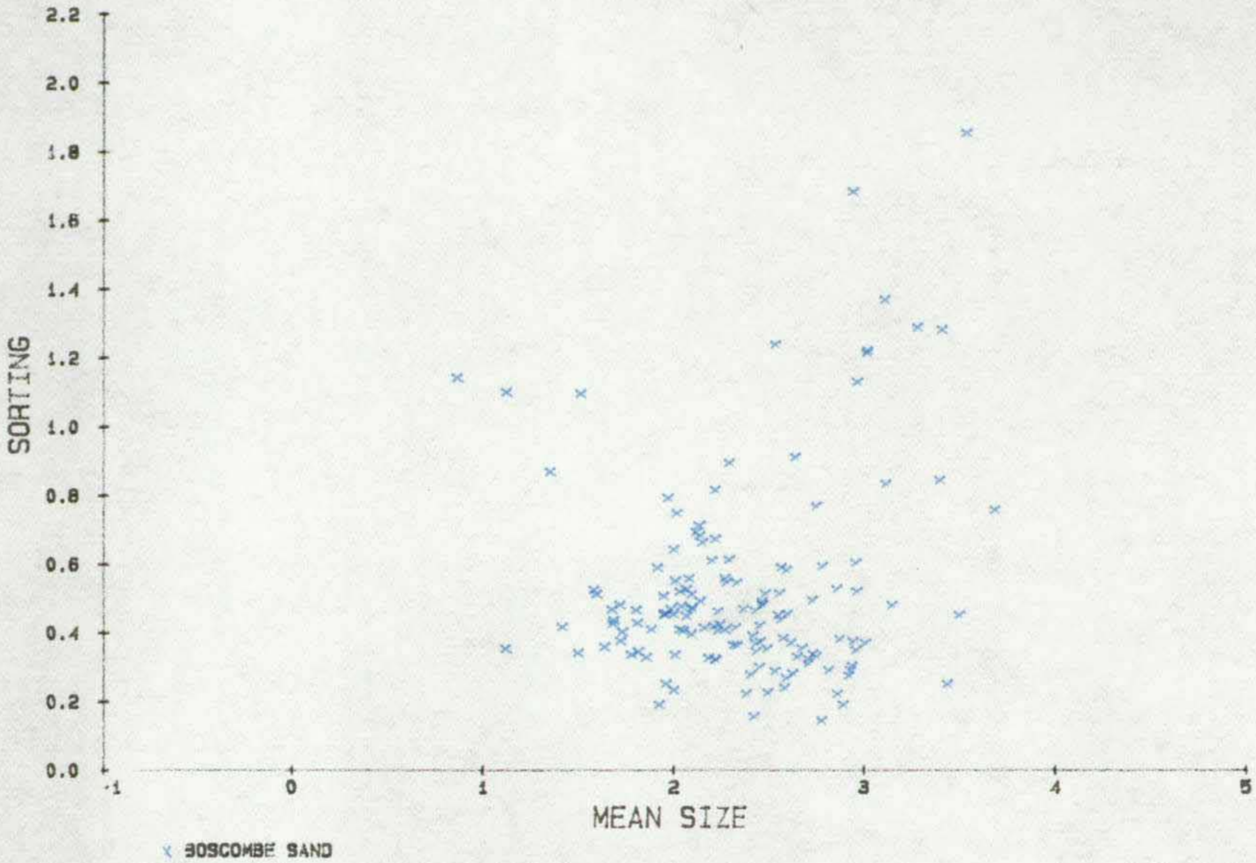
The Boscombe Sand has yielded few body fossils. The topmost beds of the member at Hengistbury Head and Southbourne contain dinoflagellates indicative of the *C. intricata* Assemblage Zone, as do the clays at the top of the Branksome Sand (Costa, Downie and Eaton, 1976).

Chandler (1963, p.18) obtained more than fifty species of plants, together with the brackish or marine bivalve ?*Meretrix*, and the foraminifer *Nummulites sp.* from the Boscombe Sand at Friars Cliff. Burton (in Chandler, 1963) recorded unspecified molluscs from the same beds.

There is faunal and floral evidence from outside the present district to suggest that these lower beds of the Barton Group are contemporaneous with marine clays in the New Forest area (Huntingbridge Formation of Curry and others, 1978).

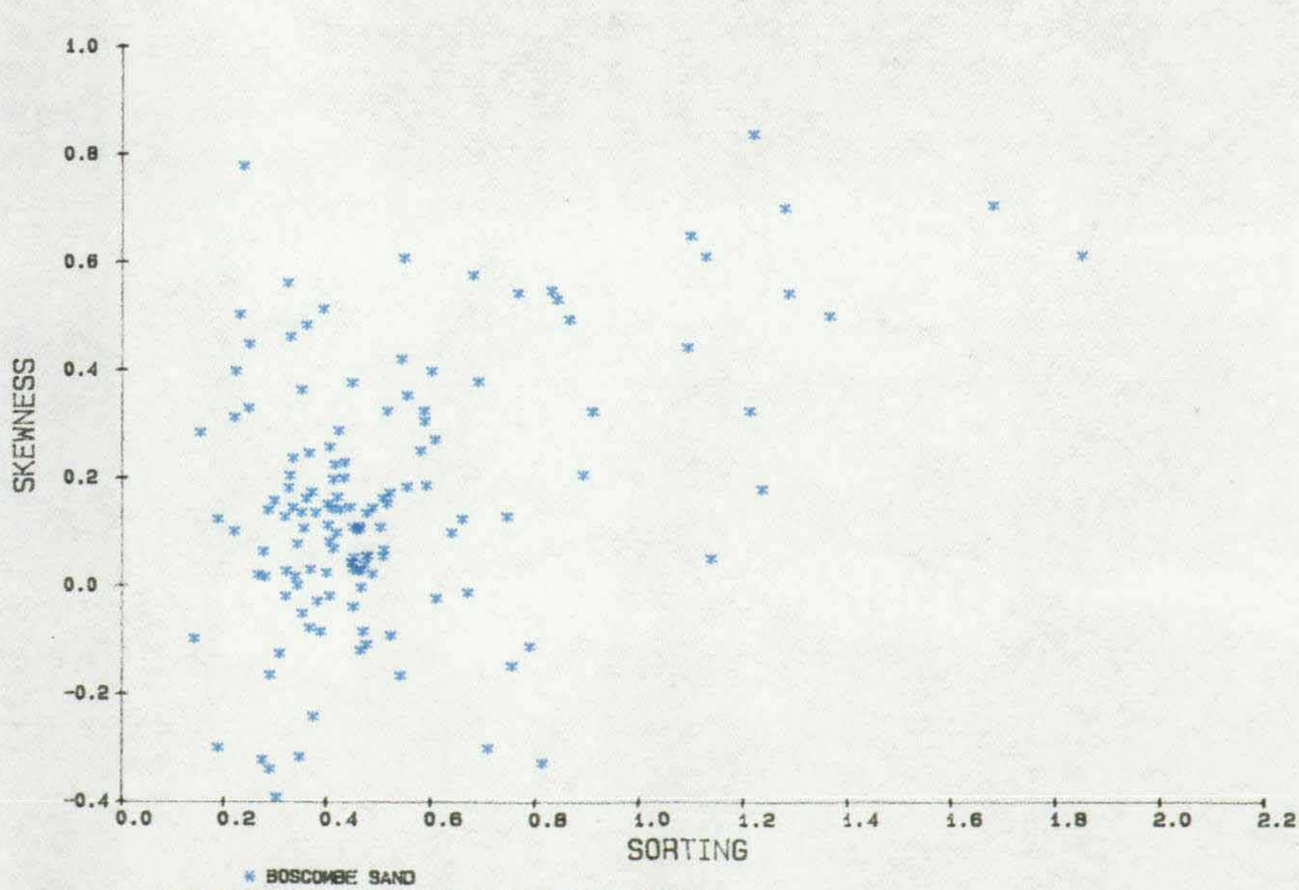
BARTON CLAY

In the district, the formation crops out in an area stretching north from the coast at Highcliffe [197 928] towards Bransgore [180 975] and Ripley [160 000], but most of the outcrop is obscured by river terrace deposits. A small outlier occurs at



BOSCOMBE SAND -POOLE/BOURNEMOUTH AREA

FIG.17



BOSCOMBE SAND- POOLE/ BOURNEMOUTH AREA

FIG.18

Hengistbury Head.

The formation consists of mainly yellow-weathering, greenish grey to olive-grey, commonly glauconitic clays, with a variable content of very fine-grained sand scattered throughout and in discrete bands. The Barton Clay is usually heavily bioturbated with little sign of lamination. Where unweathered, the clays are commonly shelly; the upper part of the sequence is particularly rich in bivalves. A sequence of up to 10m of laminated, yellow to white, fine-grained sand, the Warren Hill Sand, occurs within the top part of the Barton Clay at Hengistbury Head (Freshney, Bristow and Williams, 1984).

No obvious variation in the bulk lithology occurs in the limited outcrop of Barton Clay within the district.

The Barton Clay is about 39m thick at Barton on Sea, a few kilometres east of the present district. Estimates in the Bransgore area indicate a thickness of around 60m, and an old water borehole at Hinton Admiral House [2084 9602] shows 70m of Barton Clay.

Various definitions of the base of the Barton Clay have been given by different authors. In the original description (Prestwich, 1849), it was taken at the base of the pebble bed at the base of glauconitic sandy clay at Highcliff Castle [203 931]. Keeping (1887) adopted the incoming of the foraminifer _Nummulites prestwichianus_ at the base of the Barton Clay, an horizon about 3m above that chosen by Prestwich and within an apparently lithologically uniform glauconitic sandy clay. This interpretation was followed by Curry and others (1978). At Highcliff, Prestwich's basal bed of the Barton Clay consists of well rounded black flint pebbles set in a sandy, glauconitic clay. At Hengistbury, a similar clay locally rests on a cobble gravel at the top of the Boscombe Sand (see Freshney, Bristow and Williams, 1984, fig.7).In places the cobbles have been incorporated into the basal bed of the Barton Clay. Elsewhere, the cobble bed is absent, and the Barton Clay rests directly on clean, very well sorted, very fine-grained sand. This sand, up to 2m thick, also has a cobble bed locally well developed at its base. Plint (1983c, fig.2; 1983b, fig.6) regarded the base of this lower cobble bed (the base of his T5 transgression) as the base the Barton Clay.

For mapping purposes, a boundary taken at either the level of the incoming of N. prestwichianus (following Curry and others, 1978), or at the base of the lower cobble bed (following Plint, 1983b; c) is impractical. The present authors have therefore followed Prestwich's (1849) definition because it is based on a persistent lithological character that can be traced inland.

The problem of whether the glauconitic sandy clays, the Hengistbury Beds, at Hengistbury, are at the same stratigraphical level as similar strata, the Barton Clay, exposed at Highcliffe [200 929] has been the subject of much discussion since the time of Lyell (1827). The controversy was summarised by Hooker (1975). The currently accepted interpretation, first advocated by Prestwich (1849), is that both clays are at the same stratigraphical level. This was supported palaeontologically by Curry (1942) and by Costa and others (1976), and by Blondeau and Pomerol (1969), working with heavy minerals.

Burton (1933) divided the Barton Clay of the type area into a number of faunal and lithological divisions numbered in ascending sequence A1 to A3, and B to F (Fig.5) For the most part these are not mappable units, although unit A3, a grey clay with beds of fine-grained grey sand in the cliffs at Barton on Sea, is probably the lateral equivalent of the Warren Hill Sand at Hengistbury.

Blondeau and Pomerol (1969) studied the heavy minerals from the Barton Clay at Hengistbury. In the higher beds, kyanite and garnet are more abundant than staurolite and become increasingly abundant upwards, where they are associated with a rich assemblage of epidote, anatase, brookite, hypersthene and titaniferous corundum. The presence of epidote suggested to them a correlation with part of the lower Barton Clay at Barton on Sea. The clay minerals of Hengistbury include kaolinite (50 to 80%) with subordinate illite, although in one sample the proportions are reversed.

The Barton Clay at Hengistbury has been described by many authors (Lyell, 1827; Prestwich, 1849; Gardner, 1879; Reed, 1913; White, 1917; Hooker, 1975, and Curry, 1976). A generalised section for the Barton Clay at the western end of Hengistbury Head is given in Hooker (1975). The Barton Clay is more arenaceous there than at the eastern end; sand beds within the clay thin and pass eastwards into sandy clays. Large balls of well sorted very fine-grained sand occur in the middle part of the sequence.

The ironstone nodules, a characteristic feature of the Barton Clay at Hengistbury, are up to 1m in diameter and occur as impersistent layers at four levels; numbers 1, 2 and 4 persist throughout the section (Hooker, 1975, fig.4). The nodules were quarried and also collected from the foreshore for iron between 1847 and 1865 (Tylor, 1850; West, 1886).

Warren Hill Sand

The upper part of the cliff at Hengistbury Head consists of very fine-grained, buff and yellow, cross-bedded sands overlain by river terrace deposits. They were first noted by Lyell (1827), but not named until 1879 when Gardner referred them to the Highcliff [sic] Sands on the basis of their supposed correlation with sands (the Boscombe Sand) that crop out under the Barton Clay at Highcliffe [200 929]. A new name was therefore needed and the term Warren Hill Sand, after the type section at Warren Hill [1700 9050], Hengistbury, was introduced by Freshney, Bristow and Williams (1984).

Although thin beds of lithologically similar sand occur in the Barton Clay beneath the Warren Hill Sand, the base of the Warren Hill Sand appears to be sharp; the junction is only exposed in the upper part of the cliff and is not easily accessible. The maximum thickness of the Warren Hill Sand is about 10m. No fauna has been recorded from it.

Biostratigraphy

The clays at Hengistbury are only sparsely fossiliferous. Nevetheless the fauna is diverse and includes fish, molluscs, echinoids, crustaceans, foraminifera, otoliths and plants (Chandler, 1960; Chapman, 1913; Curry, 1942; Hooker, 1975; Reed, 1913, and Stinton, 1975; 1977).

The Barton Clay of the type section at Barton on Sea [235

929] contains an abundant marine fauna dominated by bivalves and gastropods; other fossils include corals, echinoids, serpulids and scaphopods and fish vertebrae. The fauna is indicative of shallow marine conditions of normal salinity.

Work on the dinoflagellate floras has shown that the beds up to the level of the *N. prestwichianus* nummulite horizon belong to the *intricata* Assemblage Zone of Bujak and others (1980), and that the beds above belong to the succeeding *draco* Zone (Costa and others, 1976). Dinoflagellates of the *Heteraulacacysta porosa* Zone (in part the equivalent of the *draco* Zone of Costa and Downie, 1976) were recovered from the uppermost Barton Clay at two localities inland (Nos. 1 and 2) beneath river terrace deposits.

CHAMA SAND

The Chama Sand crops out only in the north-east of the district where it has a narrow outcrop parallel to the Barton Clay. The formation consists of greenish grey to grey, slightly glauconitic, clayey silty, very fine-grained sand and extremely sandy clay. Where unweathered it is commonly shelly. The formation is highly bioturbated; in places near-vertical burrows, possibly of *Ophiomorpha* occur. The Chama Sand forms a transitional unit between the Barton Clay and the overlying Becton Sand. Its base is marked by the incoming of slightly glauconitic, clayey silty very fine-grained sand. The junction of the Chama Sand with the Barton Clay is commonly marked by a concave topographical feature and a spring line.

The Chama Sand is estimated to be around 5m thick near

Bransgore. It thickens south-eastwards to 8m at Becton on Sea.

The formation is too poorly exposed in the district to be satisfactorily sampled. However, lithologically similar samples of Chama Sand from the Southampton district have been shown to have mean grain-size ranging between 3.3ø and 5ø (25-100 um), moderately good to very poor sorting (Sorting Index = 0.5-2.31ø) and grain-size distributions that are strongly positively skewed (skewness coefficient =0.5-0.8ø). The heavy minerals are composed dominantly of Morton's (1982) Association A, ie. a garnet-epidote assemblage derived from a northern metamorphic basement.

BECTON SAND

The Becton Sand crops out in the north-east around Bransgore where it forms well drained land. It forms the uppermost part of a marine regressive sequence. Just east of the district, the formation is divided into three members, but the middle, Becton Bunny Member, is impersistent and has not been found in the present area. The upper and lower members consist of fine-grained sands and cannot be differentiated.

In surface exposures, the Becton Sand consists of yellow to pale grey, well-sorted, fine- to very fine-grained sands (Average Mean Grain size 3.09ø). Where unweathered, the sand is greenish grey. At most localities, the sand appears structureless, although some cross-bedding is present; the lower part of the sands is bioturbated and shelly. Callianassid burrows and rootlet horizons have been recorded outside the present district.

The definition of the base of the Becton Sand is arbitrary because it depends on the recognition of a gradational decrease in clay content upwards from the Chama Sand.

The thickness of the Becton Sand at Bransgore is about 7m, compared with 24m at Barton on Sea.

The lighter fraction of the Becton Sand is composed dominantly of angular to subrounded quartz. The Mean size varies between 2.4Ø and 3.7Ø (75 um - 180 um), and the sorting between very well and moderately sorted (SI= 0.18Ø - 0.90Ø). The Becton Sand usually shows low positive to negative skewness values. The heavy minerals (Morton, 1982) are dominated by northerly-derived material characterised by garnet and epidote.

HEADON FORMATION

The Headon Formation, of which only the lowest of the three members seen in the New Forest is present, crops out only in the high ground east of Bransgore where it is over 16m thick. Much of the outcrop is obscured by gravel and gravel wash. The formation consists of pale greenish grey, relatively sand-free, locally shelly clays, together with a considerable thickness of banded and roughly laminated very fine-grained sand, silt, and clay. The base is usually marked by carbonaceous silts, commonly associated with lignite. A palaeosol is developed below these beds and the roots commonly descend into the top of the Becton Sand.

The lower Headon Formation seen at Bransgore contains more sand than in the New Forest, but it is similar to that at Hordle Cliff near Barton on Sea. The clays of the formation generally have a high kaolinte content and are usually pale greenish grey. The sand and silt grade content of the clays is commonly low, and consists mainly of subangular quartz ranging in size from 10u to

100u. Some marcasite is also locally present. Fine shell debris is commonly abundant either spread throughout the clay or as bands and laminae. The macrofauna consists of brackish to freshwater molluscs.

Conditions of deposition of the Palaeogene

The Reading Formation formed in a fluvio-marine environment in which periods of sedimentation alternated with periods of emergence and soil formation in a climate with a fairly high annual temperature and a dry season (Buurman, 1980).

The sediments of the lower part of the London Clay comprise three coarsening-upward sequences (Divisions A, B and C of King, 1981), which represent the repeated progradation of a nearby shoreline or delta, followed closely by an abrupt marine transgression often marked by a flint pebble bed. The many laterite layers, however, suggest periodic sub-aerial emergence. The coastline probably trended NE-SW, and the heavy minerals suggests sediment flow along the coast from the north-east (Morton, 1982).

The grain-size distribution of the Warmwell Farm Sand suggests that it was deposited on a shoreface or beach at the end of a regressive sequence (Divison A of King, 1981). North of Poole, in the area around Wimborne Minster, shelly sediments of the third cycle (Division C) probably mark a NE-SW trending coastline with a beach barrier sand, but farther south in the Poole area, sands of the coeval Christchurch Member represent a fluviatile system bringing sediment from the west and feeding distributary or estuarine channels in the area of Poole Harbour, Christchurch and Alum Bay in the Isle of Wight. The thicker beds of silty fine-grained glauconitic sand in this member were probably deposited in channels, and the laminated brown carbonaceous clays and fine-grained sands were probably deposited in interdistributary bays. Rootlets in some of the clays, and palaeosols without rootlets, indicate periodic subaerial conditions possibly on a delta top. Thus, the coastline was interrupted by an eastward-flowing deltaic system that was constrained to the south by an active structure along the Isle of Purbeck Monocline. The delta distributaries debouched into the more fully marine area in the eastern part of the Hampshire Basin.

Deposition of the Poole Formation saw a breakdown of the relatively linear coastline a cessation of the supply of heavy minerals from the north-east, and a commencement of supply from south and west (Morton, 1982), probably the result of contemporaneous faulting which disrupted the regional sedimentation pattern at the end of deposition of the London Clay. Though Plint(1983a) regarded the sands of the Poole Formation as deposits of a meandering river, geophysical logs of the Christchurch Borehole and some of the Wytch Farm oilwells, and grainsize analysis show many coarsening-upward as well as fining-upward sequences indicative of a prograding coastline. Plint also thought that the clays of the Poole Formation were deposited in alluvial and lacustrine environments, with the laminated clays being deposited in marshy swamps and temporary lakes, and the sand-free, commonly red-stained clays (his'pure clay') laid down in extensive lakes during times of high sea level. The dinoflagellate floras, however, indicate a closer marine affinity than Plint supposed. The laminated brown clays and silts are more likely to have been deposited intertidally, or on coastal marshes with a relatively free connection to the sea. The 'pure clays' of Plint appear to be mainly palaeosols developed on the less sandy, but possibly originally laminated, carbonaceous clays that were perhaps deposited in lagoons.

In the part of the Poole Formation below the Oakdale Clay, fining-upward sequences and poorly sorted, positively skewed sands are common in the Poole-Bournemouth area, and in the Christchurch Borehole. However, grain-size analyses of some Poole Formation sands between Poole and Wimborne Minster and in the Christchurch Borehole indicate beach and shoreface conditions, particularly during the deposition of sands of the Parkstone and Broadstone clay couplets.

It therefore appears that east of the Poole-Bournemouth area, deposition in the Hampshire Basin was sub-tidal to inter-tidal up to and including the Oakdale Clay, while in the Poole-Bournemouth area and westwards, sands of a mixed fluviatile and estuarine origin were deposited. During this latter period, the current flow was dominantly from the west (Fig.12). The northerly sediment flow may have resulted from uplift in the area south of the Isle of Purbeck Monocline. The same uplift is probably responsible for the development of alluvial fault-scarp fans at Bincombe Down [SY 688 853] and at Blackdown [SY613 875] farther west in the basin (Plint, 1982).

During the deposition of the Oakdale Clay, inter-tidal conditions spread westwards to deposit clays of perhaps salt-marsh origin over most of the present district. This episode closed with some general uplift and the development of the widespread palaeosol, found in the Oakdale Clay between 158 and 171m in the Christchurch Borehole and probably a correlative of the Whitecliff Bay Bed traceable over much of the Hampshire Basin (Edwards and Freshney, 1986). There followed a marine transgression in the central and eastern part of the basin. Shoreface and beach sands were cut by an east-west, sand-dominated deltaic system with a rapidly changing plexus of distributary channels. The deposition of the Broadstone and Parkstone clays mark a reversion to more inter-tidal and coastal marsh sedimentation with periodic uplift and development of red-stained palaeosols.

The Branksome Sand has long been considered to be of fluvial origin. In his Cycles A to F, Plint (1983b) recognised channel-point-bar, overbank, levee and channel-plug deposits of a meandering river. Plint (1983b, fig. 12) interpreted the exposures along Bournemouth cliffs as a channel belt, and assumed that fine-grained overbank deposits lay to the north of this. Now that the Branksome Sand outcrop has been mapped between the cliffs and Ferndown, it is clear that there is no increase in the proportion of fine-grained material in Plint's presumed overbank area. The presence of dinoflagellates in the clays of the channel plugs indicate that these are not of purely fluvial origin.

Beach and shoreface sands occur in the Branksome Sand at Alum Bay, in the Christchurch Borehole and among the basal sands in the Parkstone and Canford Heath areas. The formation as a whole passes eastwards into glauconitic marine shelf sands of the Selsey Sand between the Christchurch Borehole and the Ramnor Borehole near Brockenhurst (Edwards and Freshney, 1986), and farther north in the area between Ringwood and Cadnam. It is probable that during the deposition of the Branksome Sand there was a SSE-trending beach barrier sand extending from Ringwood, through Christchurch to the western part of the Isle of Wight. Building eastwards into the basin was a sand-dominated delta which breached the barrier sand between Christchurch and the Isle of Wight. The finer grained sands of the delta system were then reworked into beach barriers by strong wave action. Some sand probably also came from the area to the south of the Isle of Purbeck Monocline, especially during phases of fault movement. The Cranborne Fault may also have been active, and uplift accompanying it may have caused erosion and reworking of earlier Palaeogene deposits to the north. This might explain some of the more northerly current direction derivations which occur within the Branksome Sand. The last phase of deposition in the Branksome Sand was a marine transgression which brought marine and estuarine conditions into the Bournemouth area (Bournemouth Marine Beds of Gardner, 1879).

Sedimentation in the Barton Group opened with another marine transgression (Plint's (1983b) T4 Transgression) represented by the Boscombe Sand deposited in conditions ranging from marine beach and shoreface in the lower part, to estuarine channels with a flow from the west and west-south-west in the upper part.

A second marine transgression (Plint's (1983b) T5 Trangression) is marked by the glauconitic clays of the Barton Clay. The fineness of grain, presence of glauconite, strong bioturbation and shelly fauna of the Barton Clay indicate deposition on a marine shelf below fair-weather wave base. The mean grain size, poor sorting, strong positive skewness of the grain-size distribution, bioturbation and the shelly fauna of the clayey sands indicates deposition below normal wave base.
Smaller transgressions and regressions followed. In some cases, the regression resulted in the deposition of shoreline facies, the most important being the Becton Sand at the top of the group, in which bioturbation, including callianassid burrows, rootlet horizons at the top and its grain-size and bedding characters indicate deposition in the upper shoreface to upper beach zones. Possibly, some aeolian sand is also present.

The marine regression continued with the deposition of the lower part of the Headon Formation. The freshwater and brackish fauna, the clay mineralogy, the presence of palaeosols and the relationship of the Headon Formation to the underlying Becton Sand, suggest that this part of the Headon Formation was deposited in a lagoon behind a beach barrier sand. The sand beds within the Headon Formation are thought to have been derived from easterly-flowing rivers that deposited fans of sand into the lagoon and caused a local lowering of the salinity (Plint, 1983b). The silts and finer sands within the clay may either represent distal deposits from the rivers flowing in from the west, or may in part be sands derived from a marine area that lay to the south-east. Lenticular lamination (hummocky cross stratification) commonly seen in the Headon Formation may be due to winnowing by wind-generated currents.

3. STRUCTURE

The district lies on the north-western flank of the Hampshire Basin and the dip of the Palaeogene strata is generally 1^{o} or less south-eastwards to the centre of the basin in the Isle of Wight. Local variations in the strike to E-W or NW-SE (Fig.19) can be explained by folding a faulting.

The folds are almost always asymmetrical and probably overlie faults in the underlying Mesozoic rocks. Such structures are commonly seen affecting pre-Albian beds in seismic sections in Dorset and Hampshire. One ESE-trending fault of this type, the Cranborne Fault (Allen and Holloway, 1984), lies just to the north-east of the present district and passes south-west of Burley. It causes a monoclinal flexure in the Palaeogene beds with dips up to 6^{o} SSW. Farther west, to the north of Wimborne Minster, the trend changes to E-W. A NW-trending structure with a maximum downthrow of 30m SW passes through Christchurch Harbour and continues towards Parley Green [102 973]. In the Lytchett Matravers area, where seismic sections show some E-W fault activity in the Mesozoic rocks, a strong E-W strike is evident in the contours on the base of the Poole Formation. The linear E-W outcrop of the Palaeogene on the northern edge of the Wareham Basin, suggests underlying E-W fault control.

In the western part of the district, there is a difference in the levels of the Chalk in the Lytchett Heath area and in the E.C.C. Ball Clay Co. borehole at Beacon Hill [SY 9761 9446]. The Reading Formation present near Lytchett Heath is absent in the borehole. In addition, the Oakdale Clay appears to be thin and disappears westwards. These can be explained by a contemporaneous

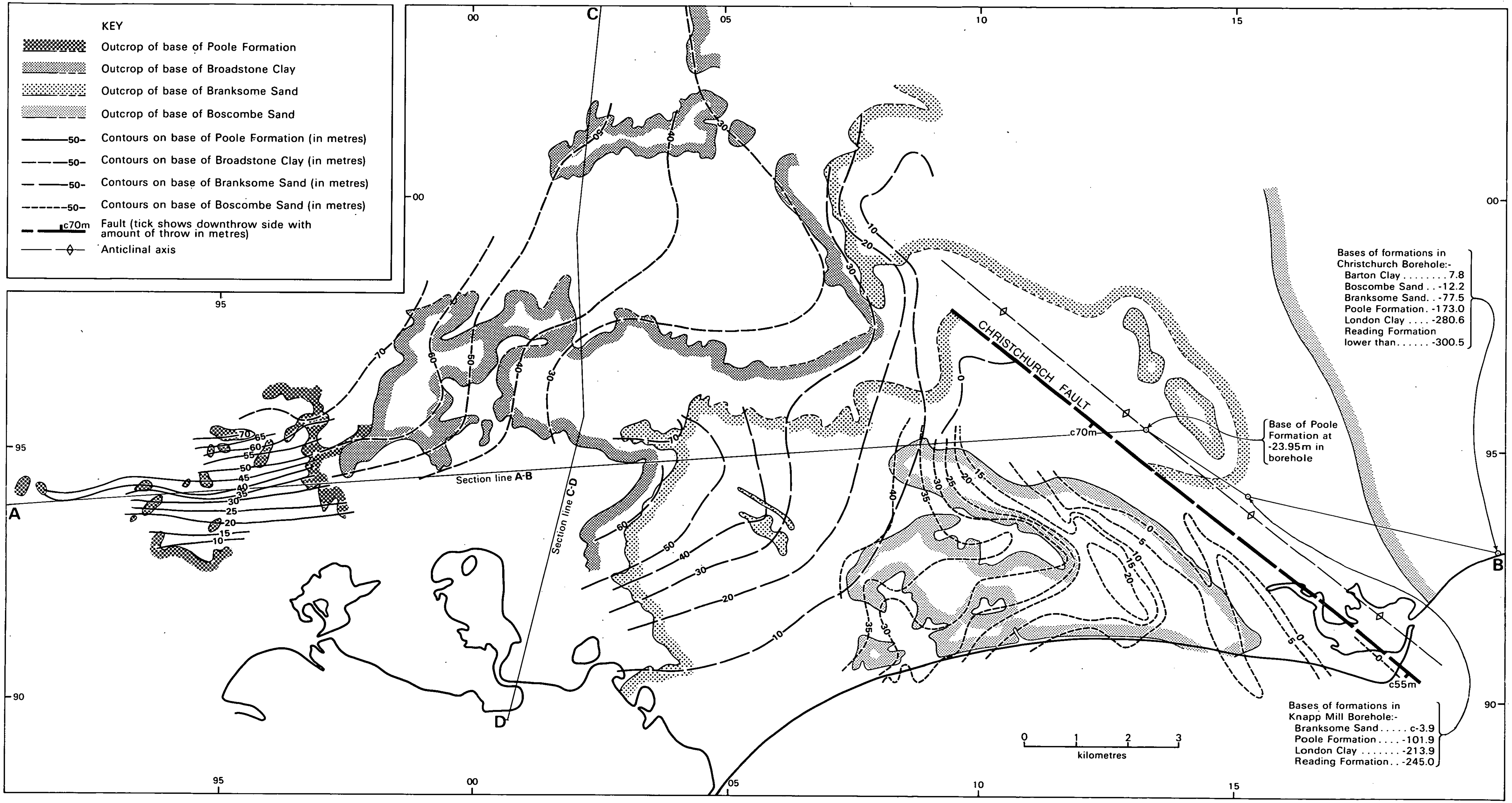


Fig.19 Contour map of the bases of the Poole Formation, Broadstone Clay, Branksome Sand and Boscombe Sand in the Poole-Bournemouth area. (Section lines **A-B** and **C-D** are those on Fig.20)

northerly-trending fault between the borehole and Lytchett Heath. The fault was inactive during the deposition of the sand of the Broadstone Clay couplet, which appears to overstep the fault with no change in level.

The gentle flexures and small faults in the Palaeogene may reflect a fracture pattern inherited from Variscan basement faulting. Faulting with a near E-W trend, and commonly truncated by post-Albian strata, is common in southern England. Some of it originates along Variscan thrust lines which relaxed in the Mesozoic (Chadwick and others,1983), possibly as growth faults. Daley and Edwards (1971) suggest this possibility during the sedimentation of the Eocene Bembridge Limestone in the Isle of Wight and invoke movements on NW-SE trending folds as likely controlling structures. Similarly, Plint (1982) suggested that movement on the Portsdown Anticline controlled sedimentation during the deposition of the Eocene Marsh Farm Formation. Edwards and Freshney (1986) expanded this concept to include controls of sedimentation particularly during the deposition of the upper part of the London Clay. Plint(1982) also demonstrated the development of Eocene alluvial fans against active fault scarps during deposition of the Bournemouth Group in the Abbotsbury area. In the present district, rapid facies changes, such as those affecting the basal Poole Formation and the topmost London Clay in the areas between the River Stour and Canford Heath, and Lytchett Heath to Upton Heath, can probably be attributed to structural control.

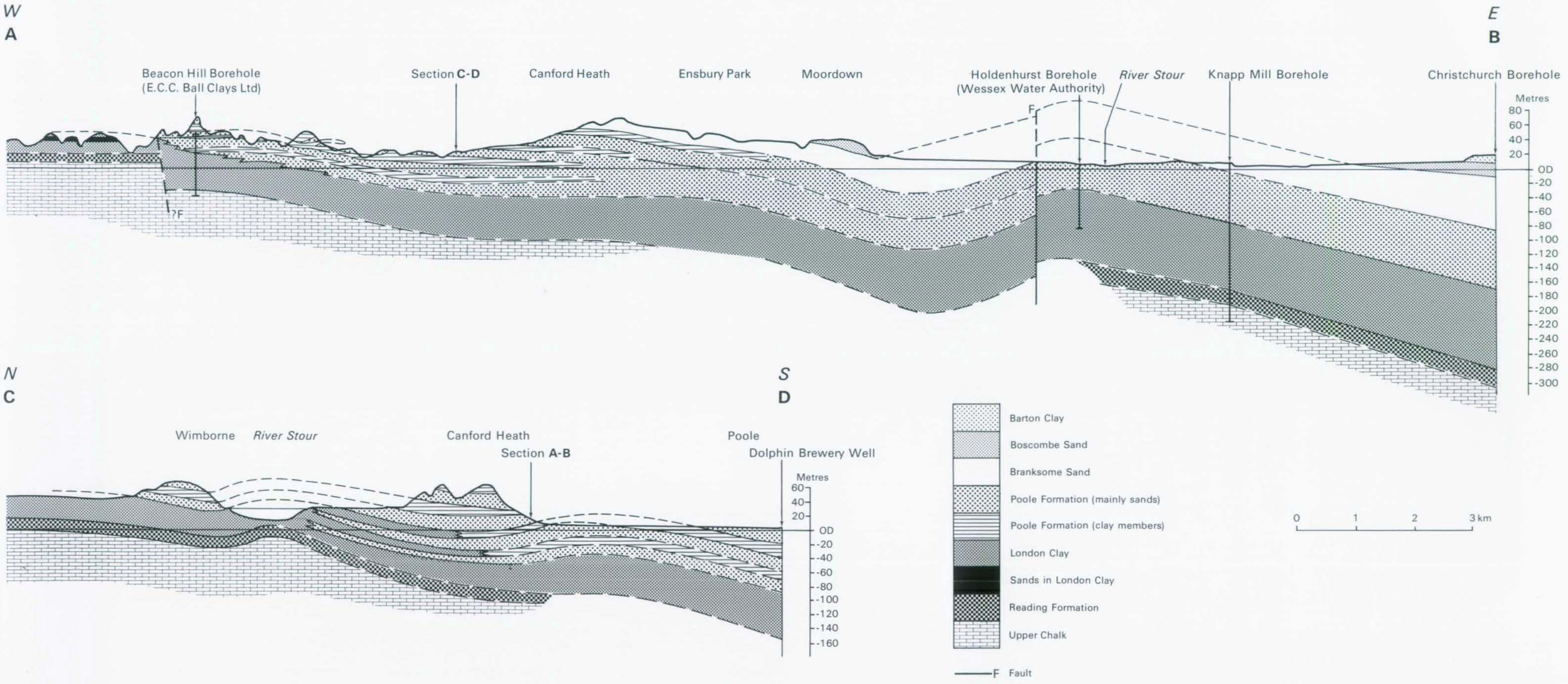


Fig. 20 Cross sections of Poole-Bournemouth area

For location of sections **A-B** and **C-D** see Fig. 19

HEAD

Head deposits in the Poole - Bournemouth area occur mainly in the valley bottoms, and to a lesser extent on the valley slopes between the river terraces. They are formed from a soliflucted downwash of gravel, sand and clay from the terrace deposits, and sand and clay derived from the solid formations. Green (1947) used the term "Bluff deposits" for the wash, scree and slumped material that occurred on the slope between two terraces. Most of the flint implements that have been found in the present district have come from Green's Bluff deposits (see also Calkin and Green, 1949).

On Hengistbury Head, a small fan-shaped, largely vegetation-free area of colluvial material, mapped as head, consists dominantly of sand and is a modern deposit which presumably originated during the working of the ironstones in the quarry nearby. It formed during periods of heavy rain when sheet flooding of sand-charged water crossed an area of made ground and debouched onto the flat surface of the river terrace deposits. The process continues today; deposition is sufficiently rigorous to stifle all but the hardiest or most rapidly growing plants (Freshney, Bristow and Williams, 1984).

In general, the thickness of head does not exceed 3m, but up to 6.5m of gravelly sand occurs on the slope between the Eighth and Fourth River Terraces between Charminster [100 946] and Littledown [128 930] (Freshney, Bristow and Williams, 1984).

RIVER TERRACE DEPOSITS

River terrace deposits laid down mainly by the rivers Avon and Stour, and with lesser spreads along the Allen, Uddens Water, and Moors Sherford rivers, have been recognised at fourteen levels within the present district. They range in height from 0.5m to 71m above the alluvial plain and have been numbered one to fourteen in ascending order (Figures 21 and 22). The higher terraces, from the sixth to fourteenth, are difficult to relate to the present courses of the rivers and may have been associated with an earlier drainage system of the proto-Solent (Reid, 1902). The larger areas of First to Fifth River Terrace Deposits bordering the Stour and Avon are clearly related to these present-day rivers.

During the original geological survey (1893-1894), the deposits currently regarded as river terrace deposits were grouped as "Valley Gravels" or "Plateau Gravels"; they correspond respectively to terraces 1 - 5 and 6 - 14 of the present survey (Table 3). Although designated as Plateau Gravels, it is clear from the Memoir (White, 1917) that these high-level spreads of sand and gravel were regarded as river terrace deposits; some, for example the Lambs Green Terrace, were individually named.

Bury (1933) divided the Plateau Gravels into an "Upper" and "Lower Plain" suite of sand and gravel. The Lower Plain suite corresponds approximately to terraces 6 - ?10, and the Upper Plain to terraces ?10 to 14 of this account. On the evidence of the flint implements found in the two terrace suites, Bury (1933) concluded that the gravels of the Lower Plain were older than those of the Upper Plain.

Green (1946) made a detailed geomorphological study of the terraces of the Bournemouth district and recognised and named sand and gravel spreads at nine levels. Whilst some of the names, for example the Christchurch Terrace, are of local origin, other names are derived from supposed correlatives in Sussex, Devon and the Thames Basin. Some of these named terraces, particularly the higher ones, can be correlated with those of the numbered sequence established during the present survey, but others appear to be composite and can now be split between several of the numbered terraces (Table 3); one, the Christchurch Terrace in the Hampreston area, is in fact the present-day Alluvium.

Sealy (1955) subdivided the terraces of the River Avon into eight. The correlation of Sealy's terraces with the authors' is shown in Table 3.

The numbering of the terraces in the present survey differs from that of Clarke (1981) for the upper reaches of the Avon and Stour. This is due to the introduction of lower terraces in the south (not seen by Clarke), and the recognition of a number of higher terraces based on geomorphological flats, particularly in the Bransgore area (Table 3.).

The relative positions of the various terraces, and their heights above the flood plain are shown in Figs.21 and 22. As mapping progressed westwards during the present survey, it was realized that a few of the terraces in the eastern part had been

This Report	White (1917)	White (1917)	Bury (1933)	Bury (1933)	Green (1946)	Sealy (1955)	Clarke (1981)
ALLUVIUM	—				Christchurch (part) (Hampreston area)		
1							not present in Clarke's area
2					Staverton (part) Christchurch (part)		1 2 (part - Hurn area)
3	Valley Gravels				Christchurch (part)	I	2, 3(part-Hurn area)
4					Staverton (part)		3 (part) 4 (part - Hurn area)
5					Muscliff Christchurch (part) Staverton (part)		3 (part) + 4
6	Berry Hill	PLATEAU GRAVELS	Lower Plain		not present in Green's area	NOT PRESENT IN SEALY's AREA	5 (part - Berry Hill area)
7					Second Lower Taplow		
8	Bransgore Terrace (in east) Lambs Green Terrace (in west)				First Lower Taplow	II + III	5
9	Higher Merley Terrace or Palaeolithic				Upper Taplow	IV	7
10			--?--		Boyn Hill	NOT PRESENT IN SEALY's AREA	
11				UPPER PLAIN	First Lower Taplow (Bransgore area)	V	
12	Eolithic Terrace		Sleight Terrace		Sleight	VI	8
13			Corfe Hills		Ambersham	VII	
14						VIII	10

Table:3: Correlation chart of the terraces of the Poole Bournemouth area

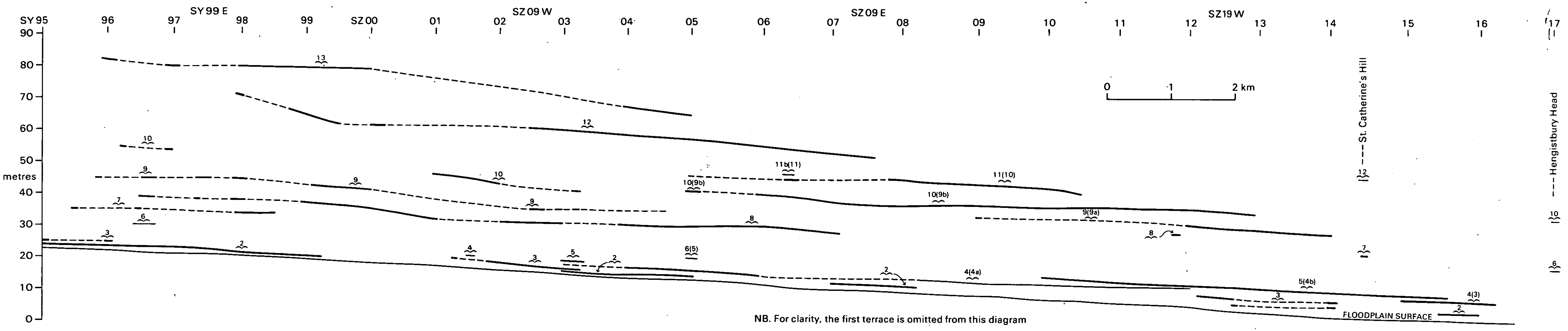


Fig.21 Profile of the River Stour and its terraces

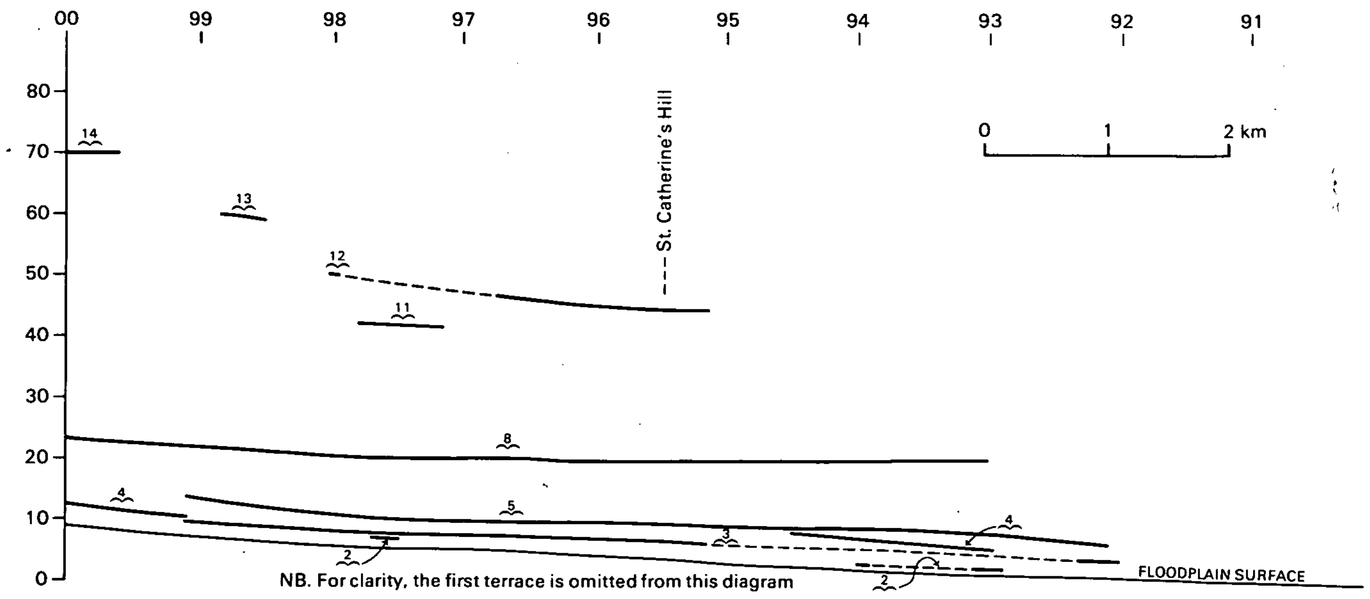


Fig.22 Profile of the River Avon and its terraces

misnumbered. The revised numbers are incorporated in this account and in Fig. 21; the old numbers are shown in parentheses after the new.

The deposits consist mainly of flint gravel with small proportions of chert, 'sarsen' stone, and limestones probably of Jurassic age. The gravel is commonly very sandy; the maximum pebble size is usually around 5cm. The pebbles are usually subangular to subrounded, but in places, if there is a nearby source of Tertiary gravel, such as at Hengistbury Head, there can be a considerable proportion of well-rounded pebbles reworked into the more recent gravels. Pebble counts by Clarke (1981, table 4) showed between 12 and 30% of rounded flint pebbles in samples from terraces two to five, and eight (of the present numbering system). The total percentage of flints varied from 96 to 100% within the present district, with 0 to 2% vein quartz, 1 to 4% sandstone and up to 1% "others". Keen (1980) had slightly differing percentages for the gravels of the Ninth River Terrace Deposits just east of the district: flint, 92.5 to 95.4%, quartz, 0.8 to 2.7%, greensand chert, 0.8 to 3.5% and "far travelled rocks", 1.1 to 3.9%.

The First to Fourth River Terrace Deposits may be covered by up to 1.5 m of silty clay to clayey fine-grained sand.

The thickness of the river terrace deposits is highly variable and may be as much as 8m or more in the First and Second Terrace Deposits and as little as 1m in some of the higher terraces, such as the Tenth. An exceptional thickness of 11m was encountered at one locality [0443 9728] in the Eighth Terrace Deposits. Most of the higher deposits, down to at least Third

River Terrace Deposits, show signs of cryoturbation, usually in the form of an irregular fabric in the gravels with involutions and flame structures.

Hand axes of several cultural types have been found in or on the surface of river terrace deposits, or in soliflucted gravel derived from the river terrace gravels. The oldest implements, of Middle Acheulian age, are associated with the "Upper Plain" gravels, and in particular the Sleight (Twelfth) Terrace of Bury (1933) (Calkin and Green, 1949). These latter authors, however, point out that the majority of the Middle Acheulian implements come from the base of soliflucted gravel derived from the Sleight Terrace. Younger implements, of Upper Acheulian age, were found on the surface of this soliflucted spread (the "Bluff-deposits" of Calkin and Green, 1949).

The Muscliff and Christchurch Terraces of Calkin and Green (1949), which correspond in part to terraces 2 to 4 of the present authors, yielded implements of Aurignacian type (ie of uppermost Palaeolithic type) and therefore are probably of Devensian age.

ALLUVIUM and ESTUARINE ALLUVIUM

The principal tracts of alluvium in this district are those of the River Stour, which flows eastwards and south-eastwards across the sheet, and its north bank tributary, the River Avon in the east. A narrow belt of alluvium occurs along the Moors River, which is also a north bank tributary of the Stour. In the south-west, the Sherford River is flanked by alluvium.

The alluvium of these rivers consists of an upper unit of

	[SY 9659 9929]	[SY 9873 9936]	[SZ 0435 9990]
Acroloxus lacustris	-	-	3
Aegopinella nitidula	-	-	6
Ancyclus fluviatilis	38	1	26
Anisus vortex	5	44	3
Armiger crista	4	2	16
Bathyomphalus contortus	43	23	6
Bithynia tentacula	617	2	59
Bithynia tentacula (opercula)	132	2	12
B. leachii?	-	-	3
B. sp. (juvs.)	-	-	90
Carychium minimum	-	5	1
Cochlicopa lubrica	1	-	-
Discus rotundatus	1	-	1
Gyraulus albus	124	4	46
Lymnaea palustris	-	3	-
Lymnaea peregra ovata	52	28	5
Lymnaea truncatula	4	134	3
Lymnaea sp.	-	1	-
Macrogastra rolphii? (frag.)	-	-	1
Ovatella myosotis (juv.)	-	-	1
Planorbis planorbis	2	-	1
Punctum pygmaeum?	-	4	-
Succinea elegans	1	-	-
Succinea oblonga	10	-	-
Succinea putris	-	-	11
Succinea sp.	20	2	4
Theodoxus fluviatilis	215	-	58
Trichia hispida	28	11	-
Vallonia excentrica	-	9	-
Valvata cristata	-	3	10
Valvata macrostoma	-	4	-
Valvata piscinalis	355	-	101
gastropod indet.	-	fragments	-
Anodonta anatina	1	-	-
Pisidium amnicum	8	-	4
Pisidium henslowanum	-	-	5
Pisidium milium	-	-	2
Pisidium nitidum	188	-	95
Pisidium subtruncatum	1	-	-
Pisidium sp.	-	5	-
Sphaerium corneum	23	-	5
Sphaerium corneum? (fragments)	18	-	-

Table 4. Mollusca from the Alluvium of the River Stour

mottled dark grey and orange, commonly organic, silts, silty clays and clayey sand resting on a lower unit of sand and gravel.

The thicknesses of the two units varies quite rapidly from 0.3 to 3.9m for the upper unit, and 0.35 to 6m for the lower. In the lower reaches of the rivers, the alluvium merges imperceptibly into estuarine alluvium.

Locally, the alluvium of the Stour contain a rich molluscan fauna. Faunas have been collected at three localities; the results are listed in Table 4. The assemblages are dominantly aquatic with minor terrestrial elements; they indicate hard, slow-flowing water with temperatures that do not differ appreciably from the present day.

PEAT

A small spread of peat occurs on the north side of the alluvium of the Moors River [117 985] and is about 0.75m thick.

STORM GRAVEL BEACH DEPOSITS

The longest storm-gravel spit in the district extends north-eastwards from Hengistbury Head, and almost closes the mouth of Christchurch Harbour. Another spit, now obliterated under Made Ground, existed in the area known as The Baiter [021 902]; it was formerly about 400m long (Freshney, Bristow and Williams, 1985). Minor gravel spits occur at several localities around Christchurch Harbour, where they may be up to 500m long, but generally not more than 1m high (Freshney, Bristow and Williams, 1984).

Burton (1931) has documented the changes in the extent of the Christchurch Harbour spit and the former positions of The Run. At its maximum, in 1880, it extended almost to Cliff End [c 198 927], approximately 1.8km NE of its position is 1847, and 1km beyond its present position.

BLOWN SAND

Two ages of blown sand occur. The more recent is on cliff tops, and consists of well sorted, fine-grained sand up to 4m thick blown up the cliff face and deposited in an area of slackening wind velocity just behind the cliff tops. It is still accumulating where not built on. Blown sand that overlies the shingle spit which extends north-north-east from Hengistbury Head, probably belongs to the same category as that seen on top of the cliffs. Burton (1931) recorded that the dunes on the spit had been up to 5m high, but that their height was much reduced by "trampling feet".

The second occurrence of blown sand is inland on the surface of some of the river terrace deposits in the Avon valley (Freshney, Bristow and Williams, 1984). There, the deposits consist of up to 3m of well sorted, fine-grained sand. It was probably derived from sand from St Catherine's Hill. Deposition appears now to have ceased.

LANDSLIP

Landslips have been mapped at two localities near Lytchett Matravers, but they have been recognised at several localities adjacent to the study area (Bristow and Freshney, 1986). All are developed on clays of the Reading Formation and are associated with springs issuing from the base of the overlying Warmwell Farm

Sand, or from sands within the Reading Formation. One of the most spectacular of the slips, 650m long by 200m across, occurs at Higher Combe Farm [SY945 977], just west of the present district.

Slips involving the Reading Formation have taken place on slopes of 10° or less. Slopes in the mixed sand/clay sequences of the London Clay or Poole Formation are locally as steep as 25° and yet appear to be stable.

MADE GROUND

Extensive areas of marshland, low-lying ground bordering rivers, several small valleys and many pits have been reclaimed in recent years. Much of the fill is domestic waste, but industrial refuse, overburden and spoil from sand and brick pits, imported sand and dredged material from Poole Harbour also form a significant part of the made ground. The known areas of made ground and their presumed compositions are shown in Freshney, Bristow and Williams (1984, fig.18; 1985, fig.22) and Bristow and Freshney (1986, fig.13). Up to 10m of made ground occurs locally (Freshney, Bristow and Williams, 1985).

5.ECONOMIC GEOLOGY

Sand and Gravel

Extensive tracts of sand and gravel are associated with the River Stour and its principal tributaries the Moors River and River Avon, and with the proto-Solent.

The higher terraces of the proto-Solent are developed principally east of line from Corfe Mullen [SY 99 97] to Canford Cliff [SZ 05 89]. West of the River Avon, most of these deposits are now sterilized by urban development, except for a small part of Canford Heath and small areas around Merley House [010 981] and Knighton [042 974]. East of the Avon, Eighth River Terrace Deposits are well developed in the Bransgore to Hinton Admiral area where they have been extensively exploited.

The sand and gravel deposits of a small part of the district in the north-east have been studied and the resources estimated by Clarke (1981) to be about 180 million cubic metres. Elsewhere, the only significant areas of potentially workable sand and gravel are in the upper reaches of the Stour in river terrace deposits on either side of the river near Sturminster Marshall, and the alluvial gravel of the Stour. There are insufficient data to calculate the resources in these areas, but the Second River Terrace gravels are at least 5m thick; the alluvial gravel is known to be up to 6m thick.

Downstream of Wimborne, large spreads of the lower terraces (chiefly Second and Fourth) occupy open country around Hampreston and East Parley. These deposits form a potential resource. Sand and gravel thicknesses in the terraces (1 to 4) on the north bank of the River Stour thereabouts vary from 2.6m to 6.9m, thickening generally southwards towards the river. South of the Stour, around Canford Magna, terraces 1 to 5 vary in thickness from 2m to 6.2m.

Of the higher terraces, the small tract [SU 064 002] near Ferndown has been worked for gravel, its thickness being about 3.6m. South of the Stour, in the west of the district, terraces 8 and 10 occupy over 1 sq km around Merley House, with thicknesses of 2.8 to 3.3m at that locality. Farther east [041 975], a tract of Eighth Terrace is being worked for gravel. Sections suggest a thickness of 1.6 to 5.5m.

Extensive areas of gravel occur in the terrace deposits of the eastern part of the River Stour and of the Avon. The areas with the biggest resources (c. 160 million cubic metres) are those underlain by Fourth and Fifth River Terrace deposits, but in the lower reaches of the rivers, those of the First to Third terraces become more important.

The resources of the south-eastern part of the district are now mostly sterilised by urban development.

Sand

The Beacon Hill Brick Co. Ltd make sand/lime bricks using sand of the Poole Formation mixed with lime which is brought to the site. Production in 1985 was 43,322 tons.

In addition to sand, which is used for brick making at Beacon Hill, sand of the Poole Formation is dug from the Henbury Pit [SY964 975] of M.B.Wilkes Ltd. The sand from this pit is used for building, horticulture and brick making. Some sand is sold "as dug" without being screened; other sand is screened for building purposes. Plastering sand, which is also produced at this pit, is a mixture of washed and screened sand.

On Canford Heath [029 967 and 031 967], sand of the Poole Formation is worked. Between 300,000 and 500,000 tons of building, mortar, asphalt, plastering and concreting sand, together with single-size aggregate are produced annually.

Much of the outcrop of the Branksome Sand, which could be of use, is built over.

The Boscombe Sand, which has a more extensive, non-sterilised, outcrop is too fine grained for use in the building industry.

In the past, other sands such as the Chama Sand and Becton Sand have been worked for moulding sand and glass sand respectively in areas east of the Poole-Bournemouth district, but it is unlikely that such sources would be suitable for today's uses.

Brick and Pottery Clays

Six different stratigraphical units have been worked for brick and pottery clays. These are the Reading Formation, London Clay, Poole Formation, Branksome Sand, Barton Clay and Headon Formation.

There is only one pit, the Knoll Manor Pit of Pilkington & Carter [SY974 978], in which clays of the Reading Formation are currently being worked. In the 1880's the pit operated as a brick pit. Prior to their acquisition of the Knoll Manor Clay Pit from Kinson Pottery, Pilkington and Carter worked clays of the Reading Formation in a pit [SY989 987] at Candy's Land. Working of this latter pit changed from opencast to adit mining in about 1950 (Mr

G. Barrington, pers. commn). The adits, about 30m long, radiated out from the face. However, this method of working proved uneconomic and the pit closed in the late 1950's.

In the Knoll Manor pit, the uppermost clays of the Reading Formation are used to produce 2500 to 3000 tons of unglazed floor tiles per year (Mr A. Smith, pers. commn). Some of the clay from this pit goes to a pottery at Stoke on Trent.

London Clay has been worked for bricks in many small pits in the Lytchett Matravers area, but all have long been abandoned (Bristow and Freshney, 1986).

The clays of the Poole Formation are laterally persistent over relatively large areas and have been extensively worked. Two main types of clay occur in this formation: one, brown carbonaceous, laminated and very sandy, and the other more homogeneous, grey but commonly red stained, and with a lower sand content. The brown sandy clays were used mainly for brick making, and the grey clays for pottery. The Parkstone Clay was the main source of pottery clay in the present district (Freshney, Bristow and Williams, 1985). Gilkes (1978) noted an eastward diminution in the kaolinite content in Tertiary clays from the Wareham ball-clay area, towards the eastern Hampshire Basin. Possibly in the Poole-Bournemouth area the kaolinite content is too low to produce the best white-firing ball clays.

Details of all the former pits and the uses to which the clay was put, can be found in Freshney, Bristow and Williams (1984; 1985), Bristow and Freshney (1986) and Young (1972). A few notes of the larger, more recent workings are included below.

The Creekmoor Clay was dug for brick clay south-west of Waterloo [005 936]; these pits are now filled and are being built over.

The Oakdale Clay has been extensively worked in the west of the district. One of the largest of these, the former Hamworthy Junction Brickworks (later part of the Kinson Pottery Company) [SY988 915], used to make bricks and glazed pipeware until about 1965. Clay from the pits at Lake [SY982 908] was worked until about 1950 for pipes, bricks and insulators. Much of the clay went to Stoke on Trent. Until 1978, a seam of grey clay in the Oakdale Clay was dug for ball clay from a pit[SY951 921] south-west of Lytchett Minster. This clay was blended with other clays from south Devon and used for frost-resistant tiles.

At the present day, the only working brick pit [SY98 95] is the Beacon Hill Brick Co. Ltd. Previously, bricks were made at this site using the local Broadstone Clay, but this has been discontinued for a number of years. Sand/lime bricks are now made using sand of the Poole Formation mixed with lime which is brought to the site. Some sand from the Henbury Pit (see below) is also used for brickmaking.

Broadstone Clay appears only to have been worked for brick clays, mainly around Beacon Hill, Broadstone and north-eastwards towards Canford Magna.

The major brick-clay pits in the Parkstone Clay were mainly in the Foxholes [030 930] to Mannings Heath [038 945] areas. The Parkstone Clay was also the main source of pottery clay in the present district.

Clays of the Branksome Sand were chiefly dug for brickmaking in the King's and Queen's Park areas of Bournemouth, as well as in other small pits in the Bournemouth to Parley area (Freshney, Bristow and Williams, 1985). The brick-clays of the Branksome Sand consist mainly of laminated, commonly carbonaceous sandy clay and silty clayey sand often described as loams in the past. Because of the highly lenticular nature of the clays, pits tended to be limited in size, and because of the extensive gravel cover they were almost always located around the margins of gravel spreads.

Clays of the Headon Formation and the Barton Clay have been worked for bricks near Bransgore (Freshney, Bristow and Williams, 1984).

Building Stone

White (1917) noted that ferruginous cemented sandstones of the Reading Formation and London Clay from the Lytchett Matravers area have been used in local buildings. He quoted examples of their use in the walls of Wimborne Minster and in the bridge at Sturminster Marshall.

Lime and marl

Lime and Marl was dug from the soft flintless Chalk in the north-west of the district during the 19th Century.

The soils of the district consist of both granular soils such as the gravels and sands of the Reading Formation, Poole Formation, Branksome Sand, Boscombe Sand and river terrace deposits, and clay soils from the Reading Formation, London Clay, Poole Formation and Barton Clay.

The gravels are usually compact and well graded with a high sand content and some clay. Some of the gravel terraces also have a silty clay to clayey fine-grained sand top. River terrace deposits generally range from 2 to 6m thick, with an average about 3m, but exceptional thicknesses up to 11m have been recorded.

Sands within the Reading Formation vary from fine- to coarse-grained and usually have a low clay content. Sands in the London Clay are dominantly fine-grained and usually have a considerable clay and silt content which can be as much as 40%. The sands of the Poole Formation are predominantly medium-grained, but very coarse-grained sands or grits occur. Generally, there is less than 8% silt and clay, and with an average silt/clay content of 3%, but the silt/clay content may be as high as 32% (Freshney, Bristow and Williams, 1985). Coarse-grained, and even very coarse-grained, sands also occur at the bottoms of fining-upward cycles. The sands are free draining, but the presence of interspersed clay beds commonly causes perched water tables.

The sands of the Branksome Sand are, overall, coarser than those of the Boscombe Sand; their chief difference is that they range from fine grained to very coarse grained. They are better

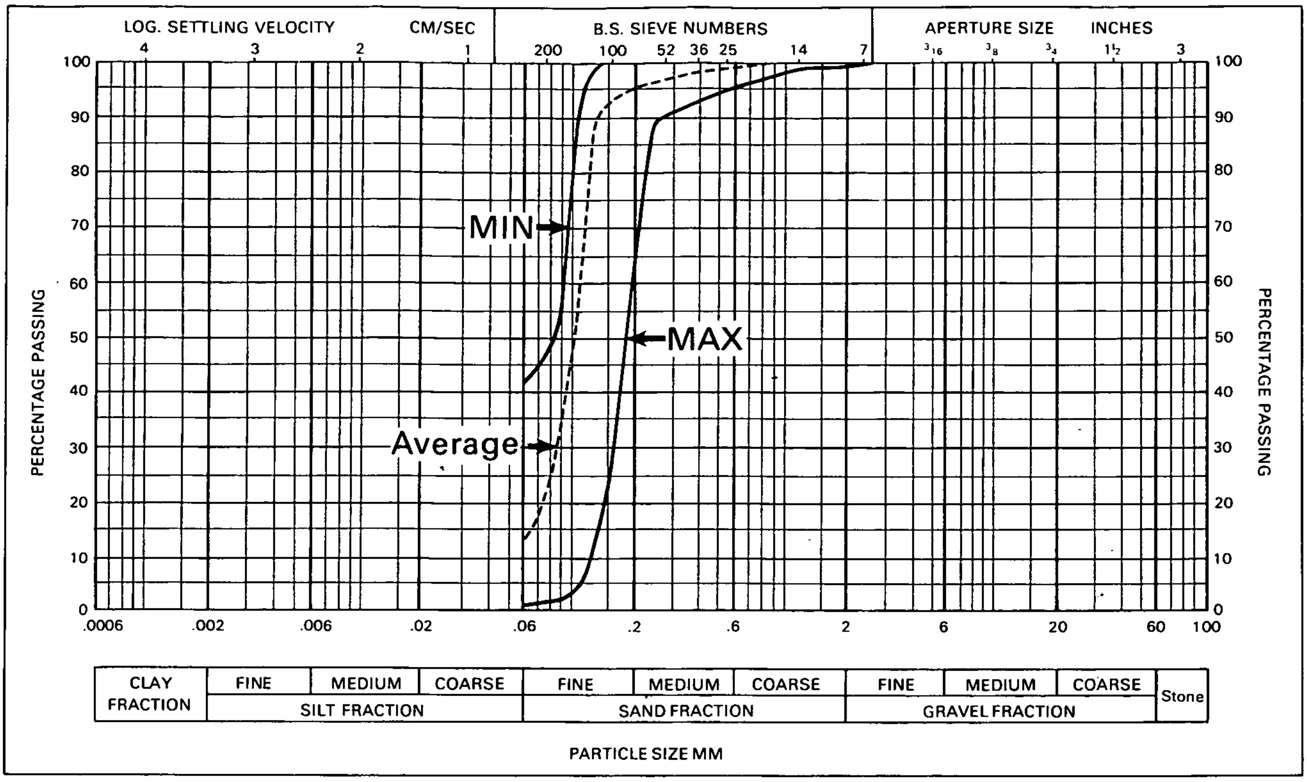


Fig.23 Grading curve envelope for sands of the London Clay in the Poole-Bournemouth area

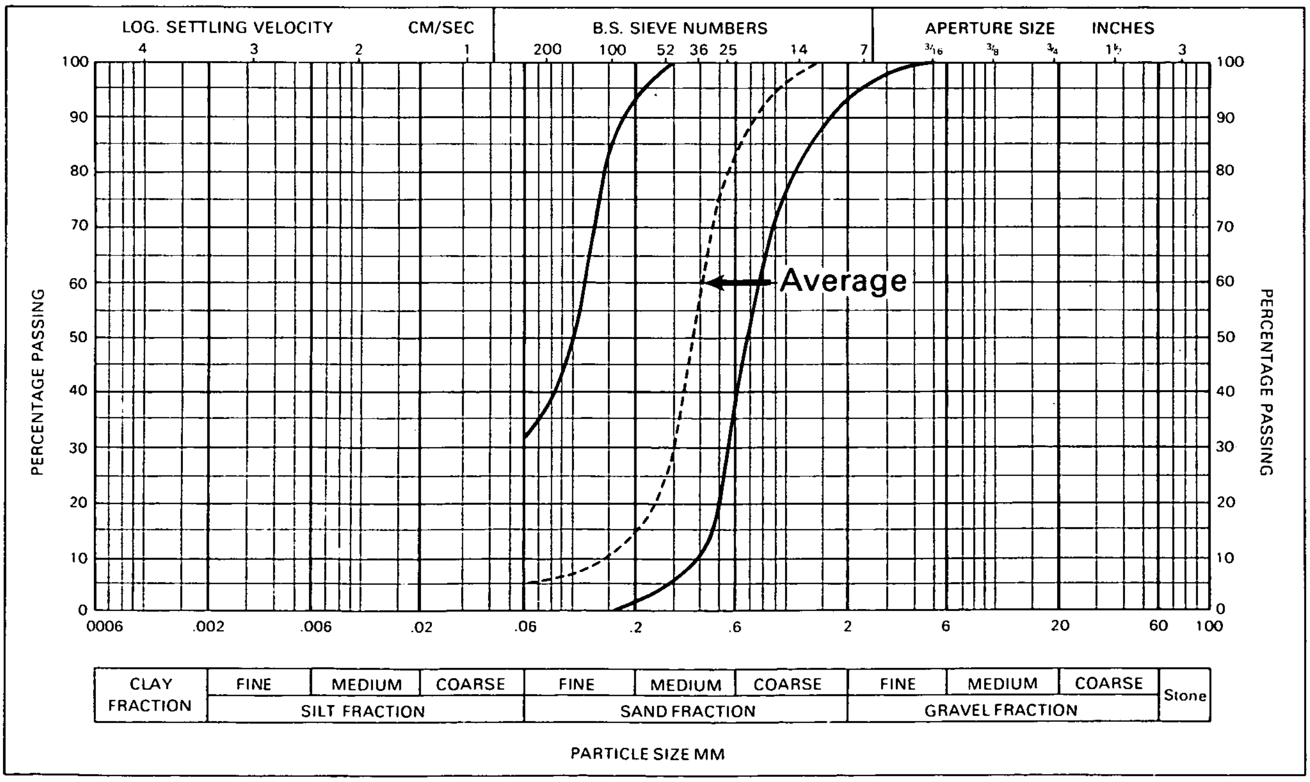


Fig.24 Grading curve envelope for sands of the Poole Formation in the Poole-Bournemouth area

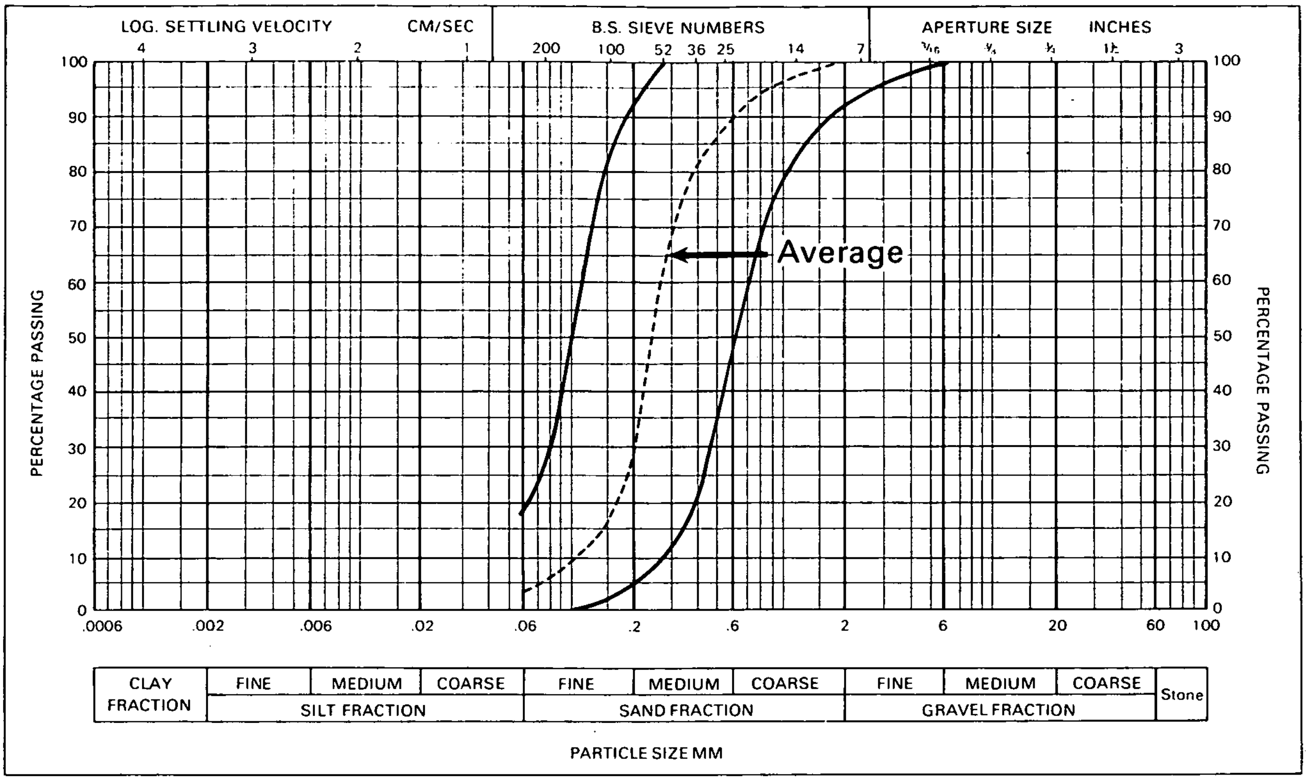


Fig.25 Grading curve envelope for the Branksome Sand in the Poole-Bournemouth area

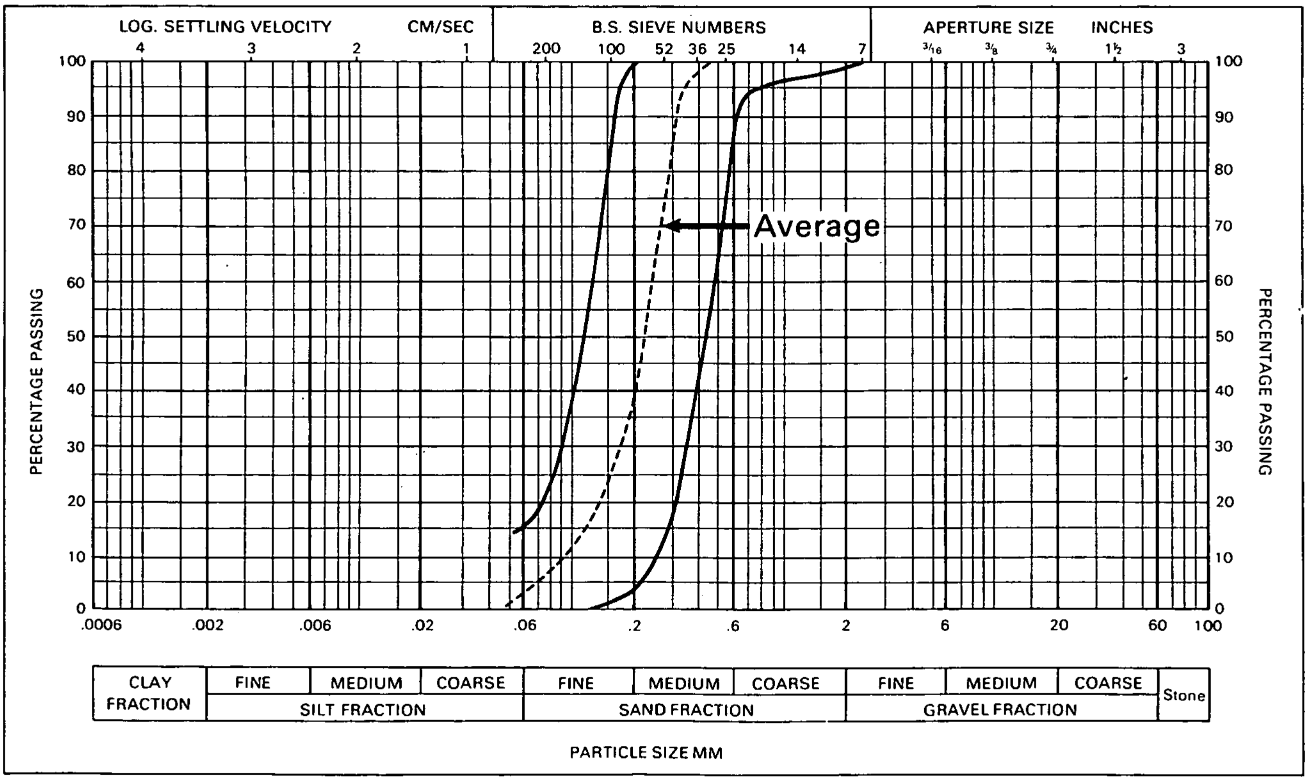


Fig.26 Grading curve envelope for the Boscombe Sand in the Poole-Bournemouth area

graded and the silt/clay content can be as high as 32%; the average is 5%. The sands of the Boscombe Sand are poorly graded; they consist mostly of fine- to medium-grained sands, with always less than 10% silt and clay, and an average silt/clay content of 2%. All the sands are dense where undisturbed and are free draining.

Extensive areas of clay subsoil occur in the Reading Formation; these clays tend to be lower in sand content than the London Clay. Since they also are usually palaeosol clays, they are likely to have been dessicated, and where unweathered, tend to be stiff to very stiff. All the landslips recognised in, and immediately outside, the present district occur on clays of the Reading Formation (see below). The clays of the London Clay are usually very sandy and where unweathered are stiff to very stiff.

The clays of the Poole Formation show considerable variation in shear strength and cohesion (Freshney, Bristow and Williams 1985, Table 2; Bristow and Freshney 1986, table 3). In many instances, the strength is a reflection of moisture content, but in others, the origin of the clay is important, with the clays that have formed palaeosols being the strongest. The spread of values is large, and the tested samples probably include materials ranging from unweathered and undisturbed to highly weathered and disturbed. The lowest strengths occur in samples of Broadstone and Oakdale clays that have high moisture contents (up to 40%). The highest strengths were recorded in clays from the Branksome Sand and Oakdale Clay that had low moisture contents

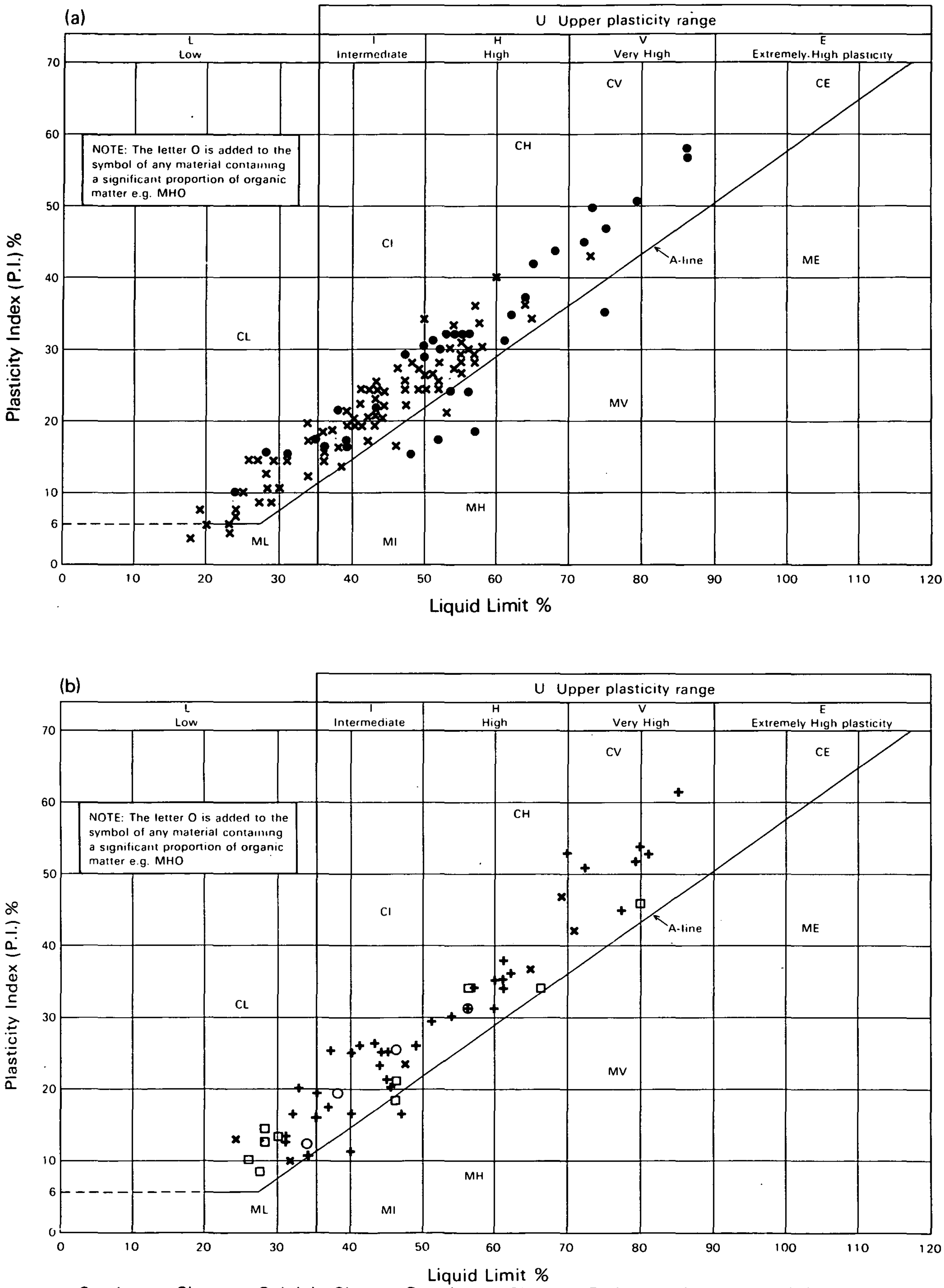
($<15\%$). These high strengths mostly occur in the palaeosol clays.

The clays of the Poole Formation range in plasticity from low to very high (Figure 27). The most plastic clays occur in the Parkstone and Creekmoor clays, although these members also contain clays of low plasticity. This may reflect the origin of the clays and their consequent clay mineralogies. Clays in the Branksome Sand plot on a plasticity chart in the low plasticity field just above the A-line (Figure 28).

The mixed clay/sand stratigraphy of the Poole Formation and Branksome Sand causes the development of many perched water tables. Springs from these are commonly seen in such areas as Upton Heath, especially in the lower ground where boggy areas occur, and in the cliffs at Bournemouth.

The amount and continuity of the fine-grained sand laminae in the clays is a major controlling factor in their moisture contents. The ability of the clays to absorb water from these sand bands and laminae could be important in excavations made in wet conditions, because it can result in a serious loss of strength. Slopes of up to 50^{o} can be stable in well-drained sands, but where a layer of clay or clayey silt occurs, even one a few centimetres thick, the generation of a perched water table renders slopes $>25^{o}$ unstable. This is particularly true where the clay is in the lower part of the slope. Little sign, however, is seen of ground instability in this area, perhaps because the sands are so free-draining. Landslips do occur, however, on Reading Formation clays where they are overlain by water-

SILT (M-SOIL), M, plots below A-line
CLAY, C, plots above A-line
} M and C may be combined as FINE SOIL, F.



● Creekmoor Clay × Oakdale Clay ○ Broadstone Clay + Parkstone Clay □ Undifferentiated clay in Poole Formation

Fig.27 Plasticity charts for clays within the Poole Formation

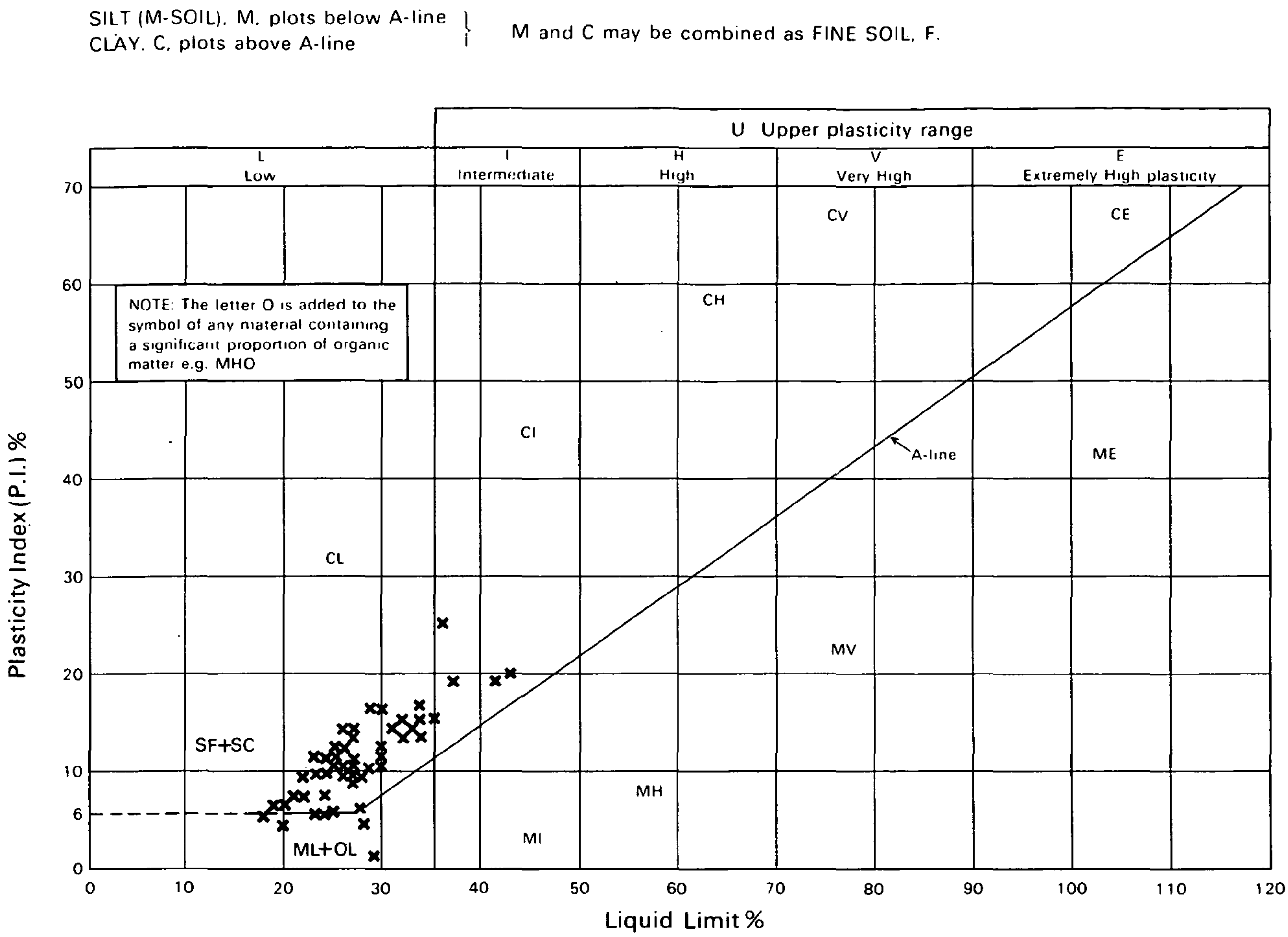


Fig.28 Plasticity chart for clays within the Branksome Sand

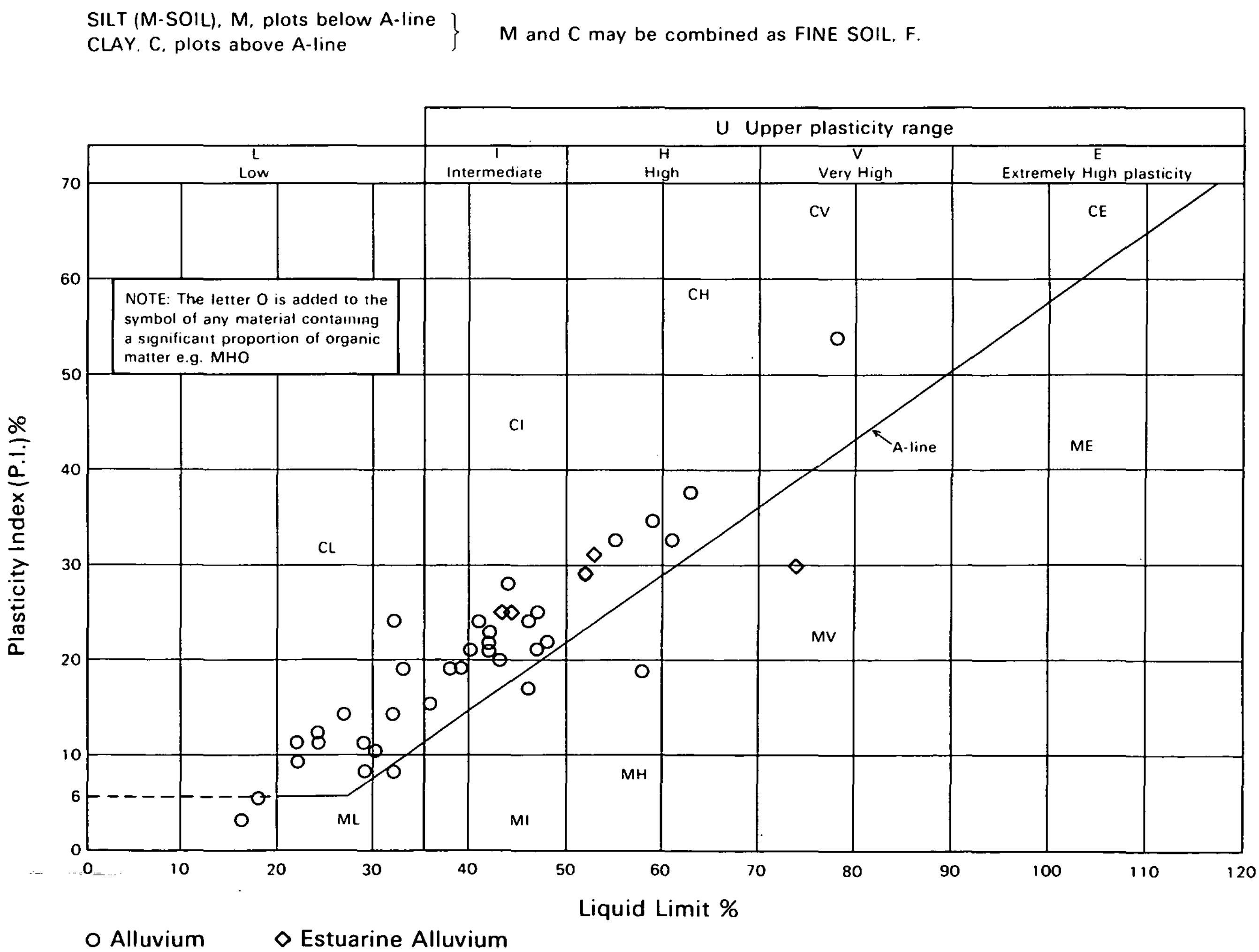


Fig.29 Plasticity chart for clays of the Alluvium and Estuarine Alluvium

saturated Warmwell Farm Sand. In these cases, the sands over the clay are horizontal and fine-grained enough to restrict draining. The distribution of areas underlain by mixed clay and sand sequences in the district, and consequently those areas most at risk from landslip, are shown by Freshney, Bristow and Williams (1984; 1985) and by Bristow and Freshney (1986).

The alluvial clays, as might be expected, have high moisture contents and very low strengths. The alluvial deposits can include very weak materials such as peat and organic-rich silts and clays with low strengths.

Many of the clays in the district contain pyrite (iron sulphide); when weathered this breaks down to sulphates and can give rise to sulphate-rich groundwaters.

Other geotechnical problems, particularly subsidence, can arise due to the presence of heterogeneous, loosely compacted material, in areas of made ground. The distribution of the larger areas of known made ground and the nature of the dominant fill are figured by Freshney, Bristow and Williams (1984; 1985) and by Bristow and Freshney (1986).

Swallow holes or solution collapse hollows developed over the Chalk have been recognised in the Lytchett Matravers area (Bristow and Freshney, 1986, fig.12).

HYDROGEOLOGY

The district lies across the boundary between Hydrometric Areas 43 and 44. The water resources are managed by the Wessex Water Authority. The district lies mainly within Unit 4 of the Wessex Water Authority, with a small part in the south-west being within Unit 5 (Monkhouse and Richards, 1982). Information on the area is also published in the Hydrological Survey for the Wessex Rivers (Anon., 1967), and further details are given by White (1917).

The central part of the district rises in places to more than 90m above sea level. The northern flank of the higher ground drains to the River Stour which flows approximately along the northern margin of the district in the west, and then flows east-south-eastwards to be joined by the River Avon near Christchurch. The southern flank is drained by small streams flowing directly into the sea in Lytchett Bay, Poole Harbour and Poole Bay.

The mean annual rainfall is about 900mm, and the mean annual evaporation probably about 450mm. Infiltration into the Chalk outcrop, which in this district is largely covered by drift, is probably about 300 mm/yr, while that into the outcrop of the Palaeogene sands is probably not less than 350 mm/yr.

Most of the water supply is taken from sources outside the district. However, surface water is taken from intakes on the River Stour, both for public and for private (industrial) supply. In the west, some 33 megalitres per day (Mld) are available from boreholes in the Chalk at Corfe Mullen [SY974 983], while a further 20 Mld can be taken from a site just outside the district near Sturminster Marshall, also from the Chalk. Four borehole sources are licensed for industrial use in the central tract, and there are shallow wells supplying groundwater for agricultural and domestic use.

Chalk, the major aquifer in the Wessex Water Authority area, crops out in the valley of the River Stour, although there it is almost completely concealed by drift. The junction with the overlying Palaeogene dips gently south and south-eastwards until, at the coast, it lies at a depth of between 130m in the west and 250m and more in the east.

In the Stour valley, and beneath a thin cover of Reading Formation, the Chalk has a mean yield of 11.5 litres per second (l/sec)for a drawdown of 10m from boreholes of 300mm diameter penetrating 30m into the saturated aquifer.

Near Wimborne Minster and northwards, boreholes of 200mm diameter, penetrating 50m of saturated Chalk beneath Reading Formation and London Clay, would be expected on average to yield some 3.5 l/sec.

As the thickness of cover increases, yields tend to become less, and near the coast, a borehole of similar dimensions might be expected to yield less than 0.6 l/sec for a drawdown of 10m.

A deep borehole drilled for water at Christchurch [1545 9380] in 1905, penetrated Chalk from 251m to 281m depth, but little water was obtained. Interestingly, an unusually high yield of more than 30 l/sec was taken from seams of lignite in the Branksome Sand at a depth of some 60m, but the water was so rich in iron that the borehole had to be closed off, and was subsequently abandoned.

The quality of Chalk groundwater in the north is generally good, with a total hardness of between 250 and 400 mg/l and a chloride ion concentration of about 30 mg/l. Towards the coast, information is limited, but the chloride ion concentrations appears to increase to more than 200 mg/l, and possibly more than 500 mg/l.

Chalk becomes less permeable under increasing cover, and this, combined with the necessarily deeper (and therefore more costly) boreholes required to tap the aquifer, makes the development of borehole sources unattractive.

Moderate yields of groundwater have been recorded from the sandy beds (where present) of the <u>Reading Formation</u>. However, most of the Reading Formation consists of clay, and where sandy horizons are developed within this formation, principally in the west, they contain a significant clay and silt fraction, permeability is usually low, and the Reading Formation is generally regarded as an aquiclude.

The <u>London Clay</u> is for the most part an aquiclude. Small supplies of groundwater can be obtained from the thicker sandy beds present in the west, and from the weathered zone, but even these yield water only reluctantly to wells and boreholes. The quality is usually poor and lack of proper well design can cause pollution from surface drainage. The thicker sands, such as the Warmwell Farm Sand, do throw out springs of some size, even as much as $50m^3/d$. However, the water quality is usually poor with high concentration of iron and sulphate.

Potentially, the <u>Poole Formation</u> forms a good aquifer consisting of sandy beds separated by clays. Nevertheless, relatively little use has been made of this aquifer other than a few shallow wells for domestic supplies. Boreholes with properly designed filter packs and sand screens should be capable of yielding up to 3.5 l/sec, possibly up to 8.0 l/sec.

The groundwater quality in the Poole Formation should generally be good. The total dissolved solids content should not exceed 300 mg/l or the total hardness 200 mg/l. The chloride ion concentration should be less than 30 mg/l, although adjacent to the coast higher concentrations might be expected. Nitrate and sulphate concentrations should also be low. However, iron may often be present in concentrations of more than 1.0 mg/l.

The Branksome Sand and Boscombe Sand have similar hydrogeological characteristics and may be considered as a single multi-layered aquifer. These strata contain the only significant groundwater resources of the district. Groundwater levels are commonly close to the ground surface, and boreholes not infrequently overflow.

Allowing for the run-off from urban areas, the average annual replenishment to the Palaeogene sands is probably about 10 to 15 million cubic metres per annum (m^3/a). Because of the multi-layered nature of the aquifer, it would in practice be difficult to develop this potential to the full.

Boreholes of 200mm diameter penetrating 15m of saturated sand would be expected to have an average yield of about 6.0 l/sec for a drawdown of 5m. For a diameter of 300mm, the average yield should approach 8.0 l/sec for the same drawdown. Sand screens with properly designed filter packs (Monkhouse, 1974) would be necessary, both to support the borehole wall and to prevent the ingress of sand; natural filter packs could probably be developed in the coarser sands. Boreholes penetrating running sand have often failed, or even collapsed, where inadequately designed and developed sand screens have been fitted.

A study of well yields in the Branksome and Boscombe Sands and their lateral equivalents over the whole of the Hampshire Basin, has shown that yields in the Bournemouth-Christchurch area seem to be rather less than elsewhere in the basin. Table 5 shows the yields that might be expected from these in the present district.

Table 5

Expectancy of yields (in l/sec) from the Branksome and Boscombe sands that would be exceeded in the given percentage of cases. It is assumed that 30m of screen are present in the saturated aquifer, and that the drawdown is 5m.

Borehole diameter (mm)	Percentage of cases		
	75%	50%	25%
150	3.7	6.4	11.3
300	5.1	8.9	15.9
450	6.2	10.9	19.3

In general within the Hampshire Basin, borehole yields do not appear to increase significantly at depths greater than about 60m beneath the potentiometric surface. There is insufficient information in the present district with which to construct contours of the potentiometric surface. In general, levels have not been recorded more than 10m above Ordnance Datum; they are near sea level close to the coast, and rise gently inland.

The groundwater quality is usually fairly good with total dissolved solids mostly $<$250 mg/l. The total hardness (as $CaCO_3$) is generally $<$100 mg/l and is not known to exceed 200 mg/l, while the chloride-ion concentration is normally $<$40 mg/l. Iron, however, is often present in concentrations of $>$1.0 mg/l, and may be sufficiently high to cause water-treatment problems.

In areas adjacent to the coast, prolonged pumping may lead to seawater intrusion, and the siting of boreholes less than 500m from the shore is not recommended.

The Barton Clay forms an aquiclude and does not yield useful supplies of groundwater. The Chama Sand, the Becton Sand and the Headon Formation are present only in the extreme north-east corner of the district. Small supplies (probably $<$0.5 l/sec) might be obtained from the Chama and Becton sands, but the grain-size tends to be very fine, and it would be difficult to install satisfactory sand screens in boreholes.

Drift deposits are generally too thin and of too limited an extent to comprise a useful groundwater resource. Where permeable drift overlies the Palaeogene sands, the two are usually in hydraulic continuity, and it is customary to construct boreholes into the solid formation rather than into the superficial.

Supplies of $>$10 l/sec have been obtained in the east from the thicker river terrace deposits, but only where these extend below Ordnance Datum.

A number of shallow wells and boreholes have in the past taken groundwater from river terrace deposits in the Stour valley. One site north of Corfe Mullen yielded up to 390 m^3/d for public supply. Terraces at higher levels tend to drain rapidly and thus have low storage capacities. Boreholes are not generally employed to abstract groundwater from the river terrace deposits and large (up to 3m) diameter shafts or tube-wells are preferred. The groundwater quality can be good, but with the water table close to the ground surface, the supplies are vulnerable to pollution from surface sources. Where abstraction sites are located near water courses, there is a possibility of induced recharge and the groundwater quality may then reflect the surface-water quality. Most of the sources in these superficial deposits are now no longer in use.

The alluvium of the district generally has a high clay content and yields little water. Its hydrogeological significance lies in its ability to limit the infiltration of river water into the underlying deposits.

Protection of aquifers

The Control of Pollution Act 1974 and the relevant E.E.C. Council Directive (Anon., 1979) require that groundwater be protected from pollution. The vulnerability of an aquifer (as distinct from a source such as a well or borehole) may be regarded as a measure of the ease with which pollutants may pass from ground surface to the saturated zone. Considering the multi-layered nature of the Palaeogene aquifer, it is difficult to propose any definite rules for its protection on this basis.

In general, pollutants may quickly reach the saturated zone in sandy aquifers where the water table is close to ground surface. In a multi-layered succession, the less permeable layers will inhibit the spread of pollution so that only a part of the aquifer may be endangered in a specific case.

Protection of sources

In aquifers where the water table is close to ground surface, overground drainage can reach the saturated zone quickly, the more so if the well or borehole is poorly constructed. It is inadvisable to locate sources close to polluting agencies such as farm yards, stables or waste disposal sites. Drainage from roads, particularly major raods, can also be a hazard where it is normally discharged to soakaways.

Excavated shafts should have a water-tight coping and be surrounded by a concrete apron. Boreholes should be fitted with a length or lengths of plain lining tube extending from the ground surface at least to the saturated zone, and this tube should be sealed externally with cement grout.

6. IMPLICATIONS FOR LAND-USE PLANNING

Throughout the text, and in the individual area reports, references have been made to areas where geological conditions may have an important bearing on land-use and planning. They relate broadly to four factors, all of which ought to be taken into account when making planning decisions:

a) Ground instability

b) Foundation conditions

c) Natural resources

d) Hydrogeology and protection of aquifers.

It is emphasised that only general statements are made in this report, in some cases based on limited data, and further investigations are always likely to be necessary to elaborate on specific points.

a. Ground instability

Reading Formation

Landslips on natural slopes are only developed on the clays of the Reading Formation and commonly have taken place on slopes of 10° or less (Bristow and Freshney, 1986). They are all associated with springs issuing from a perched water table within the overlying Warmwell Farm Sand.

London Clay to Barton Clay

Areas of mixed sand and clay sequences, classified according to the natural slope angle, are shown in Freshney, Bristow and Williams (1984, fig.17); Freshney, Bristow and Williams (1985, fig. 24) and Bristow and Freshney (1986, fig.16).

From these figures it is apparent that natural slopes up to 25° generally appear to be stable. However, perched water tables occur in these multi-layered aquifers, and may cause drainage and stability problems similar to those encountered in excavations in the cliffs on either side of Bournemouth Pier (Freshney, Bristow and Williams, 1985).

b. Foundation conditions

The ability of the ground to support buildings and other structures depends on many geological factors. These should be explored during site investigations, but some general comments are given below.

Tertiary sands

Tertiary sands are usually compact, poorly graded, well draining and can have high compressive strengths. In general, they provide adequate foundations for most small to medium-sized structures. Locally, the sands are ferruginously cemented and may prove difficult to excavate. Interbedded clays of variable thickness may, in places, alter these overall characteristics.

Tertiary clays

The in-situ strength of the Tertiary clays is related to their natural moisture content. This is partly determined by the position of the water-table in associated thick units of sand, but the amount and continuity of thin beds and laminae of fine-grained sand in the clays is also a major controlling factor. The ability of the clays to absorb water from these sand beds and laminae is important where excavations are made in wet conditions. The Tertiary clays vary tremendously in plasticity, shear strength and cohesion within any one unit (Freshney, Bristow and Williams, 1984, fig. 16, Table 2; Freshney, Bristow and Williams, 1985, figs. 19 to 21, Table 2; Bristow and Freshney, 1986, fig 11, Table 3, and figs 27 to 29 of this report). Some of the Tertiary clays are lenticular, which might cause problems with differential settlement.

Clays in the Reading Formation, and several in the Poole Formation, are commonly palaeosol clays. They generally have a low sand content and are likely to have been dessicated. When unweathered they tend to be stiff to very stiff and have low compressibility.

River terrace deposits and alluvial gravel

The terrace gravels and alluvial gravels are usually compact and well graded and provide adequate foundations for most small to medium-sized structures. The lower-lying river terraces commonly have a cover of silty clay or clayey fine-grained sand. These have much lower compressive strengths than gravel, but the beds are usually less than 1m thick. Up to 5m of weak soils, including peat and highly organic silts and clays, can occur in the alluvial deposits.

Made Ground

Extensive areas of marshland, low-lying ground bordering rivers, several small valleys and many pits have been reclaimed in recent years. Much of the fill is domestic waste, but there is also industrial refuse, overburden and spoil from sand and brick pits, imported sand and dredged material from Poole

Harbour. These areas and their probable dominant fill are shown by Freshney, Bristow and Williams (1984, fig.18); Freshney, Bristow and Williams (1985, fig.22), and Bristow and Freshney (1986, fig.13). Up to 10m of made ground occur locally.

Because of the heterogeneous nature of the fill, differential compaction can be expected in most sites. Decaying organic waste and some industrial waste could produce toxic discharge which may pollute the ground water or flow directly into surface drainage. Methane is also commonly given off. In general, no structure should be erected on made ground without a rigorous site investigation and adequate design for any proposed buildings.

Underground workings

Clay is known to have been mined in underground workings at Hamworthy in the south, near Corfe Mullen in the north, and at Beacon Hill (Bristow and Freshney, 1986; White 1917). The extent of the underground workings is not known except for those near Corfe Mullen, where the adits, about 30m long, radiated from the face (Bristow and Freshney, 1986). There is a possibility that underground clay extraction took place elsewhere in the Poole-Bournemouth area, but has gone unrecorded.

Solution - collapse hollows

Numerous solution-collapse hollows have been mapped on Tertiary strata which overlie Chalk at shallow depth in the Lytchett Matravers area (Bristow and Freshney, 1986, fig.12). They do not always have a surface expression, but they may be located by geophysical and remote sensing methods.

Oil and gas seepages

Although hydrocarbons occur in the Mesozoic rocks of the area, there are no local records of oil or gas seepages. The nearest are from Wealden sands at Worbarrow Bay in the Isle of Purbeck and from the Corallian near Ringstead. In the Bournemouth area, several impermeable clay formations such as the Oxford Clay and the Gault overlay the main Mesozoic reservoir formations forming an effective barrier to the upward migration of hydrocarbons except along faults. The highest source rock, but not reservoir rock, for hydrocarbons is the Kimmeridge Clay. It is largely absent from the Wytch Farm area because of pre-Cretaceous erosion, but it is probably present under parts of the Poole-Bournemouth area. It is impermeable and is likely to be capped by the impermeable Gault. Tertiary strata, such as the Oakdale and Parkstone clays, contain sediments with a high level of organic matter. Although these clays have never been deep enough to mature sufficiently to produce large amounts of gas, it is possible that some lenticular sand beds within the clays may have a small gas content. Sand beds at the top of the Boscombe Sand at Hengistbury Head are impregnated with autochthonous black bituminous material which can be removed by solvents.

In general, the high permeability of the sands over most of the Tertiary outcrop would prevent the accumulation of any gases produced by organic-rich clays, but it is possible that a large concrete structure covering a major clay outcrop could impede the free release of any gases produced and allow a build up in cavities in foundations. It might therefore be prudent in such a case to monitor the hydrocarbon gas levels in any enclosed space in contact with Tertiary formations.

Sulphate concentrations

Marcasite (iron sulphide) concretions in clays of the Poole Formation and Branksome Sand breakdown and give rise to high sulphate concentrations in the ground water. This may corrode certain construction materials.

c. Natural Resources

The principal bulk minerals in the Poole-Bournemouth area are clay, sand and gravel. Chalk has been worked for lime, but because of its limited occurrence within the district, it need not be considered further. In recent years, the presence of hydrocarbons south-west of the district at Wytch Farm has led to the drilling of two wells at Hurn and Bransgore

The principal clay, sand and gravel pits in the district are shown in Freshney, Bristow and Williams (1985, fig.23) and Bristow and Freshney (1986, fig.14).

Brick and pipe clay

Several companies exploited the clays of the Poole Formation for bricks and pipes from large pits on the fringe of Poole until the 1960's and 70's. Now, much of the outcrop of the worked clays is sterilized by urban development. Areas of potentially workable clay still exist between the northern side of Holes Bay and Upton Heath and on either side of the Sherford River.

Ceramic clays

The Upton Heath area lies in the current Ball Clay

Consultation area (see Highley, 1975), but no ball clay has been worked from the heath. Until 1978, ball clay was dug from a pit in the Poole Formation south-west of Lytchett Minster. This clay was blended with clays from south Devon and used for frost resistant tiles. Apart from this occurrence, there is a strong possibility that ceramic clays of a quality suitable for tile manufacture may occur elsewhere within this, and also the Upton Heath, outcrops. Farther north, the West Park Farm Member is dug for the manufacture of unglazed floor tiles. The West Park Farm Member forms an important potential resource of ceramic clay. The sands of the Poole Formation show considerable variation in particle size from fine- to very coarse-grained. They are exploited for construction sand (ie. building sand, asphalt sand and concreting sand) in large pits on Canford Heath (Freshney, Bristow and Williams, 1985) and at Henbury Plantation (Bristow and Freshney, 1986). The Beacon Hill Brick Co. Ltd make sand/lime bricks using sand of the Poole Formation mixed with lime. Sand is dug locally at Beacon Hill, and is also brought in from the Henbury pit.

Sands of the Poole Formation also may be sufficiently coarse-grained to be used as a source of fine aggregate for concrete and perhaps also for concrete tile manufacture.

The Poole Formation sands and the Branksome Sand, therefore, form a large and important resource, but it is rapidly being worked out and sterilized by urban development.

Silica sand

The Poole Formation has been exploited only on a limited scale in Dorset as a source of silica sand, mainly because there are no major local markets for it. However, the sands of the Poole Formation are clean and well-sorted and locally they may be of relatively high purity. For example, 'as dug' sand from a trial pit on Gore Heath west of the present district sunk by Gore Heath Sand Supplies Ltd., contained 99.2% SiO_2 and 0.09% Fe_2O_3. Such a sand would be of sufficient chemical purity for most industrial applications, though it would be unsuitable for colourless container glass manufacture without further processing. Further work is necessary to evaluate the potential resource of silica sand in the area, but it should not be discounted by planning authorities.

Sand and gravel

Much of the Poole-Bournemouth area is underlain by sand and gravel of the river terrace deposits, but large areas have already been sterilized beneath housing. West of the River Avon, small potential resources are indicated by Freshney, Bristow and Williams (1984; 1985) and Bristow and Freshney (1986). Within this area, there is only one recently opened working gravel pit [041 974] near Knighton. In the east, the terraces of the River Avon occupy large areas. Potential resources of sand and gravel in the lower reaches have already been sterilized, but north of the railway, and extending up the Avon to Ringwood, potential resources exceeding 200 million cubic metres occur. These have been assessed by Clarke (1981). Any further building development on the river Terrace deposits in the Poole-Bournemouth area, could be done as at Sleight (Bristow and Freshney, 1986, p.86), by building in the old pit after extracting the sand and gravel.

Hydrocarbons

The area covered by this report is adjacent to Wytch Farm, the most important onshore oil field in the United Kingdom. The main producing horizons are the Bridport Sands and the Sherwood Sandstone, the latter holding the largest reserves. The Cornbrash and the Corallian are of lesser importance. All four formations are probably present under the whole of the Poole-Bournemouth area. At Wytch Farm, the top of the Sherwood Sandstone is at a depth of around 1600m, the top of the Bridport Sands at 900m and the top of the Cornbrash at 750m. These formations probably lie at a greater depth under Poole and Bournemouth. The oil reservoir at Wytch Farm lies to the south of an approximately E-W trending fault passing to the north of Furzey Island in Poole Harbour and probably does not continue under the urban area to the north. Seismic surveys have been carried out in the area, and some test drilling was carried out in 1986 at Hurn and at Bransgore. Information is not freely available from the drilling companies, but the possibility of other oil reservoirs being present in the area cannot be ruled out.

d) Hydrogeology and protection of aquifers

Chalk, the principal aquifer within the Wessex Water Authority district, crops out only in the extreme north-west of the district. Though its use as an aquifer decreases south-eastwards with increasing depth below the Tertiary formations, it is important that the Chalk outcrop should be pollutant-free in and around this area. Pollutants can be carried down dip (south-eastwards) in the aquifer from outside the area, and contaminated water from the Stour may enter the Chalk from the river bed.

The Poole Formation forms a good potential aquifer with good quality water, but because of its multilayered nature it is difficult to exploit. Similarly, the Branksome and Boscombe sands may be considered together as a single multilayered aquifer.

A number of shallow wells and boreholes have in the past taken good quality groundwater from low-level river terrace deposits in the Stour Valley. Terraces at higher levels tend to drain rapidly and have low storage capacities. They are of limited value as a source of water.

The Control of Pollution Act 1974 and the relevant EEC Council Directive (Anon. 1979) require that groundwater be protected from pollution. In general, pollutants may quickly reach the saturated zone in sandy aquifers (as in the case in the present area) where the water table is close to ground surface. It is therefore important that no potential polluting agency should be sited in areas where there is a risk of polluting an aquifer. In areas adjacent to the coast, prolonged pumping from an aquifer may lead to seawater intrusion. Water boreholes should not be sited less than 500m from the shore.

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