Mineral Resources of East Dorset

Commissioned Report CR/01/138N

BRITISH GEOLOGICAL SURVEY

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Mineral Resources of East Dorset

C R Bristow, D E Highley, C M Barton, J F Cowley[1], E C Freshney[2] and N R Webb[3]

Contributors

A J Bloodworth, I Cooke, M A Lewis, K A Linley, J Mankelow, F E McClaren, C P Smith, A T Riddick, R Rose[3], C Simpson and R White

[1] Mineral & Resource Planning Associates
[2] Geological consultant
[3] Centre for Ecology and Hydrology

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Front cover

View from Creechbarrow, westward along the Chalk ridge to Povington ball clay pit, and ball clay extraction at Doreys pit.

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MAPS

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Figure 3

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☎ 028-9066 6595 Fax 028-9066 2835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

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Summary

The Wareham Basin of East Dorset contains internationally important but scarce deposits of ball clay - a clay used in the manufacture of high quality ceramics – together with regionally important sand and gravel resources. Elsewhere in the UK, ball clay is confined to only two small areas in Devon. The Wareham Basin is also subject to very extensive landscape, and international and national nature conservation designations. These include the Dorset Area of Outstanding Natural Beauty, and numerous Special Areas of Conservation and Special Protection Areas designated in accordance with European Directives. The constraints on mineral extraction are, therefore, very severe and it is becoming increasingly difficult to identify acceptable sites for future mineral working.The Department for Transport, Local Government and the Regions wished to examine mineral resource and policy issues in the area in order to identify the best means of approaching this problem. The British Geological Survey was commissioned, in association with the Centre for Ecology and Hydrology, Mineral & Resource Planning Associates and Dr E C Freshney, to undertake a detailed study of the inter-relationships of the mineral, land-use and environmental resources of the Wareham Basin and to make recommendations for the future. The research included detailed geological mapping, a small borehole programme, together with associated sampling and analytical work, the creation of a large borehole database and the collation of a large amount of data on the environmental constraints. To facilitate the interaction and interpretation of the large amounts of spatially related data collected a Geographical Information System (GIS) has been designed and incorporates the main elements of the data to facilitate their rapid analysis.

The results of the research are presented in this Technical Report, which provides a full account of the background to the study, the methods of investigation and results, together with the potential for heathland restoration. A Summary Report entitled *Sustainable development issues for mineral extraction in the Wareham Basin of East Dorset* (Highley et al., 2002) sets out recommendations in relation to resource management issues, the planning process and sustainable development considerations. It is intended that the reports and their associated maps and databases, will deliver information that will assist sustainable resource management, planning and policy development in the Wareham Basin.

The study recommends:

- that Government should take a view on the national importance of ball clay;
- the results of the study should be used for the identification of the extent of commercial ball clay deposits in the area, and the location of these in relation to landscape and nature conservation designations;
- the Geographical Information System and associated database developed should be maintained to provide a framework for planning, and specifically mineral planning, in the area;
- that the options for the supply of ball clay, including alternative sources and materials, should be monitored and reviewed;
- that research on the restoration of mineral workings, especially the re-creation of natural habitats in isolation and as part of an integrated resource and rehabilitation programme, should be promoted by the planning process; and
- that consideration of whether the current approach to safeguarding ball clay resources is adequate.

The databases and maps, which underpin the conclusions set out in this Technical Report and the associated Summary Report are available from the British Geological Survey, Keyworth, NG12 5GG.

1 Introduction

This Report describes research undertaken for the Department for Transport, Local Government and the Regions' project *Mineral Resources of East Dorset.* It reviews the nature and extent of the economically important mineral resources of the Wareham Basin of east Dorset - principally ball clay, but also sand and gravel - and relates these to a wide range of environmental and planning issues, together with the potential for heathland restoration. The project was undertaken by the British Geological Survey, in association with the Centre for Ecology and Hydrology and the consultants Mineral & Resource Planning Associates and Dr E C Freshney.

A Summary Report (Highley, et al., 2002) sets out recommendations in relation to resource management issues, the planning process and sustainable development considerations.

1.1 THE PLANNING ISSUES

Minerals are important national resources. Their extraction and use makes an important contribution to our economic well being and quality of life. An adequate supply of minerals is essential for manufacturing, construction and related industries. Recycled materials can meet part of these requirements, but new minerals are also required.

Mineral resources are fixed in place and can only be worked where they occur. Their potential for extraction, including their quantity, quality and suitability for the market, closely define the location of workable deposits. However, mineral extraction may involve conflict with other desirable aims of society, such as nature conservation, as defined by environmental and development constraints. Minerals cannot, therefore, be worked everywhere they occur, even if they are suitable in economic terms.

Effective planning for the supply of minerals depends on identifying the most appropriate locations for extraction, undertaking operations with the minimum environmental impacts and ensuring high quality restoration to appropriate subsequent uses. The overall aim is to meet society's need for minerals, as far as practicable, at least social, economic and environmental costs.

It is the function of the town and country planning system to regulate the development and use of land in the public interest and to strike an appropriate balance between the need to provide essential minerals, to conserve and protect the environment, and to enhance quality of life. The planning system also has a key role in helping to achieve the Government's objectives for sustainable development. These objectives are addressed through the development plan process, and through decisions and controls on planning applications to extract minerals. Minerals Local Plans should assess the need for future mineral supplies and identify, through general policies and specific allocations, areas in which mineral extraction proposals might be acceptable or where they will normally be resisted. Since proposals that are in conformity with the plan, and that are acceptable in other respects, will normally be permitted, this helps to give certainty to both the industry and to local residents in respect of proposals for extraction. However, the identification of generally suitable areas depends on a good understanding of both the mineral resources and on the constraints to minerals extraction. This requires comprehensive information on the nature and distribution of mineral resources, the characteristics of areas where minerals occur, the likely implications of working these resources, both for the environment and for the quality of life of nearby residents, and the likely levels of demand for the mineral. Such information is also needed for the preparation of policies in regional planning guidance and in considering specific planning applications for minerals extraction, or for other forms of development in mineral resource areas.

To assist these functions and objectives, the decision-making process requires access to reliable and up-to-date information on the extent and nature of the relevant mineral and environmental resources. It is important, therefore, to know and understand the relationship between the thickness, distribution, quality and relative importance of mineral resources and any environmental constraints that may affect their extraction.

Successful and sustainable management of Britain's natural assets, including its mineral resources, requires the integration of a wide range of land-use and related information. In locations where minerals of particular economic importance or rarity occur, or where the extent of the mineral resource is uncertain, or where other resource and environmental factors are of particular importance, resource-management decisions require more detailed appraisal. This is particularly the case where subtle variations in the properties of a mineral or the sensitivity of an environmental resource could be of major significance.

The Wareham Basin of east Dorset is a location where such issues are of increasing concern, particularly with respect to ball clay and nature conservation. The area contains, perhaps, the most diverse range of potentially conflicting resource development and management pressures in England. This report sets out the results of research assessing the quality, location and inter-relationships of the mineral, land-use and environmental resources in the Basin so as to assist the planning process.

1.2 THE WAREHAM BASIN

The study area, covering 510 km^2, is the Palaeogene (Tertiary) Wareham Basin of east Dorset, together with surrounding areas of superficial deposits. The Basin contains interbedded sands and clays, some of which are important sources of construction sands and ball clay, and these deposits are extensively overlain by superficial deposits containing economically important gravels. In most of the area, the responsibility for minerals and waste planning rests with Dorset County Council. The district councils of Purbeck, West Dorset and East Dorset have responsibility for all other aspects of land-use planning. The exception is a small part of the east of the area where Poole Borough Council is responsible for all planning matters (Figure 1).

The Basin consists of a gently rolling plain of heathland, farmland and forest and is drained by two main rivers, the Frome and Piddle, which flow eastward into Poole Harbour. The Purbeck Ridge forms the southern skyline, but the most prominent relief feature is Creechbarrow (192 m OD), just north of the ridge, and the highest Palaeogene outcrop in southern England. Within the Basin, exposures are rare and almost entirely confined to quarries.

Perhaps the most defining character of the area is the sense of open landscape created by the inter-related mosaic of semi-natural habitats, including heathlands, wetlands, woodlands, grassland, estuaries, rivers and standing water and the complementary enclosed landscape of the coniferous forest. In form, colour and land use, the Basin contrasts markedly with the surrounding chalk landscape to the north, west and south, and Poole Harbour to the east. Only in the east around Poole and Wareham is there significant urbanisation.

Many natural habitats have been severely fragmented and reduced in extent over the last decades, mainly by agricultural improvement, forestry and urbanisation, and to a lesser extent, by mineral extraction. The presence of these natural habitats is partly a product of past and current land management practices. They would decline in nature conservation value if not actively and effectively managed with due attention to all parts of the ecosystem. Without such land management, heathland, for example, would only exist as a marginal and pioneer stage of limited and scattered extent, climax vegetation types, primarily oak with birch or hazel, would predominate.

The degree of nature-conservation importance is heightened by the location of the Basin in north-west Europe. This is at the junction of southern and northern, and maritime and continental climatic and ecosystem types. The area has, therefore, representative species of these climatic zones at the limits of their range. This considerably increases species diversity and, therefore, habitat value.

Two further factors are significant. First, the dominance of westerly maritime winds bringing in unpolluted Atlantic air. Second, the absence of major industrial/urban complexes upwind and upstream ensures that both air and water quality is high and that ground contamination is minimal. Therefore, the level of pollutants is low, creating conditions favourable to species such as heathers and epiphytes. Climate data demonstrate the moderating maritime influence during winter and the high temperatures and sunshine hours in summer. The significance of the moderating influence in nature-conservation terms becomes of considerable value when severe weather conditions occur on the Continent or elsewhere in Britain.

The geology, climate and topography have produced soils of a varied nature which have the potential to support different nature conservation and agricultural interests. Broadly, the sands and higher terrace gravels are overlain by acidic podzols, while the clays are overlain by brown earth loams. The lower terraces, particularly those around Crossways, are covered by well-drained loamy soils. The Frome and Piddle, while flowing across a non-calcareous basin, have headwaters in the Chalk and their floodplain soils are locally calcareous and loamy.

Because of its attractive landscape and rich variety of habitats, the Wareham Basin has very extensive landscape and nature conservation designations (Figure 2 and Table 1). A large part of the area, and most of the Basin south of the River Frome, lies in the Dorset Area of Outstanding Natural Beauty (AONB). In addition, the Purbeck Heritage Coast also falls within the AONB and, in 1984, received the Council of Europe Diploma for Conservation.

The Basin is also highly valued for its nature conservation importance for heathland and wetland habitats and species. There are very extensive areas of international nature conservation importance, including Ramsar sites designated in accordance with the Ramsar Convention, and sites designated as Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and Priority Special Areas of Conservation in accordance with European Directives. National nature conservation sites include National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSIs). Most of these areas coincide but even so a substantial part of the Basin is subject to some type of international or national designations (Table 1).

Heathland vegetation is rare in national and international terms and provides habitat for a range of rare species of plants, insects, reptiles and birds which are interdependent, but which exploit different aspects of the heathland habitat. The wetlands are also of international importance, both as habitats in their own right and as wintering, passage or breeding locations for migratory birds. The designated sites also include areas of acidic and neutral grassland, woodland and stream systems. While smaller in extent than the two main ecosystems, and not of international significance, these are still of national importance. These areas also need to be conserved and are material considerations in the planning process.

One factor which particularly enhances the value of nature-conservation sites in the area is their extent and continuity across subtly changing physical and climatic situations (from sheltered maritime fringe to exposed hilltops). This ensures the conservation of each habitat within the whole ecosystem. It also reinforces the diversity of species, and the stability and viability of populations such as raptors, which may need large and varied territories, or of micro-fauna which may migrate slowly. This also provides opportunities for recolonisation of species-poor areas.

The nature-conservation importance of the area has been known for decades and, with loss of habitat elsewhere, the protection of the remaining heathland and wetland has become of considerable importance. The desirability of protecting the remaining habitat is now supported by actions to increase the extent of such habitat in the Basin by re-creation in accordance with biodiversity objectives (UK Action Plan on Biodiversity, 1995).

Figure 1 The extent of the Wareham Basin of east Dorset

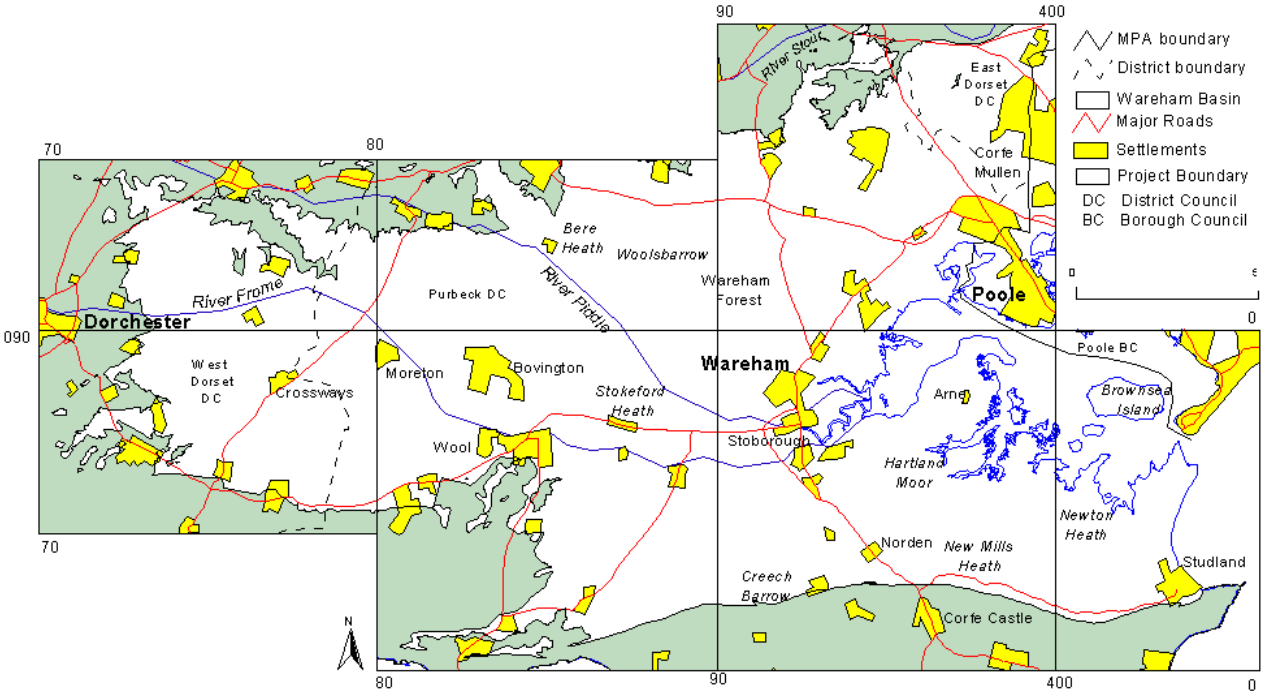


Figure 2 The extent of major environmental designations in the Wareham Basin

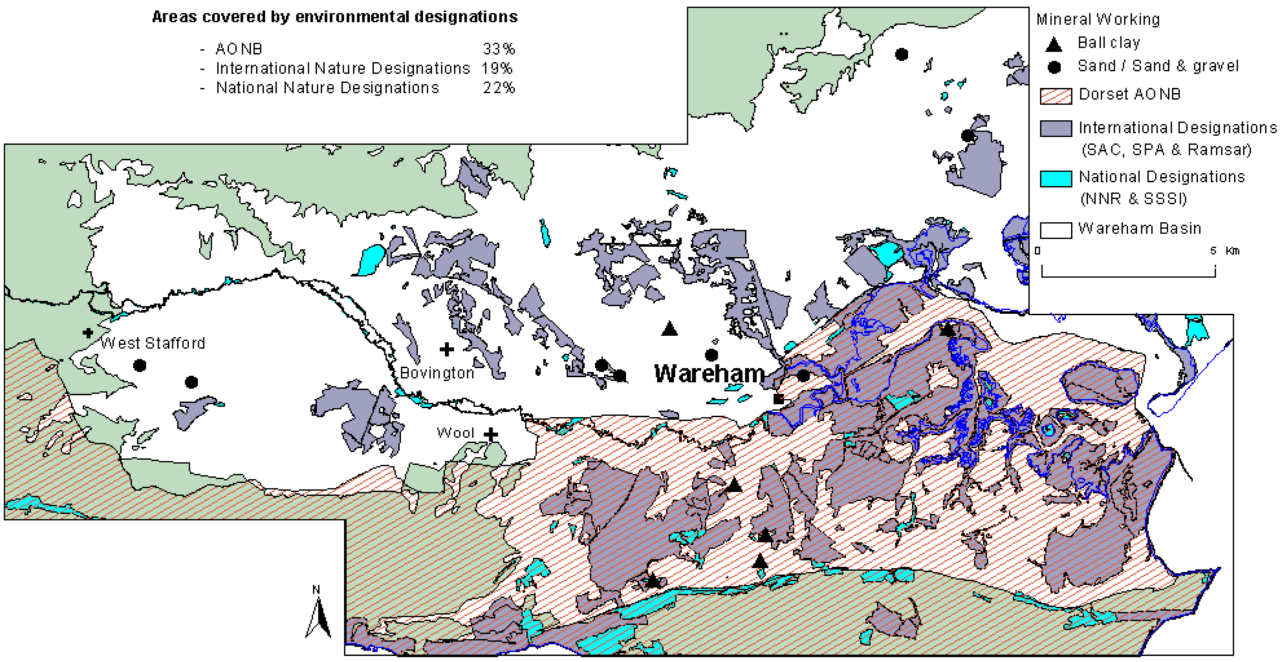


Table 1 Areas covered by selected planning considerations within the Wareham Basin

Designation	Area (ha)	% of Wareham Basin
Area of Outstanding Natural Beauty (AONB)	10,799	33
Purbeck Heritage Coast	5,337	16
Special Area of Conservation (SAC)	5,289	16
Special Protection Area (SPA)	6,291	19
Ramsar site	6,345	19
National Nature Reserve (NNR)	1,182	4
Site of Special Scientific Interest (SSSI)	7,158	22
Conservation Areas	1,262	4
Grade 1 Agricultural Land	0	0
Grade 2 Agricultural Land	533	2
Ministry of Defence Land	2,883	9
National Trust	1,740	5
Extent of Wareham Basin (to high water mark)	**32,684**	**100**
Note: Designations are not mutually exclusive.		

The Basin also contains numerous Scheduled Monuments and other non-scheduled features and archaeological sites, Conservation Areas and buildings of historic and architectural importance. Groundwater resources and some of the limited high-grade agricultural land in the county also occur. Extensive areas are in the ownership of the National Trust or under commercial forestry. The Ministry of Defence uses large areas for military training (Figure 3). In addition, the area is important for tourism and adjoins the Poole-Bournemouth conurbation, one of the fastest growing areas in the country.

The mineral resources of the Wareham Basin include internationally important deposits of ball clay, as well as sand and gravel, and brick clay. The area also contains Europe's largest onshore oilfield, Wytch Farm, but hydrocarbons fall outside the terms of this study.

The Wareham Basin is one of only three areas in Britain where economic ball clay deposits occur (Figure 4). The area accounts for around 20 per cent of national production. There has been a local ball clay industry in the Wareham Basin since the 17th century. Unworked resources are fairly widespread, but a major part of these are within areas that have been identified as worthy of conservation. A key issue is, therefore, the extent to which acceptable new sites for future ball clay extraction can be identified in the Wareham Basin.

The Basin also contains important resources of sand valued primarily for use as aggregate, but with a minor quantity also used as industrial sand, and which supply a sub-regionally important construction sand industry. Gravel aggregate is also produced currently, but both reserves and resources are rapidly becoming depleted. There are large resources of clay potentially suitable for brick and tile manufacture, although current production is very small. A significant part of the sand and gravel outcrop occurs in areas of international and nature conservation importance.

All these factors either create pressure to use or to inhibit the utilisation of land in the Basin. Although human actions have influenced the extent and value of resources, such resources are primarily defined by the physical limits of the Basin. Particular geological factors have created and preserved the rare ball clay and other mineral deposits in the area. The presence and quality of heathland and other environmental resources in the area is a direct consequence of the inter-relationship of the geology, groundwater regimes, topography and climate. Options to develop or safeguard mineral resources or to conserve environmental resources need to be considered within the limitations of their occurrence.

The report, therefore, considers the:

- economic importance of the mineral resources
- extent and variations in quality
- practical limitations which apply to mineral extraction and processing
- extent of the major environmental and other economic resources
- spatial relationship between the mineral and other resources
- development of the mineral resources
- extent to which constraints can be overcome, or mitigation measures can be used to reduce damage to environmental or other resources to acceptable levels
- current planning process, (policies at both national and local level, decisions on development) and whether it adequately addresses these pressures
- changes to the planning process that may improve the quality of the response.

Figure 3 The extent of selected land holdings and designations in the Wareham Basin

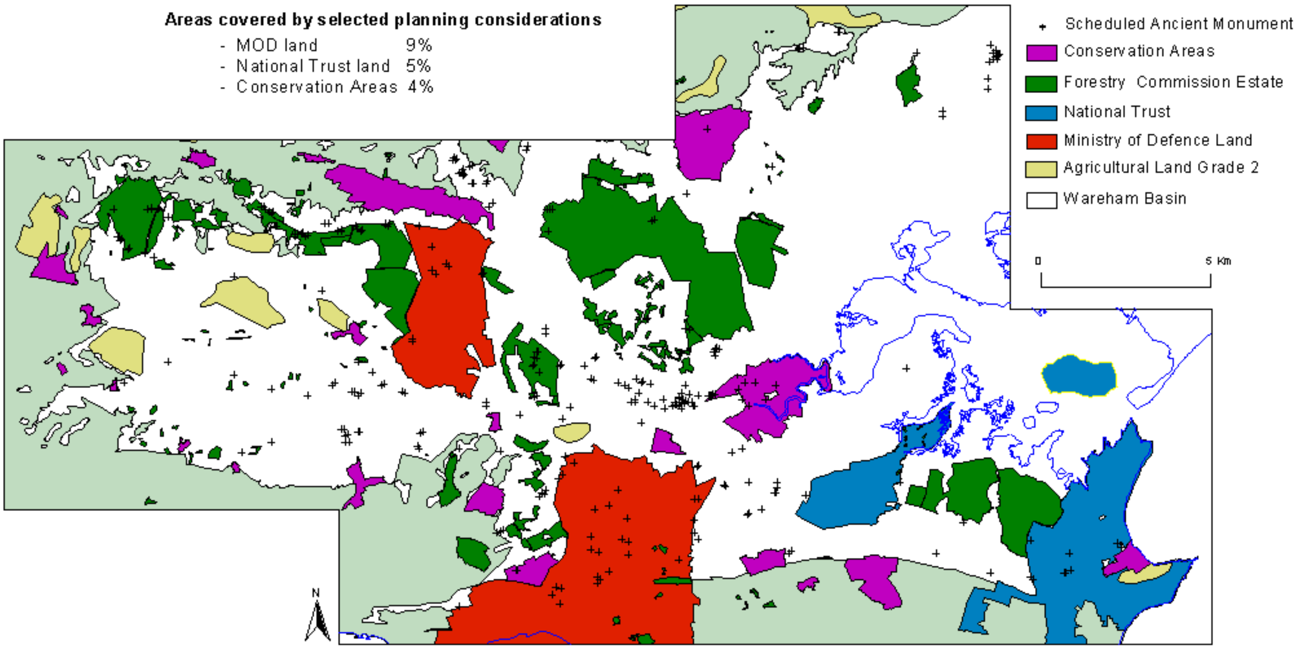
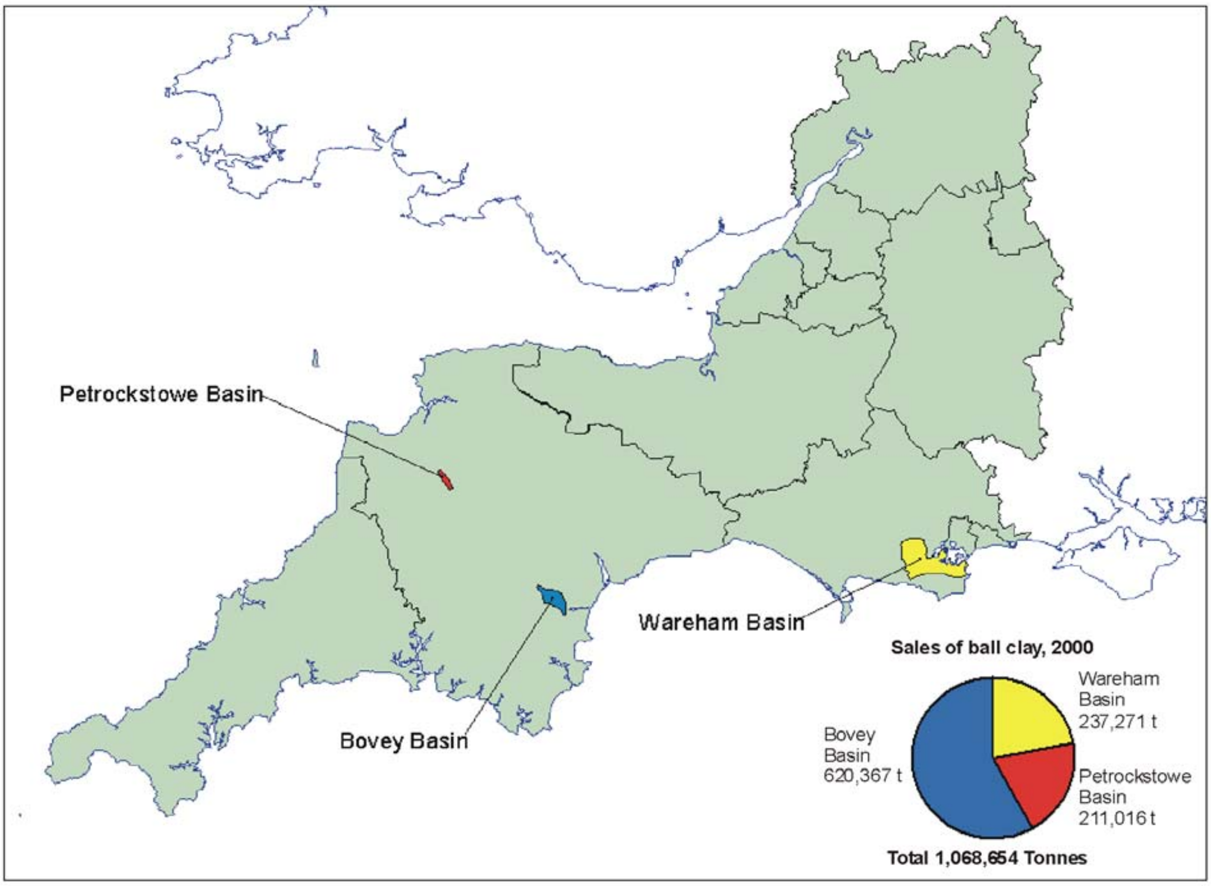


Figure 4 Location and output of ball clay-bearing basins in South-west England



2 Geology

2.1 GEOLOGY AND HYDROGEOLOGY

The Palaeogene (Tertiary) sediments of the Wareham Basin crop out in an east-west trending, gently eastward-plunging, syncline, the axis of which runs approximately along the Frome Valley. The Wareham Basin is strongly asymmetrical; on the northern margin, Palaeogene strata and the underlying Chalk dip gently southwards, but along the southern margin, the same strata are near vertical. There, the Palaeogene/Chalk contact is a complex series of strike faults over most of its length and strata, including ball clays, locally display considerable structural complexity with thrusts, and steep dips, and may be locally overturned. However, the structural disturbance tends to extend no more than 500 m northwards from the Palaeogene/Chalk contact.

2.2 BEDROCK GEOLOGY

Chalk occurs either at surface or depth beneath the whole area. The overlying Palaeogene strata consist dominantly of sands and clays. They are divided into formations and members on the basis of their dominant lithological characters. The Poole Formation (formerly known as the Bagshot Beds) is the most extensive and economically important in the area. The schematic stratigraphy and thickness of the Palaeogene strata are shown in Figure 5.

2.2.1 Chalk

Chalk bounds the Wareham Basin on the northern, western and southern margins, and underlies the Palaeogene rocks at shallow depth on the northern and western fringes, but reaches 160 m below OD under Poole Harbour. Chalk is quarried in adjacent areas, but this project excluded consideration of Chalk.

Chalk is the main aquifer in the area (over 95 per cent of licensed abstraction in the area is from the Chalk) and its groundwater resources extend beneath the Palaeogene rocks. The predominant flow mechanism in Chalk is fissure flow. This means that the aquifer is highly vulnerable to pollution. At outcrop, the water is hard, but normally of good quality. Nitrate levels are increasing due to agricultural pollution. Where confined by Palaeogene deposits, yields decrease, water is softened by cation exchange, and nitrates fall due to denitrification.

2.2.2 London Clay

The London Clay, up to 65 m thick, has a fairly wide outcrop on the northern and western margins of the Basin, but in the south, because of either steep dip or faulting, its outcrop is narrow or absent. The formation consists of an alternating sequence of sands and clays. The clays were formerly worked for brickmaking in the area, but are now only worked at the Knoll Manor Clay pit [973 977] near Corfe Mullen for the manufacture of red-bodied floor tiles. Sand is worked, in conjunction with Poole Formation sands, in the Henbury Pit [965 975] near Corfe Mullen for facing and moulding sand in clay-brick manufacture.

2.2.3 Poole Formation

The Poole Formation consists of an alternating sequence of sands and clays. It hosts the important ball clay and construction sand resources in the area. In the central and eastern parts of the outcrop four 'host' clays and associated sand units have been recognised and mapped (Figure 6). They are, in ascending sequence: the Creekmoor, Oakdale, Broadstone and Parkstone clays and underlying sands. In the west, well-defined mappable clays are largely absent, such that the Poole Formation consists predominantly of undifferentiated sand.

The Poole Formation varies in thickness from 150 m near Creech, to about 85 m under Trigon Hill. Over much of the rest of the district, the higher parts of the succession are mostly absent because of erosion.

SANDS IN THE POOLE FORMATION

The outcrops of the sand members vary across the Basin (Figure 7). They show great variation in thickness, from 0 to 44 m, but generally in the range 10 to 15 m (see Table 2), and may contain silt, clay, gravel and iron-cemented beds, all of which decrease the value of the resource.

Figure 5 Generalised vertical section of the rocks in the Palaeogene Wareham Basin

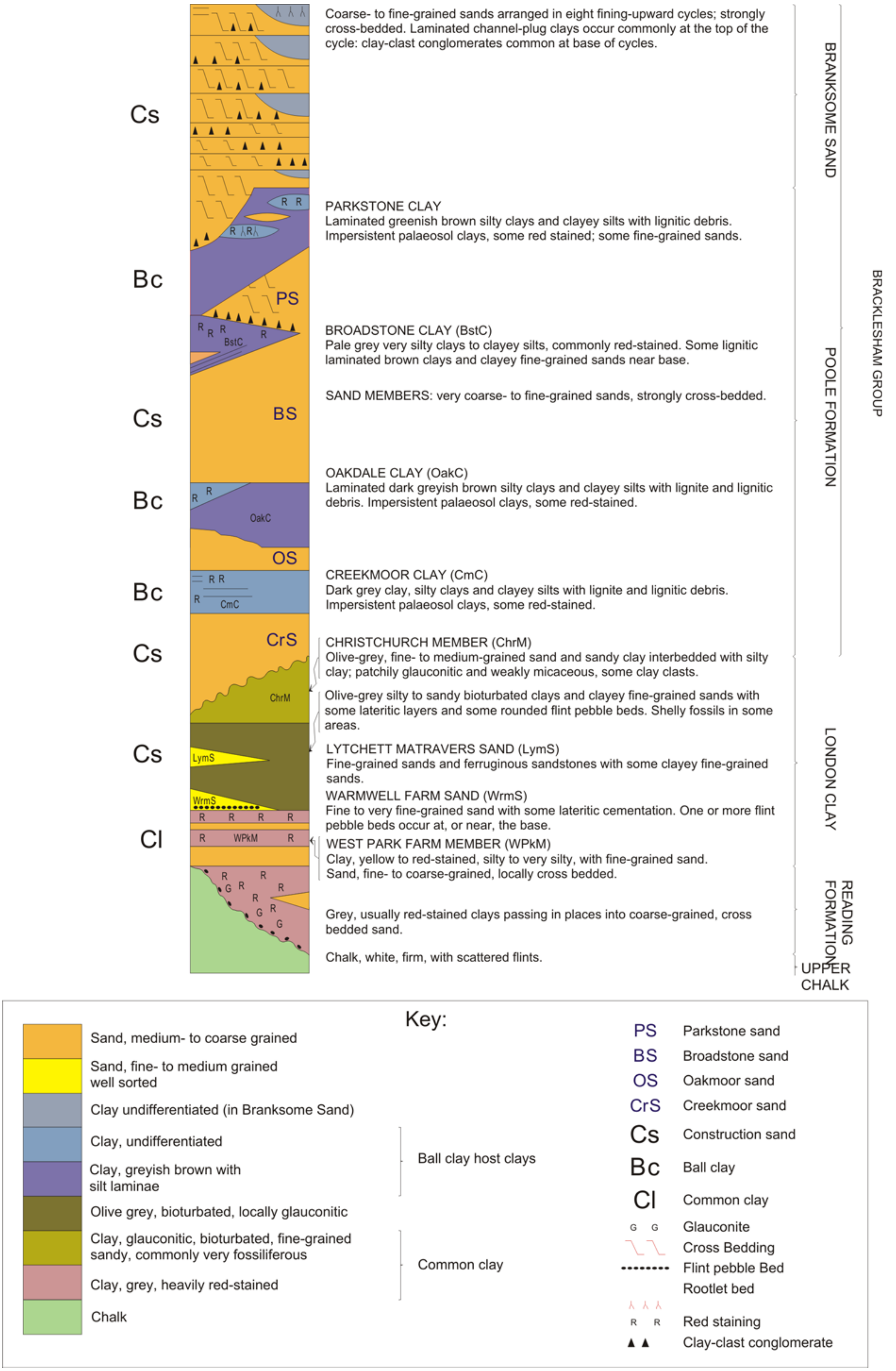


Figure 6 The extent of ball clay-bearing host clays

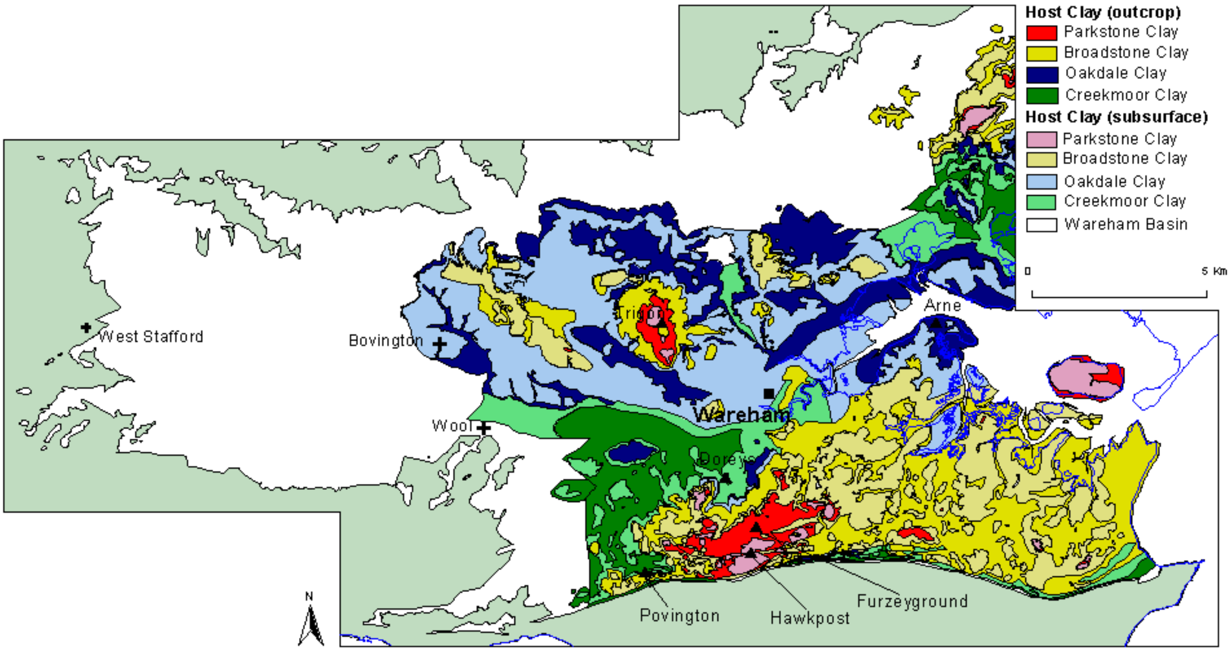


Figure 7 Extent of Poole Formation sands in the Wareham Basin and the ball clay-bearing host clays

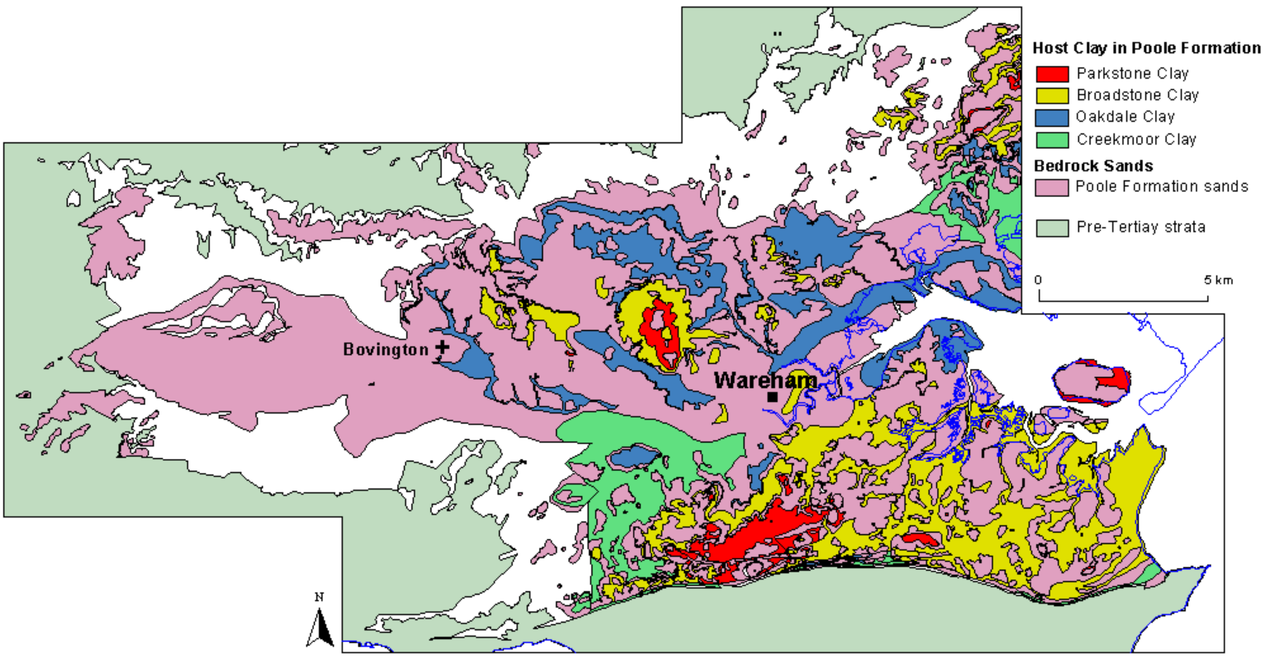


Figure 8 Thickness of the Creekmoor Clay (719 records)

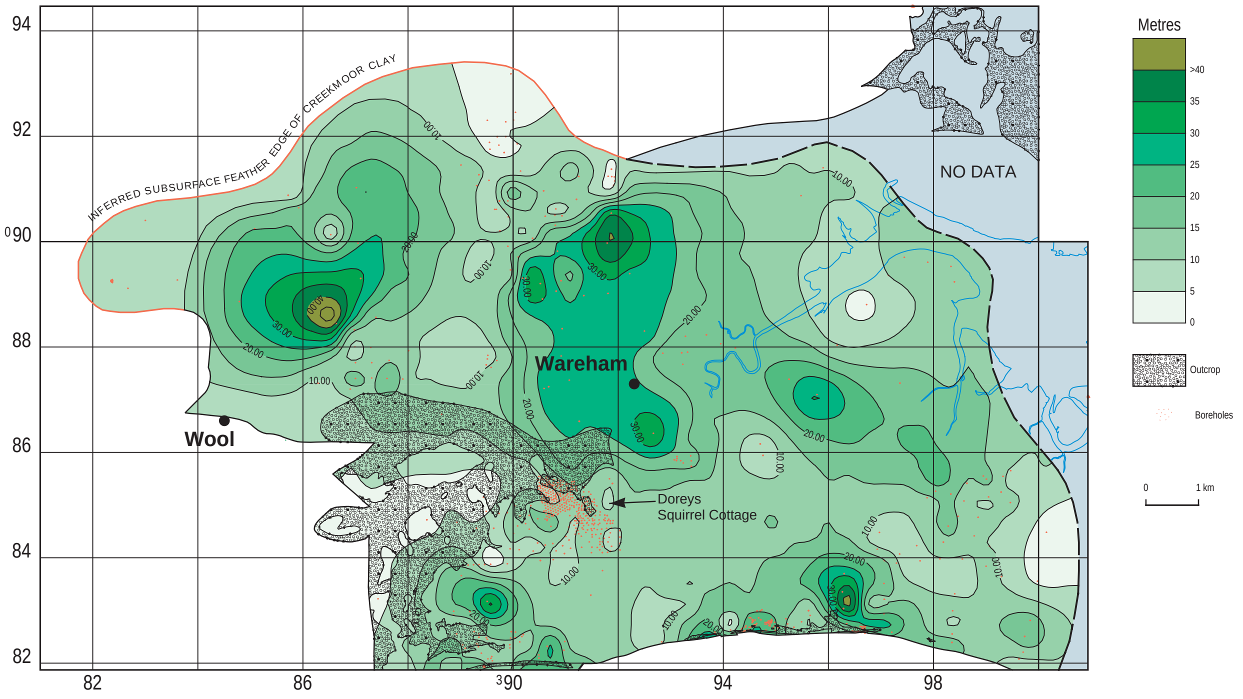


Figure 9 Thickness of the Oakdale Clay (1068 records)

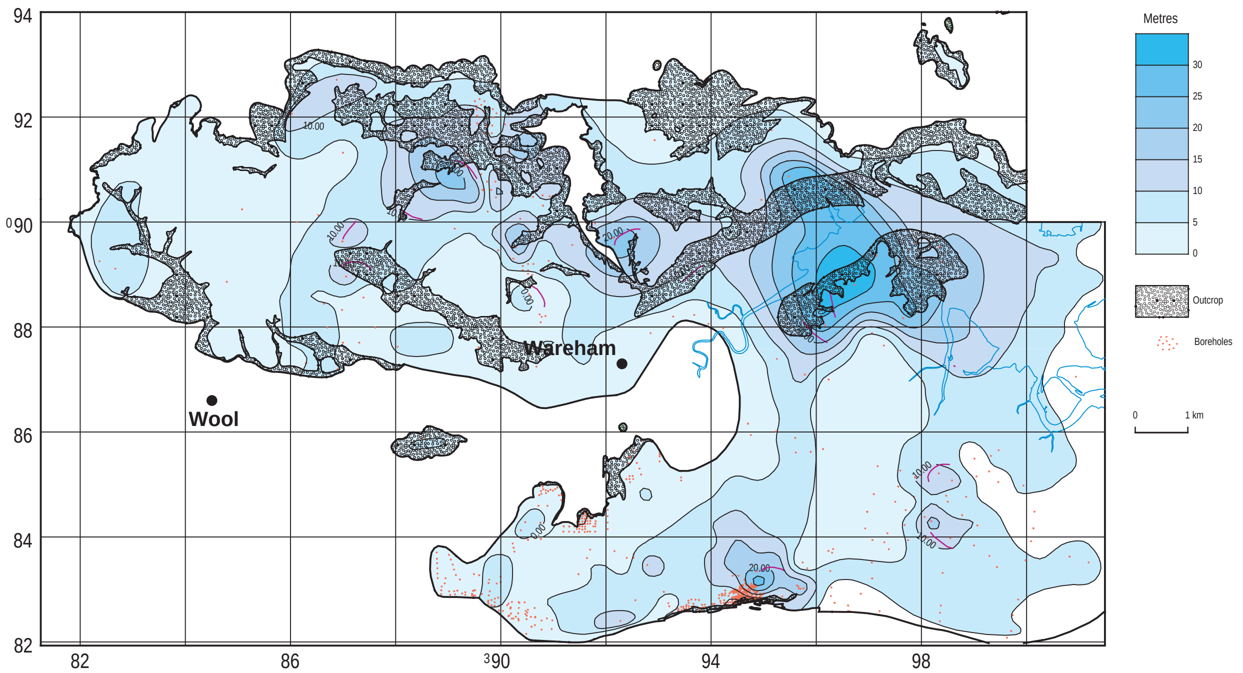


Figure 10 Thickness of the Broadstone Clay (632 records)

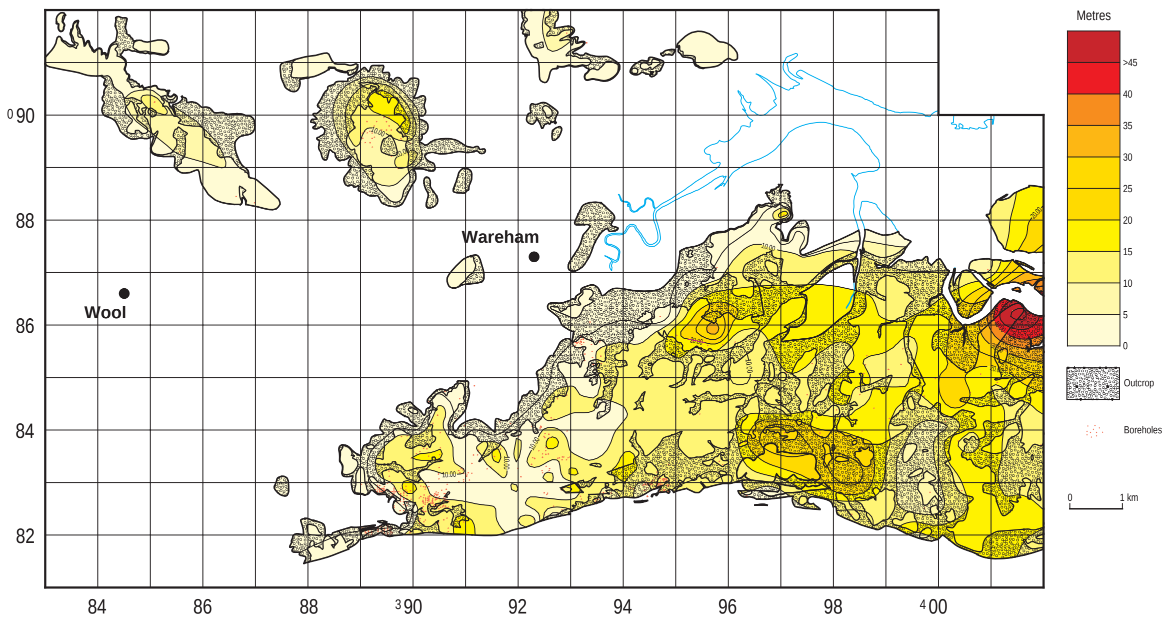


Figure 11 Thickness of the Parkstone Clay (125 records)

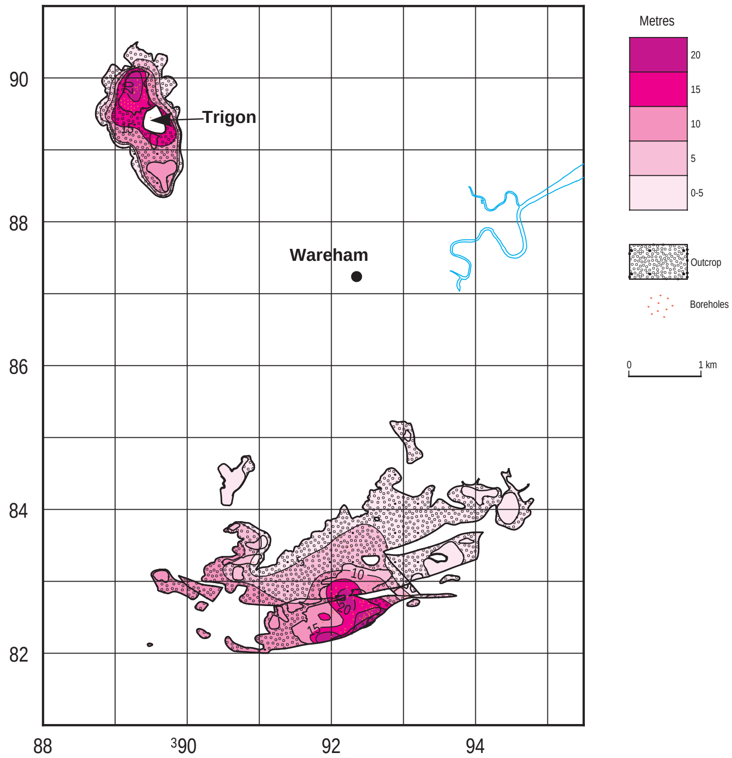


Table 2 Thickness and grading data for the principal sand units

[1]Thickness (m)	Total data	Min.	Max.	Average
Parkstone Sand	232	0.00	29.87	9.99
Broadstone Sand	501	0.00	43.89	9.94
Oakdale Sand	950	0.00	42.37	13.22
Creekmoor Sand	93	0.00	34.75	14.73

[2]Mean grain-size (mm)	No. analyses	Av. per cent fines[3]	Min	Max	Average
Branksome Sand	3	2.87	0.84	0.89	0.86
Parkstone Sand	63	3.18	0.20	2.00	0.63
Broadstone Sand	124	5.67	0.10	1.50	0.61
Oakdale Sand	124	5.34	0.08	1.95	0.50
Creekmoor Sand	7	3.43	0.28	0.81	0.40
London Clay sands	20	10.43	0.06	0.58	0.22

[1]All thickness data are taken from the borehole database
[2]Average grain-size in millimetres
[3]Weight loss on washing samples through 63µm sieve.

An extensive area of sand with little or no interbedded clay in the west underlies the valley of the River Frome and adjoining terrace gravels and is a major area of sand extraction, principally in association with working the overlying terrace gravels deposits.

The grain-size distribution of the Poole Formation sands (Table 2) shows considerable variation; the mean ranges between 0.4 and 0.9 mm, with an average close to 0.6 mm. This makes them generally suitable for use as fine aggregate in concrete and mortar. The sands contain significant quantities of water (Whitaker and Edwards, 1926) and are used for water supplies that could be affected by ball clay workings. Currently, there are abstractions for public supply, for gravel washing and small agricultural, industrial and commercial use. The Creekmoor Sand is the best aquifer; boreholes may be artesian. Boreholes have frequently failed or collapsed due to pumping running sand.

The waters have low total dissolved solids contents, but are acidic, corrosive to metals and iron-rich. Marcasite (iron sulphide) concretions in the clays give rise to high sulphate concentrations in groundwater.

CLAYS IN THE POOLE FORMATION

The clays in the Poole Formation, which can be up to 50 m thick (Table 3), host laterally impersistent beds of ball clays. The thickness and properties of these clays are summarised in Table 3 and Figures 8-11. Ball clays are highly plastic, kaolinitic clays and are valued for the manufacture of ceramic whiteware. Quality of the host clay and associated ball clay can vary quite rapidly over short distances. The clays can be silty, locally carbonaceous and lignitic, commonly laminated and patchily red-stained. In the north-east of the area, clay quality deteriorates, such that the host clays no longer provide a source of ball clay. However, they were formerly worked for the manufacture of bricks, pipes and tiles.

The sand content of the Creekmoor Clay increases northward and beds of sand have been recorded in boreholes north of the Frome. Commensurate with the northerly increase in sand is a decrease in kaolinite (Figure 20) resulting in diminished ball clay quality. The uppermost bed is commonly red stained. Red-staining of the clays is more common in the north of the Basin and is thought to be the reason why this member has not been worked for ball clay in the north-east of the area. Carbonaceous beds are common at several levels in the Oakdale (see Bristow et al., 1991, pl. 2) and Broadstone clays.

2.2.4 Branksome Sand

The Branksome Sand occurs as outliers around Trigon Hill in the centre of the area, around Beacon Heath in the north-east, on Brownsea Island in the east, and Creech Hill in the south. At all these localities, the Branksome Sand forms a large potential source of sand. The maximum thickness is about 74 m on Creech Hill.

The formation consists dominantly of fine- to medium-grained sand. Locally, thin beds of silty and sandy clay occur. On Creech Hill, such a clay, the Creech Brick Clay, up to 5 m thick, was formerly worked for brickmaking. Groundwater in the Branksome Sand is likely to be similar to that from the Poole Formation.

Table 3 Thickness and properties of Poole Formation clays derived from the borehole database

	Host Clay	Total boreholes	Minimum	Maximum	Average	Standard Deviation
Thickness (m)	Parkstone Clay	125	1.22	33.83	16.34	7.09
	Broadstone Clay	632	0.0	56.08	10.20	6.60
	Oakdale Clay	1072	0.0	35.36	5.56	6.32
	Creekmoor Clay	722	0.0	50.60	14.01	8.23
Overburden thickness (m)	Parkstone Clay	350	0.00	78.03	12.32	11.47
	Broadstone Clay	928	0.00	60.05	11.39	9.97
	Oakdale Clay	947	0.00	78.03	16.57	12.27
	Creekmoor Clay	2851	0.00	95.00	22.26	14.42
$Fe_2O_3 + TiO_2$ (per cent)	Parkstone Clay	207	1.86	4.52	2.86	0.43
	Broadstone Clay	410	1.95	9.10	3.43	1.00
	Oakdale Clay	327	1.81	9.45	3.06	0.95
	Creekmoor Clay	1858	1.75	10.85	3.20	0.80
SiO_2 (per cent)	Parkstone Clay	224	50.90	78.75	64.91	6.09
	Broadstone Clay	409	41.33	77.00	60.96	6.17
	Oakdale Clay	327	48.00	76.00	59.90	5.01
	Creekmoor Clay	1860	44.63	73.00	53.67	3.44
Kaolinite content (per cent)	Parkstone Clay	172	19.21	47.46	31.86	5.68
	Broadstone Clay	192	17.20	79.44	45.13	15.22
	Oakdale Clay	176	16.10	70.91	36.08	8.91
	Creekmoor Clay	1347	12.20	81.42	52.56	10.03

2.3 DEPOSITIONAL ENVIRONMENT AND ORIGIN OF BALL CLAY

High-quality ball clays are relatively scarce both in Britain and world wide. This is a function of the unusual combination of geological factors that are required for their formation and subsequent preservation. Most importantly, climatic conditions prevailing in Palaeogene times had the greatest impact on their origin, together with the environment in which they were deposited.

An understanding of the depositional environment of the Poole Formation and the origin of the Dorset ball clays is helpful in predicting their likely extent, spatial relationship and quality, and also explains the characteristics of the sands.

Dorset ball clays are the same approximate age as those in Devon, but differ both in the origin of the clay and their depositional environment. Devon ball clays are of continental origin and were laid down either in a flood plain and backswamp environment bordering a river (Freshney et al., 1979) or lake (Vincent, 1974). In contrast, the Dorset clays were deposited in an estuary, where both river and marine influences had a control on sedimentation.

Most of the kaolinite (the key component of ball clay) in Dorset and Petrockstow ball clays is derived from the erosion of tropical to sub-tropical weathering profiles developed on land surfaces. At Petrockstow, Bristow (1968) described fine-grained kaolinite, with a disordered crystal lattice, being formed at the expense of other minerals such as illite, chlorite and sodium feldspar in weathering profiles on Carboniferous mudstones and sandstones. In the Bovey Basin, the origin of the kaolinite is more variable because of a large input from kaolinised Dartmoor Granite. This kaolinite is coarse to medium grained and has a more ordered crystal lattice.

Dorset clays were derived from weathering profiles developed on mudrocks of various ages and probably did not differ greatly from those in Devon, despite their disparate source rocks. The differing depositional environments, however, exerted a strong control on the subsequent mineralogy, geochemistry and physical properties of the clays.

Dorset ball clays were laid down where an eastward-flowing river system carrying sand and clay flowed through an estuary towards a sea (Figures 12 and 13). Cyclical changes in sea level controlled the sedimentation of sand and clay (Newell, 1998). During times of rapid sea-level fall, erosion of the river valley was greatest, with little deposition of sediment. When sea level started to rise again, sands were deposited in a probably braided river. The Poole Formation sands represent this type of sedimentation.

When the rate of sea level rise slowed and sea level reached its maximum, marine conditions migrated westwards towards east Dorset. A sequence of estuarine interbedded clays and fine-grained sands and silts, commonly with an erosional or channelled base, were deposited on river-deposited sands, probably in the inner and central zones (Figure 13) of an estuary (Newell, 1999). The inner zone, with rapid sedimentation rates, was dominated by fairly energetic fluvial depositional processes with low salinities and was an unsuitable environment for ball clay deposition. In the central zone, however, where fluvial flow with clay material met more saline tidal waters, current velocities were lower and flocculation of clay particles occurred with the formation of kaolinite-rich clays. The position of the central zone varied with time. As a marine transgression progressed westwards, central zone sediments, including ball clays, were deposited on top of non productive inner zone sediments. If the transgression was continuous throughout the deposition of the host clay,

Figure 12 Palaeogeography of South-west England during the deposition of ball clay

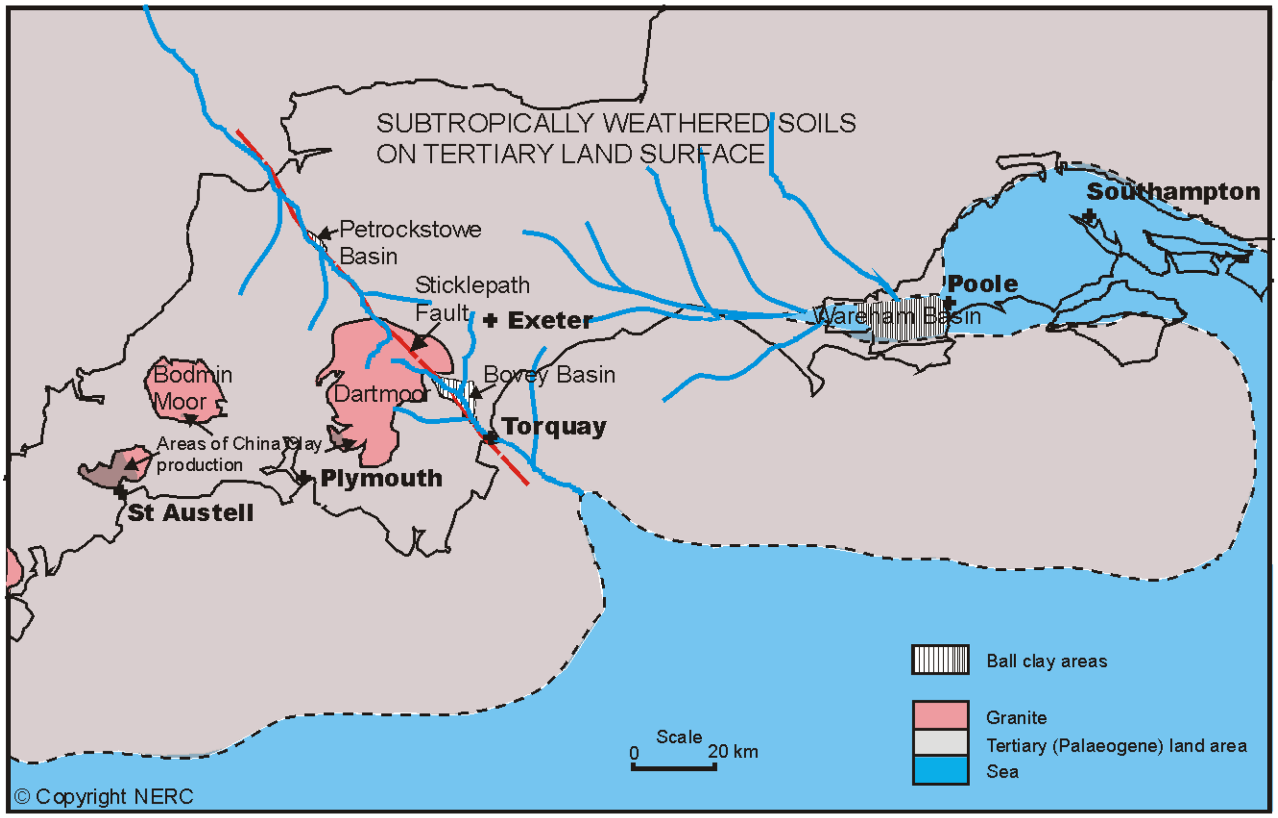


Figure 13 Depositional environment for Dorset ball clays

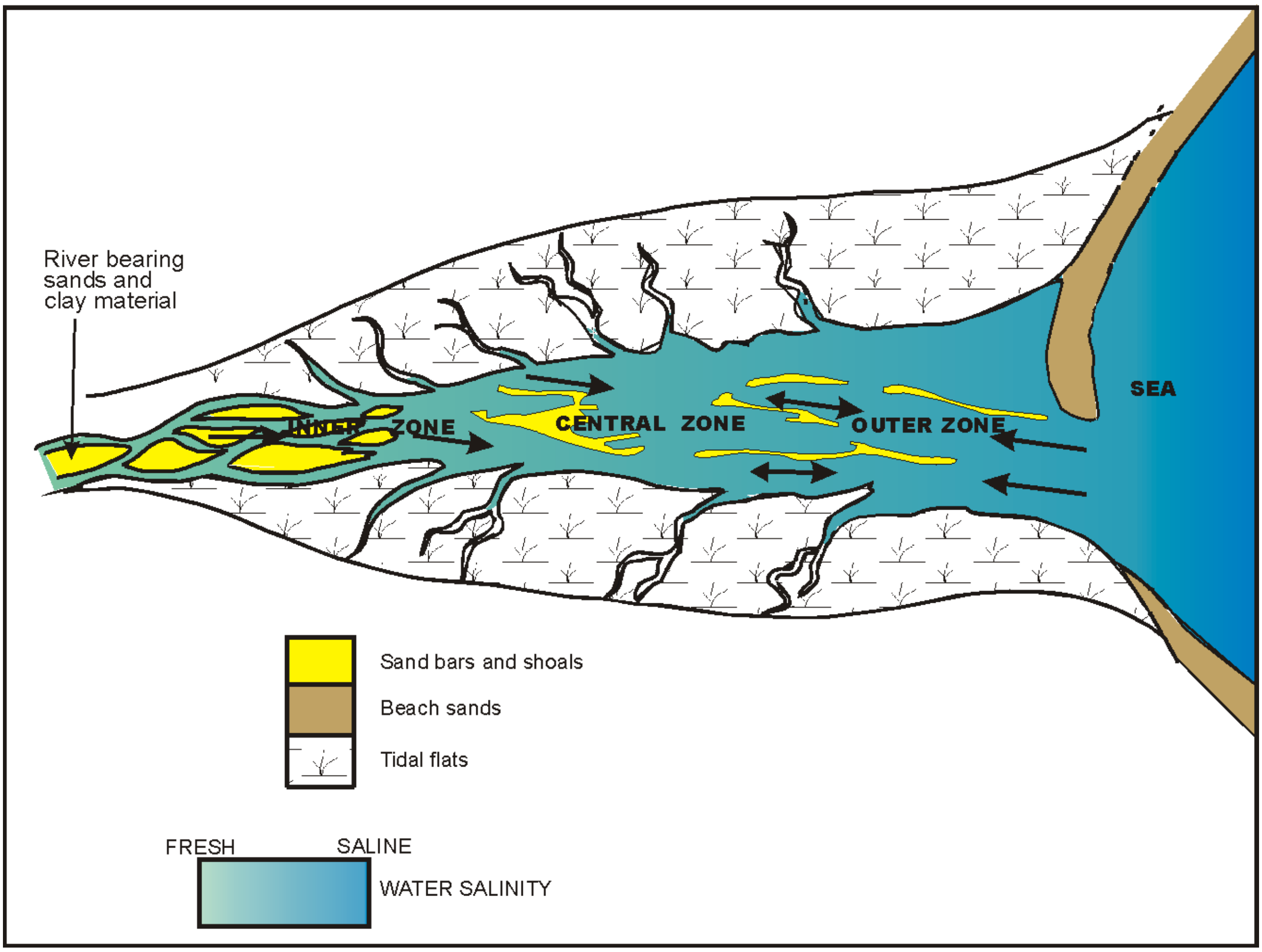
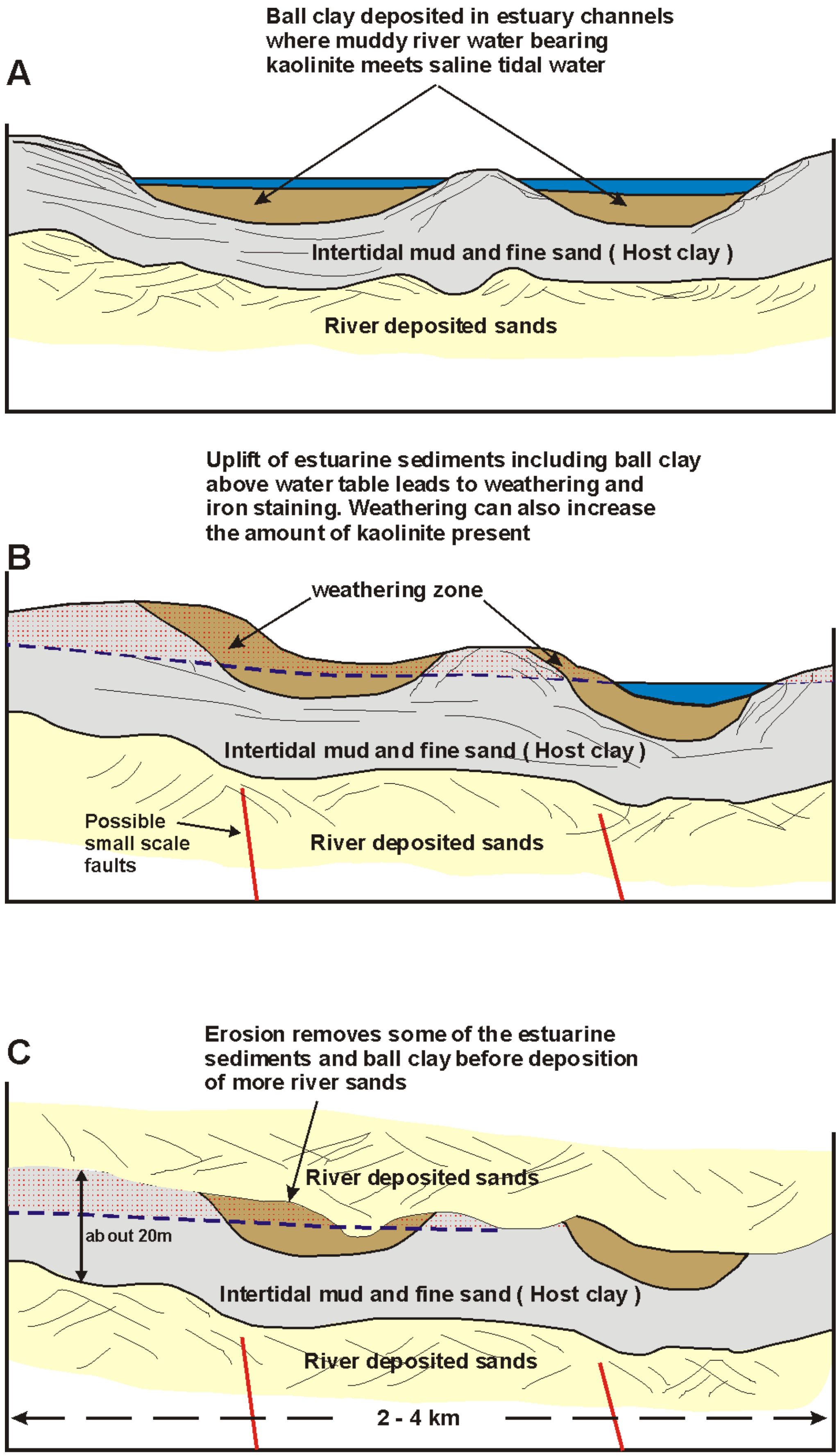


Figure 14 Sequence of events controlling the deposition, alteration and preservation of ball clays. (A) Deposition from muddy river waters in an estuarine channel. (B) Differential uplift, possibly caused by small fault movements, subjects the ball clay to weathering which could increase the amount of kaolinite in the clay but which could also cause the development of iron oxide staining. (C) Erosion removes some of the ball clay, followed by deposition of sand (as summary)



the lower part of the member would be inner zone clays and fine sands, and the upper part would be central zone clays rich in ball clay. As ball clays usually occur in the upper parts of host clays, it suggests that they are near the culmination of the transgression. Commonly, however, there is a sandy stained sequence above the ball clays suggesting a return to inner zone sedimentation just prior to the main rapid regression marked by the overlying sands.

The relatively higher alkali content of the Dorset ball clays compared to those of Devon is part of a general easterly increase noted in Devon by Bristow and Exley (1994) and in Dorset during the present study.

Host-clay deposition was terminated by a rapid fall in sea level and by subaerial weathering. If ball clays were intensely aerated during weathering, strong red and lilac staining developed reducing their commercial value (Figure 14). If, however, weathering took place with a high water table and acidic groundwater conditions, then alteration of clay-minerals could occur, with partial conversion of illite to kaolinite. The consequent erosion triggered by the rapid fall in sea level was in some areas responsible for the partial or complete removal of the clay member, including any ball clay.

The presence or absence of ball clays, and their thickness and quality, is, therefore, controlled by the following geological constraints:

- clay-rich source rocks affected by tropical to subtropical weathering, which produced the fine-grained disordered kaolinite, a key component of Dorset ball clay, and which leads to good plasticity and high strength.
- a depositional environment with a sufficiently low current energy and the optimum chemical conditions to allow flocculation and sedimentation of clay minerals.
- a central position in the Basin where there was only a small amount of contamination by marine clay minerals such as illite.
- a location where estuary channels allowed thick clay to be deposited.
- little uplift after deposition, thus preventing the development of intensely stained weathering profiles, but with sufficient weathering to augment kaolinite formation.
- a minimum of erosion prior to the deposition of the succeeding sand member.

It is difficult to fulfil all these conditions over the whole of the Basin, and thus ball clays are impersistent and variable in quality over quite short distances.

2.4 SAND AND GRAVEL

The bedrock deposits of the Wareham Basin are extensively covered by river terrace deposits, alluvium, head, peat and blown sand, all typically less than 3 m thick. The most extensive and economically important source of gravel are river terrace deposits (Figure 15). Gravels also occur at the base of the alluvium, but these deposits have only been worked on a minor scale.

2.4.1 River Terrace Deposits

River terrace deposits occur at various heights above the present-day flood plain. The area of terrace, and alluvium, is about 140 km^2, but the deposits are comparatively thin, with an average thickness of 2.35 m, and comprise an upper layer or overburden of gravelly sandy clay, typically 0.8 m thick (range 0 to 2.6 m), overlying 1 to 2 m (range 0 to 7.1 m) of sand and gravel. A consequence of this is that extensive areas of terrace deposits will need to be worked to yield significant quantities of gravel.

Water yields from the lower terrace deposits can be high, up to 15 900 m^3/d (184 l/sec), from shallow, large-diameter wells or catchpits. However, the water is in hydraulic continuity with the adjacent river systems and generally is similar in composition, with low dissolved solids contents, but liable to surface contamination and may contain suspended matter. Where gravel overlies Chalk, the water will be harder, as some will be derived from the Chalk.

2.4.2 Alluvium

Alluvium typically consists of up to 2.5 m of poorly stratified brown silt and clay, commonly organic or peaty, overlying 'sub-alluvial' gravel which ranges in thickness from about 0.6 m to 6 m, and generally increases downstream; more than 10 m of gravel have been proved locally around the confluence of the rivers Frome and Piddle. The sub-alluvial gravel forms an important resource, but much of it falls in the AONB. Additionally, any extraction would be ‘wet’, which would lead to a loss of fines, unless active de-watering takes place, with the consequent, perhaps only local, effect on the surrounding environment.

Marine alluvium borders Poole Harbour. On the west side of the harbour, at least, marine alluvium comprises an upper unit between 2.2 and 5 m thick, of silt and clay, overlying sand and gravel that can be up to 5 m thick (Mathers, 1982). The inferred extent of sand and gravel beneath marine alluvium is shown on (Figure 15). Most, if not all, falls in the AONB.

2.4.3 Made and worked ground

Much of the area is predominantly rural without a legacy of industrial development and associated modifications to the natural environment. The principal man-made deposits are those associated with mineral working. The most common artificial deposit in the area is waste from mineral extraction, such as overburden and slimes lagoons from washing sand. Areas of worked ground are commonly used as repositories for industrial and household waste. The areas of man-made artificial deposits at the time of the resurvey are available in the database. Ball clay was formerly mined, but the last mines closed in August 1999. Mining resulted in controlled subsidence, but has had limited impact because of the small-scale nature of the operations. However, subsidence will affect topography, as seen west of the former Squirrel Cottage pit, and local groundwater regimes.

Figure 15 Extent of superficial sand and gravel deposits in Wareham Basin

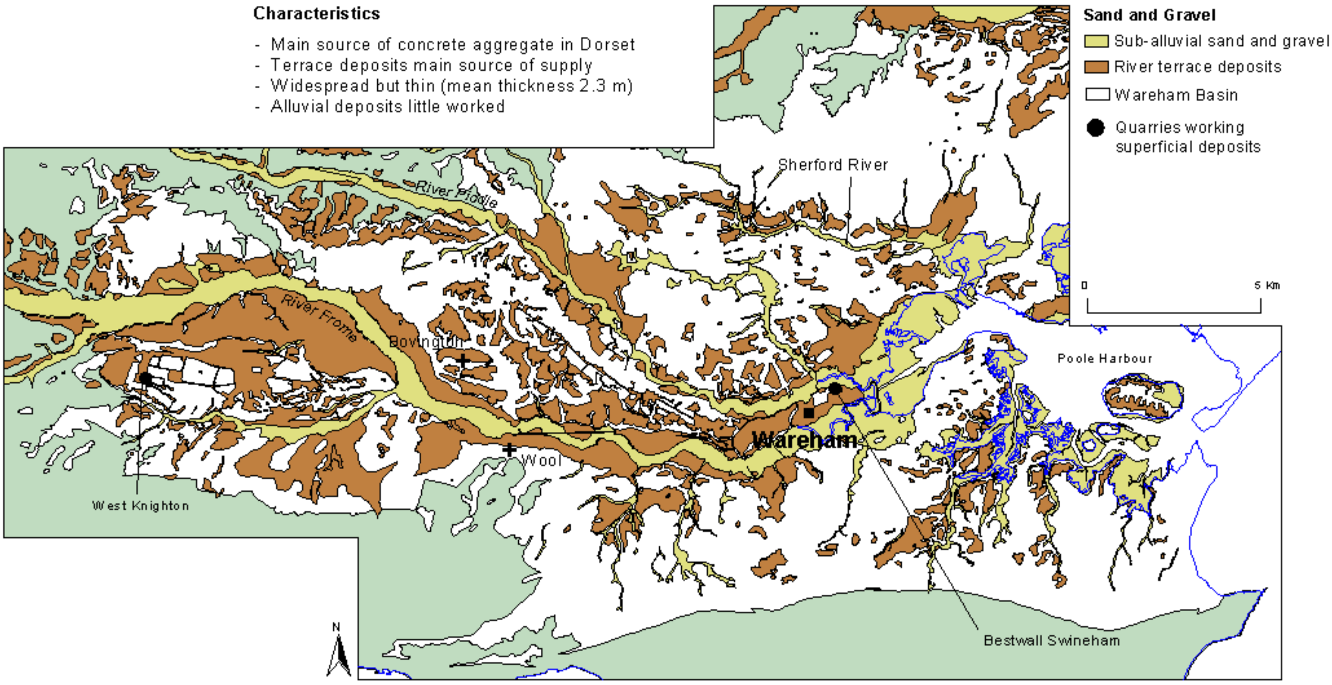
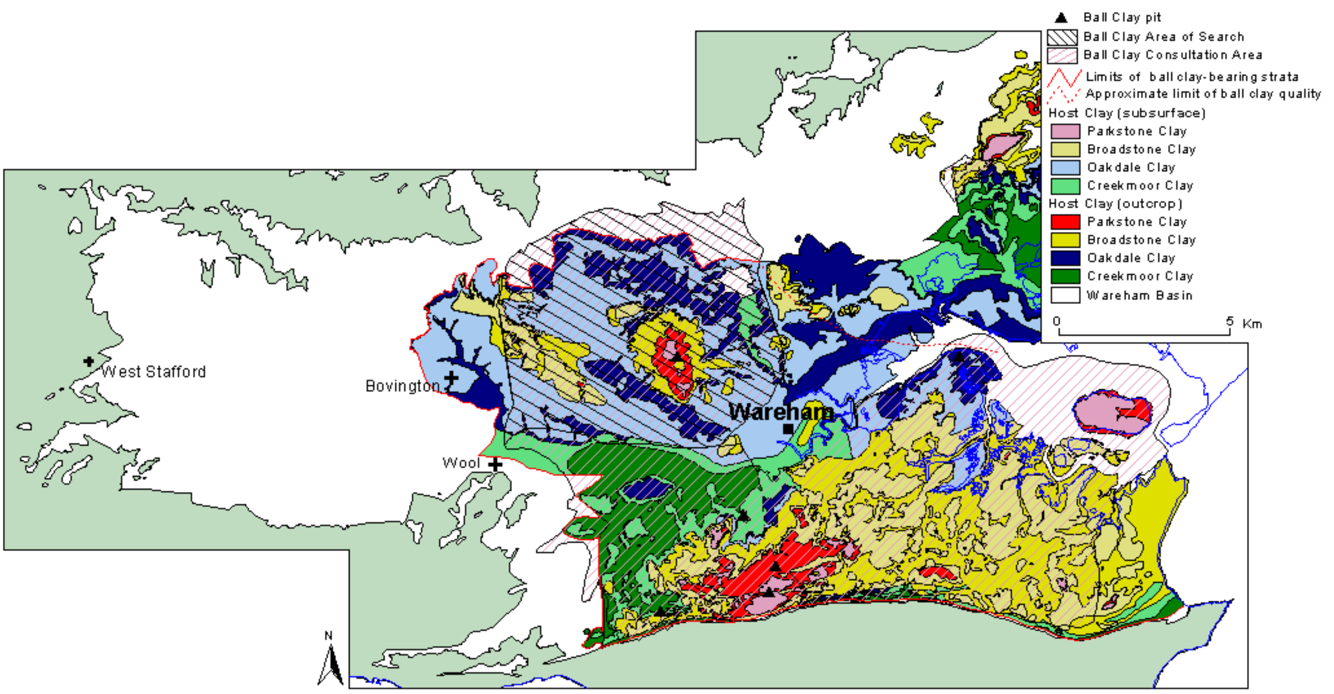


Figure 16 Ball Clay Consultation Area and Area of Search



3 Mineral Resources

3.1 INTRODUCTION

The Wareham Basin hosts one of Britain's few sources of ball clay and had an output of over 200,000 tonnes in 2000. Ball clay is used almost entirely in the manufacture of ceramic whiteware. The area is also an important source of sand and gravel used mainly as aggregate in construction, although small amounts of sand for industrial applications are also produced. Production of sand and gravel is some 2 million t/y. A small output of 'common' clay is used in the manufacture of red-bodied floor tiles. The area also includes Europe's largest onshore oilfield, Wytch Farm, which had an output of 2.92 million tonnes in 2000 and accounted for 90 per cent of UK onshore production and 2.5 per cent of total UK production.

3.1.1 Mineral resources

Mineral resources are natural concentrations of minerals, or bodies of rock, that are or may become of potential economic interest as a basis for the extraction of a commodity. They will exhibit physical and/or chemical properties and occur in sufficient quantity to be of intrinsic economic interest. The distribution of sand and gravel resources, together with the clays which host the ball clays, are shown on Figures 6, 7 and 15. Larger scale (1:30 000) versions of these maps are available if required.

Mineral resources defined on these maps delineate areas in which potentially workable minerals may occur. The areas are not of uniform potential and do not take account of planning constraints. However, planning designations that may restrict mineral working are shown on associated thematic maps and are considered later in the report. The economic potential of specific mineral sites can only be proved by a systematic and detailed evaluation programme involving drilling and sampling. Such an investigation is an essential precursor to submitting a planning application for mineral working. The individual merits of the site may then be judged against other land-use planning issues.

Mineral reserves are those resources which have been evaluated and are commercially viable to work. In the context of land-use planning in Britain, however, the term **mineral reserve** should strictly be further limited to those minerals for which a valid planning permission for extraction exists (i.e. **permitted reserves**). Without a valid planning consent, no mineral working can take place and consequently the inherent economic value of the resource cannot be released and resulting wealth created. Reserve evaluation is a matter for the minerals industry. The ultimate fate of a permitted reserve is to be either physically worked out or to be rendered non-viable by changing economic circumstances.

3.1.2 Mineral Policies

Policies for the development of the mineral resources in the area relate to individual characteristics and end uses of the minerals. At national level, requirements for sand and gravel as aggregate are defined in relation to the need to maintain an adequate and steady supply of aggregates to the construction industry (MPG6, 1994). For industrial sands, a long-term strategy is supported to take account of the requirements for particular end uses and processing sites (MPG15, 1995). Ball clay is acknowledged as a resource of limited occurrence and for this reason, national policy requires that adequate permitted reserves are maintained for the long term (MPG1 1996). The particular characteristics of common clays are also considered in MPG1, and MPAs should take into account the special needs of the brick clay industry.

An important element of Government policy is also safeguarding mineral resources against unnecessary sterilisation by surface development. Of primary significance in relation to ball clay is the provision for consultation on any development which may sterilise ball clay. In 1955 a Ball Clay Consultation Area (Figure 16) was defined in the Wareham Basin (Anon, 1953). Aggregate and industrial mineral consultation areas have also been defined.

Current local planning policy for minerals is contained in the Dorset Minerals and Waste Local Plan (Dorset County Council, 1999), which has been adopted by both Dorset County Council and Poole Borough Council. The main thrust of policy at local level reflects considerations for each mineral. There is no specific policy requirement at local level for industrial sand and common clay. However, general policies would restrict the potential for their extraction in the AONB or in other major designations. The policy towards sand and gravel reflects the size of the landbank and the relationship to the development plan timescale. There is a continuing shortage of available gravel, and policies are directed towards maintaining a reserve in accordance with national guidelines. The situation for construction sand is different, in that reserves are significantly larger and, therefore, the policy framework is not to provide for further reserves. These matters may be reviewed given the relationship between the resources, and the fact that the bedrock sands may be worked from beneath gravel-bearing deposits.

The primary consideration in relation to ball clay is to move production, in the longer term, from the Dorset AONB to the area north of the River Frome, subject to detailed assessment of other designations and impacts. In the interim, provision is made through the identification of Preferred Areas for extensions to existing sites within in the AONB. The plan also encourages the industry to maximise the use of resources outside the AONB by finding ways to improve lower quality clays and to reduce specifications for ball clay. To support this objective an area to the north of the AONB has been allocated as an Area of Search (Figure 16) in which ball clay exploration and extraction would be broadly supported. The Plan also emphasises the need to use high quality clays for high quality uses. The Plan, therefore, requires consideration of the extent to which new areas might be developed for ball clay extraction without unacceptable environmental impacts.

3.2 BALL CLAY

Ball clays are fine-grained, highly plastic, sedimentary clays, which are essentially kaolinitic in character and light-firing when fired in an oxidising atmosphere. They are used predominantly in the manufacture of ceramic whiteware. The term 'ball clay' is derived from the original method of clay extraction. The clays were cut with a 'tubal' into cubes, the sides of which rapidly rounded during handling, thus giving rise to the term 'ball clay'.

3.2.1 Production of ball clay

The occurrence of ball clay in the UK is confined to three relatively small areas, all in the South West Region of England. These are the Bovey and Petrockstowe basins in Devon, and the Wareham Basin (Figure 14). Demand for ball clay continues to grow. UK sales were just about 1.1 million tonnes in 2000 and the industry generated direct revenues of some £56 million, including some, £46 million from overseas. About 83 per cent of total UK sales is exported mainly to countries in the European Union, notably Spain and Italy. Home sales help to underpin the UK whiteware ceramics industry, which had total sales of about £900 million in 2000. About 22 per cent of current UK ball clay production is from the Wareham Basin, of which 83 per cent is exported. Output from the Wareham Basin has been increasing in recent years and was a record 237 000 tonnes in 2000 (Figure 17).

3.2.2 Properties and uses of ball clay

Ball clays are, above all, ceramic raw materials valued for their key properties of plasticity, unfired strength and light-firing characteristics. Some 93 per cent of Dorset sales are consumed in the ceramics industry. About 76 per cent of Dorset clays are used in the manufacture of wall and floor tiles, the remainder is used for refractories, electrical porcelain, tableware and sanitaryware. In a ceramic body[1], ball clay acts as the binding agent and contributes to plasticity, workability and dry strength in the pre-fired state, which allows the body to be formed and handled safely between the shaping, drying and firing process. Ball clays also contribute to the strength of the fired body.

Ball clays consist of a natural mixture of predominantly three minerals: kaolinite (b-axis disordered), a micaceous mineral (illite) and quartz in varying proportions, and each in a finely divided form. Each component contributes different properties to the clay, and ultimately, therefore, to a ceramic body. Production grades of Dorset ball clays have the following typical ranges of composition: kaolinite, 24 to 77 per cent, micaceous mineral, 12 to 35 per cent and quartz 7 to 54 per cent. In addition, minor components, including carbonaceous matter, and iron-bearing minerals, such as siderite and hematite, may play an important role in modifying the ceramic properties of the clay. In particular, iron oxides (Fe_2O_3) and titania (TiO_2) markedly affect fired colour and at combined levels above 3.0 per cent generally make a clay unusable for light-firing ceramic bodies. The variation in mineral composition and particle-size distribution of ball clays, together with the crystallinity (degree of disorder) of kaolinite, accounts for their differing ceramic properties, both between and within seams (Highley, 1975; 1995).

Dorset ball clays are characterised by a high-bonding strength and high plasticity, which are related to their mineralogical composition and, particularly, particle size. Plasticity increases with decreasing particle size and with increasing proportions of kaolinite, particularly disordered kaolinite (Glasson, 1993). Kaolinite is, therefore, a key component of ball clays. Dorset clays are particularly noted for their fine particle size, with most samples being less than 2 μm and some being 80 per cent <0.5 μm. Some clays also exhibit very low carbon contents which is important for uses where fast-firing processes are involved, such as in tile manufacture. The fast-firing tile market is the major market for Dorset clays. The division between low- and high-carbon clays is taken at about 1 per cent C, but for fast-firing processes, carbon contents are required to be as low as possible, which in practical terms means 0.2 – 0.3 per cent C. However, there will be variations depending on body compositions and firing conditions. The presence of appreciable amounts of finely divided illitic mica in the Dorset clays, which contributes alkalis, acts as a highly effective flux in ceramic bodies such as floor tiles and electrical porcelain. Fired colour is the critical parameter, and a $Fe_2O_3 + TiO_2$ content should be less than 2.5 per cent for most whiteware bodies, with a maximum limit of 3.0 per cent for light-bodied tiles (Figure 18). The desirable properties of ball clays are:

- high kaolinite content (the higher the better)
- light-firing properties (low Fe and Ti-oxides content)
- high plasticity (a high proportion of fine kaolinite particles)
- low carbon content (the lower the better).

However, other factors may also be important and, for example, the amount and type of organic matter present will influence rheology. Soluble salts also have a detrimental affect on rheology, which is important for clays used in casting slips[2].

3.2.3 Resources

Ball clays occur in the four host clays in the central and eastern parts of the area: east of Bovington, north of the

[1] A 'body' is the term used by ceramists to describe the final mass that will be subject to the forming, decoration and firing process to yield the desired ceramic article. Whiteware ceramic bodies consist of four components: ball clay, china clay (kaolin), a flux (to lower the vitrification temperature of the body) and an inorganic filler/extender. The relative proportions and quality of each component varies widely according to the type of fabrication.

[2] A slip is a high density aqueous suspension of insoluble solids. When poured into a plaster mould a proportion of the water is absorbed so that the body builds up on the walls of the mould.

Figure 17 Sales of ball clay from the Wareham Basin, 1983 - 2000

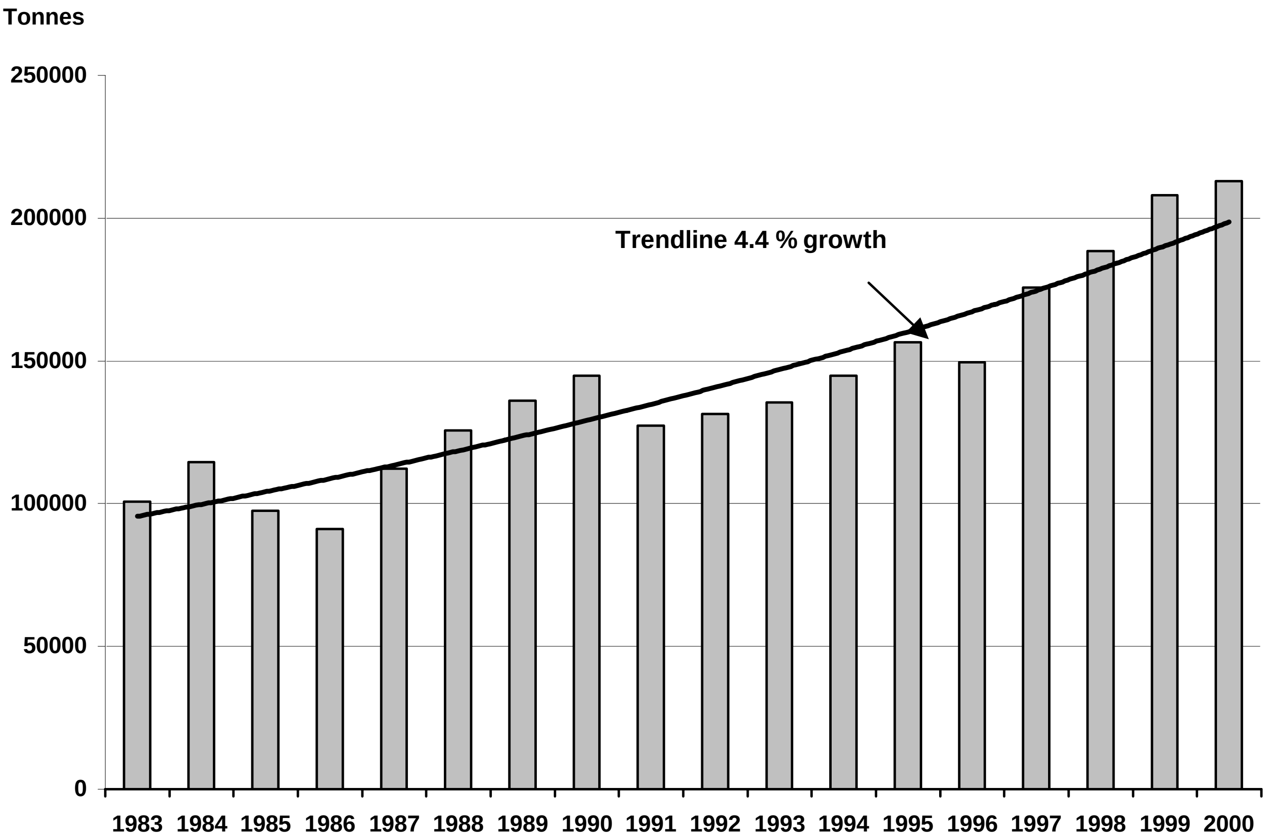
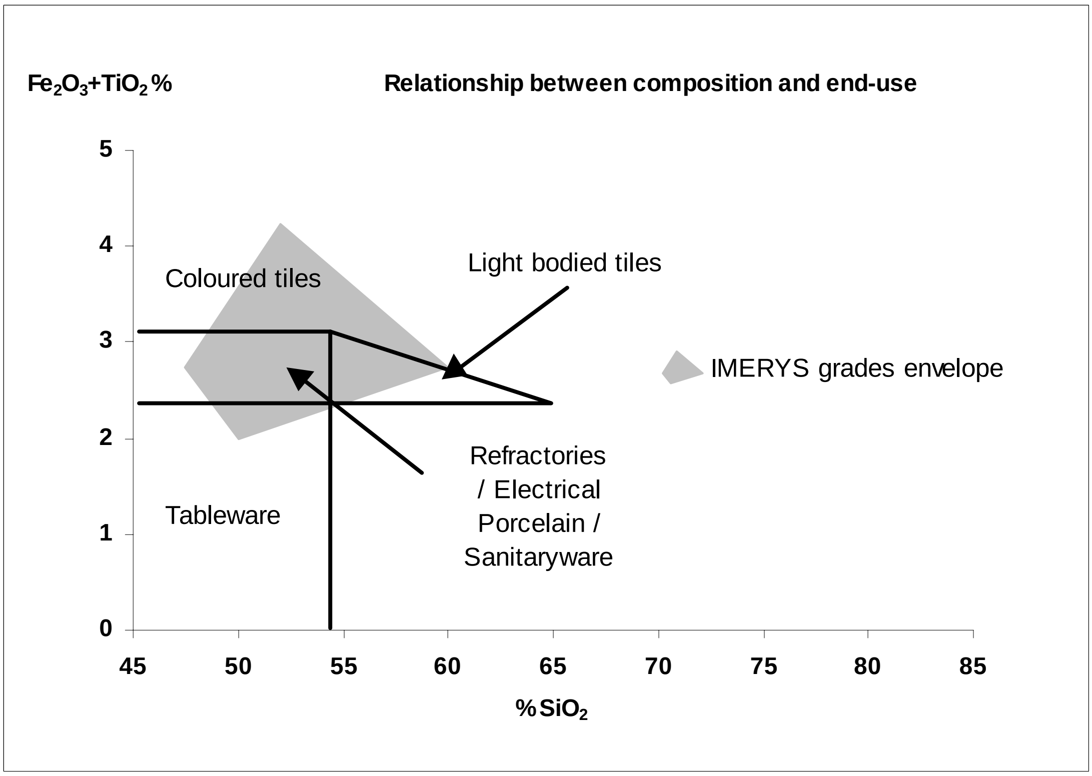


Figure 18 Relationship between composition and end use



River Frome and from East Stoke eastwards south of the River Frome. Their outcrop and sub-surface distribution is shown on figures 8 to 11 and these areas define the limits of potential ball clay-bearing strata within the Basin. North-east of Lytchett Minster, the clays deteriorate in quality.

Host clays may be up to 50 m thick, but can vary rapidly over short distances. Not all host clays occur throughout the area. Each host clay contains workable ball clay, together with beds of inferior quality clays, and small amounts of lignitic and carbonaceous clays of no commercial value. Ball clay deposits are laterally impersistent and commercial grade material present in one area may pass into non-commercial clay over a short distance. The proportion of ball clay in a host-clay sequence varies, but may range from 10 per cent, for example at Trigon, to 24 per cent at Povington. Due to deterioration in quality, ball clay may be absent in certain areas. Some ball clays occur infilling sinuous channels in host clays (in the Broadstone Clay in particular) and are difficult to predict or locate by boreholes. In addition, because of their relatively limited occurrence, they are unlikely to provide a significant resource. The main reason why parts of host clays do not form commercial ball clays is the level of impurities present, such as iron oxides and carbonaceous matter, or where the clays become too siliceous. Iron staining is a common reason for rendering inherent balls clay unusable for light-firing bodies.

The principal physical and chemical characteristics of each host clay is shown in Table 3 and described below in stratigraphical order.

Creekmoor Clay (Figures 8, and 25 to 28)

Creekmoor Clay crops out in two principal areas south of the Frome (Figure 6). The northern occurrence is structurally simple with broad outcrops of gently dipping clay. There, the northern boundary of the Creekmoor Clay underlies the alluvium of the River Frome from just downstream of Wool almost to Stoborough. The wide outcrop extends southwards under the Army firing ranges as far as Povington. From Povington eastwards, the Creekmoor Clay crops out in an extremely complex structural belt with the clay occurring as thin, steeply dipping, fault slices or in the cores of tight anticlines. Because of its generally high kaolinite content (Table 3), particularly in the south, the Creekmoor Clay provides the highest quality and most versatile ball clay which is used in many blends. It accounts for some 55 per cent of ball clay output in Dorset. It is only worked south of the Frome at Povington and Doreys pits.

The thickness, quality and extent of ball clays in the Creekmoor Clay are illustrated (Figure 19) by a cross section from Povington in the south, through Doreys pit in the Frome valley, north to Wareham Forest. Borehole SY88SE/1047 [8933 8234] (Figure 20), is representative of the Povington sequence, and shows two intervals of ball clay, 2.4 and 2.7 m thick, in the upper part of the host clay, which form about 26 per cent of the sequence. The upper interval includes the high-quality 'Povington Blue' clay. The lower seam overlies the 'Povington Brick Clay', a red stained clay 3.5 m thick, that is not regarded as a ball clay. The variation in thickness and composition is apparent from Borehole SY88SE/1341 [8921 8274] (Figure 19) nearby, where only the upper ball clay, 1.1 m thick, is present. There, ball clay accounts for only about 12 per cent of the host clay.

A 4 m-thick ball clay, about 31 per cent of the host clay, at Doreys (Borehole SY98SW/3250) [9150 8491] (Figure 19), correlates with the upper unit at Povington. About 1 km north-west, between Doreys and East Holme (Borehole SY98NW/823) [9052 8531] (Figure 19), the same clay, 3 m thick, forms 33 per cent of the host clay.

Data north of the Frome suggest that potential ball clays in the Creekmoor Clay are thin or absent. A single, thin, interval is present in Borehole SY98NW/290 [9088 8640] (Figure 19) south of Worgret, although analytical data are largely absent. In Borehole SY98NW/287 [9067 8724] (Figure 19) north of Worgret, there is a ball clay, 2.3 m thick, in the upper part of the sequence. The overlying clays are siliceous, while the thick sequence beneath has high Fe_2O_3 values. No potential ball clay is present in boreholes SY98NW/292 [9056 8891] and 39 [9179 8997] farther north (Figure 19), although analytical data are almost completely absent.

- Thickness ranges from zero to 50 m; average (of 722 boreholes) 14 m (Table 3).
- The most kaolinite-rich host clay; averages over 10 per cent more kaolinite
- The least siliceous host clay (Table 3). Silica values, typically less than 55 per cent, show no discernible regional trend.
- Fe-Ti oxides about 3 per cent in the south and under much of Stokeford Heath.

Oakdale Clay (Figures 9, and 29 to 32)

The Oakdale Clay crops out principally on the Arne Peninsula south of the Frome and in Wareham Forest to the north, but is worked only on the Arne Peninsula. It accounts for about 15 per cent of ball clay production.

In a representative borehole (SY98NE/87) [9739 8944] at Arne, Oakdale Clay is 27.4 m thick with about 15 per cent ball clay in two 2.1 m thick intervals (seam codes 7.16 to 7.23; 7.26) (Figure 21). The ball clays are relatively high in silica (55 to 60 per cent) and iron and titanium oxides (2.4 to 2.8 per cent) and with moderate alumina. The very low silica and high alumina of Seam 7.25 indicates a seatearth. Comparable ball clay thickness and geochemistry are predicted south of the pit, and toward the south-west, where the Oakdale Clay thickens. For example, Borehole SY98NE/49 [9672 8802], 1 km south-west, show a slightly thicker ball-clay sequence (24 per cent) in a single interval about 8.5 m thick (Figure 22).

- Thinnest (average 5.6 m, Table 3) and least persistent host clay, particularly in the south. Thin overburden to extensive outcrops in the north
- Kaolinite values relatively low and average 36 per cent; typically less than 35 per cent west of Arne
- Both silica (average 59.9 per cent) and Fe-Ti oxides (average 3.1 per cent), although variable, tend to be greater in the west of the Basin

Broadstone Clay (Figures 10 and 33)

The main outcrops of Broadstone Clay are around Trigon in the north and extensively in the south between Creech, Ridge and Rempstone. The Broadstone Clay is no longer

Figure 19 North–south section in the Creekmoor Clay across the Wareham Basin showing the variability in the proportion of ball clay to host clay

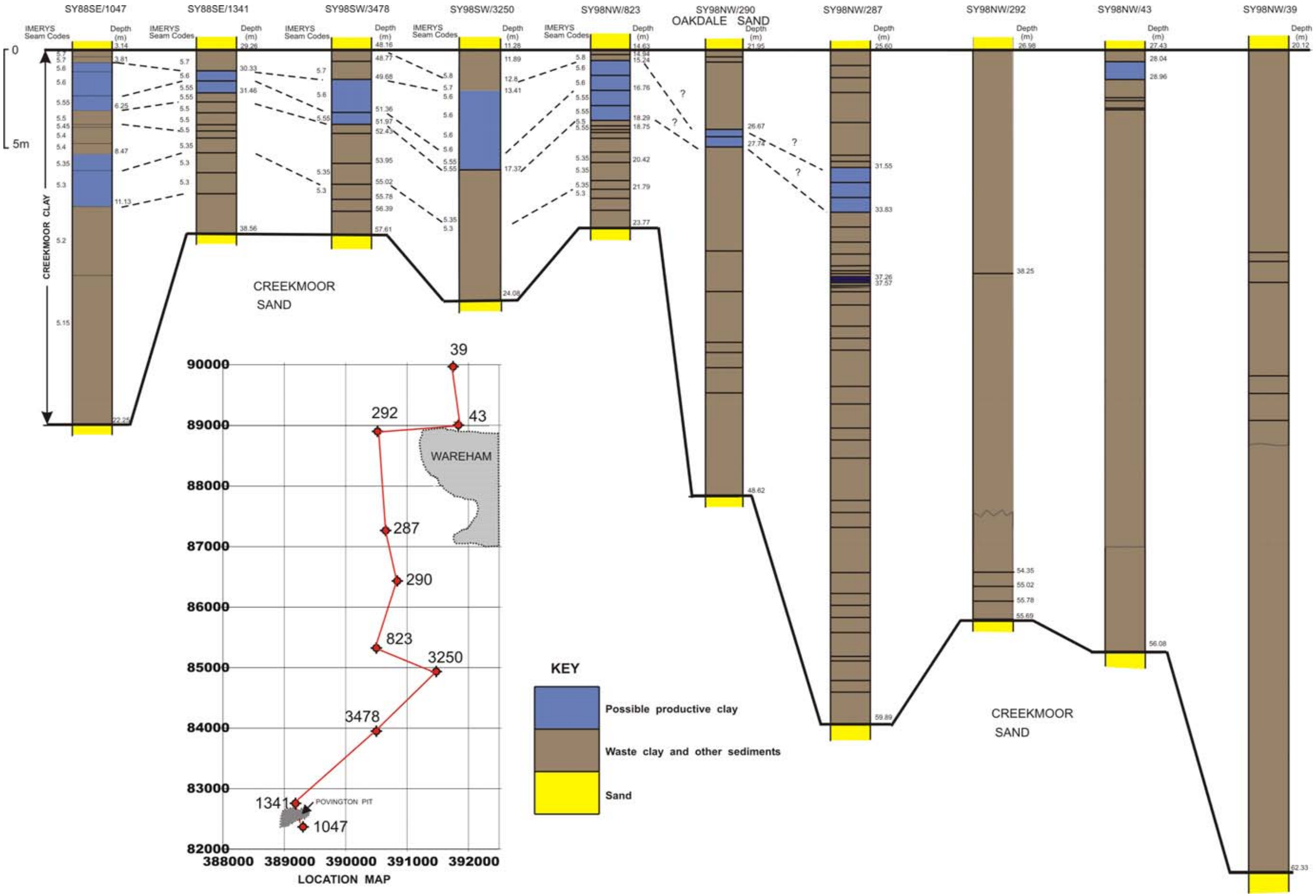


Figure 20 Log of the Creekmoor Clay in Borehole SY88SE/1047

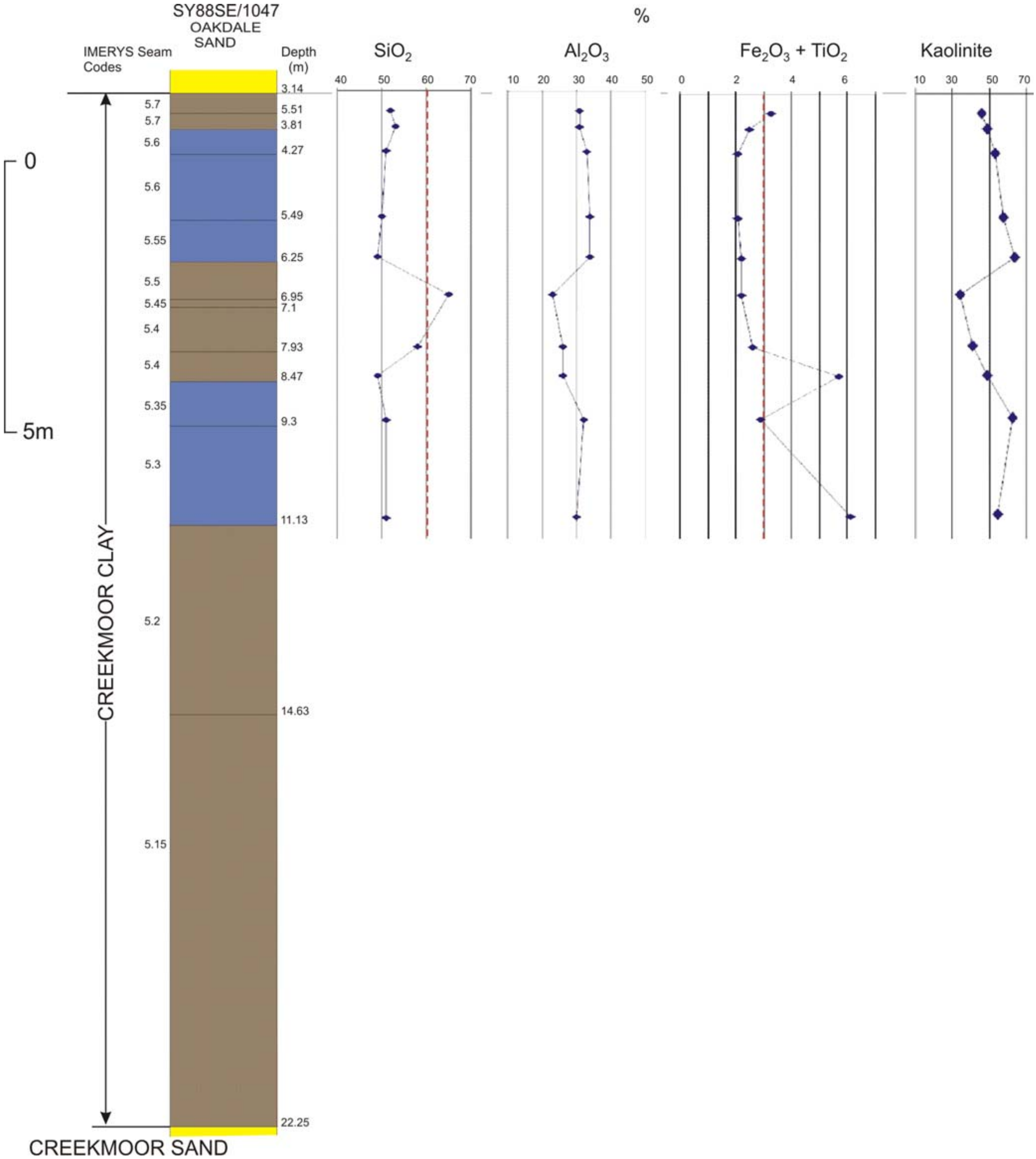


Figure 21 Log of the Oakdale Clay in Borehole SY98NE/87

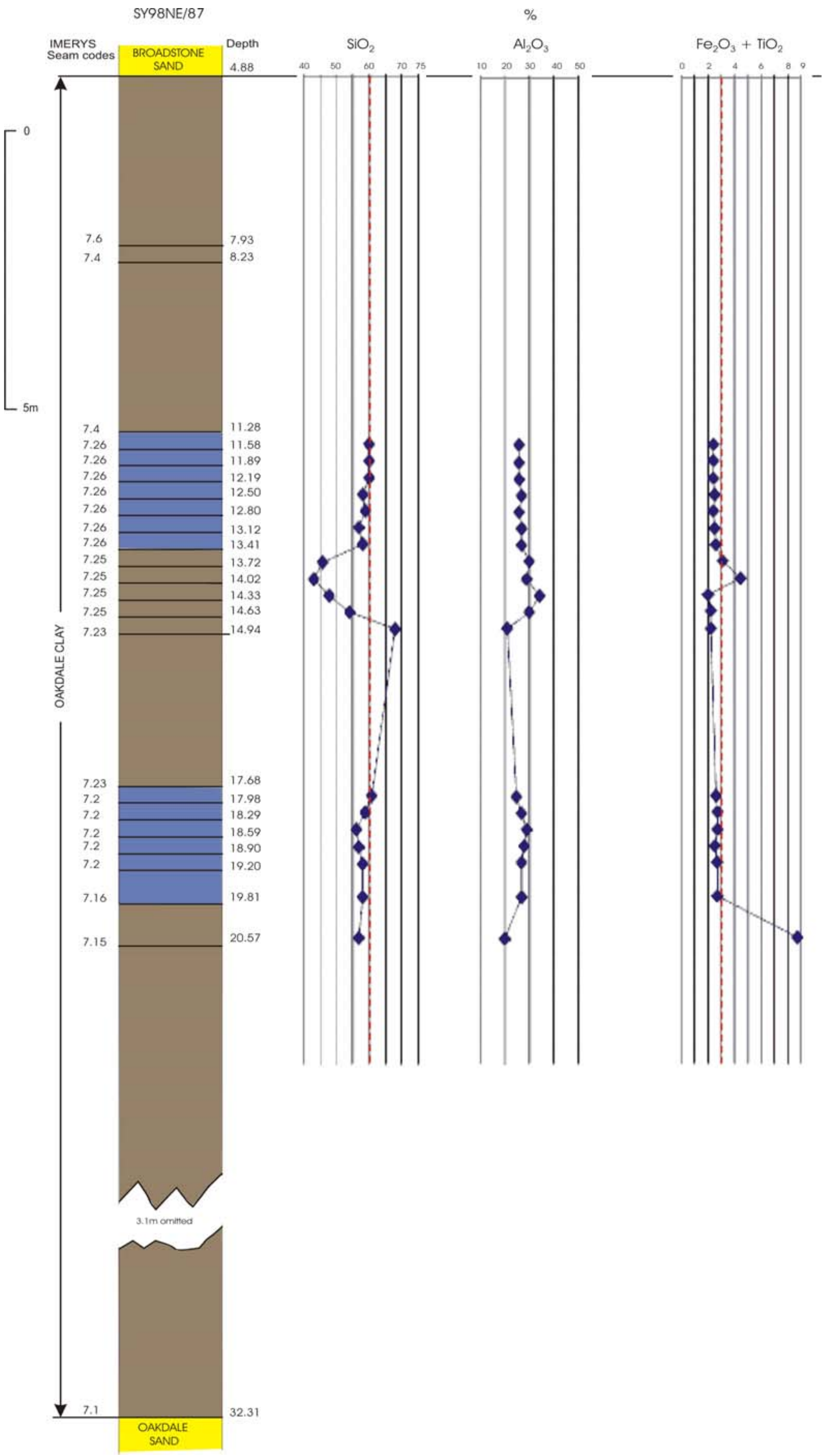
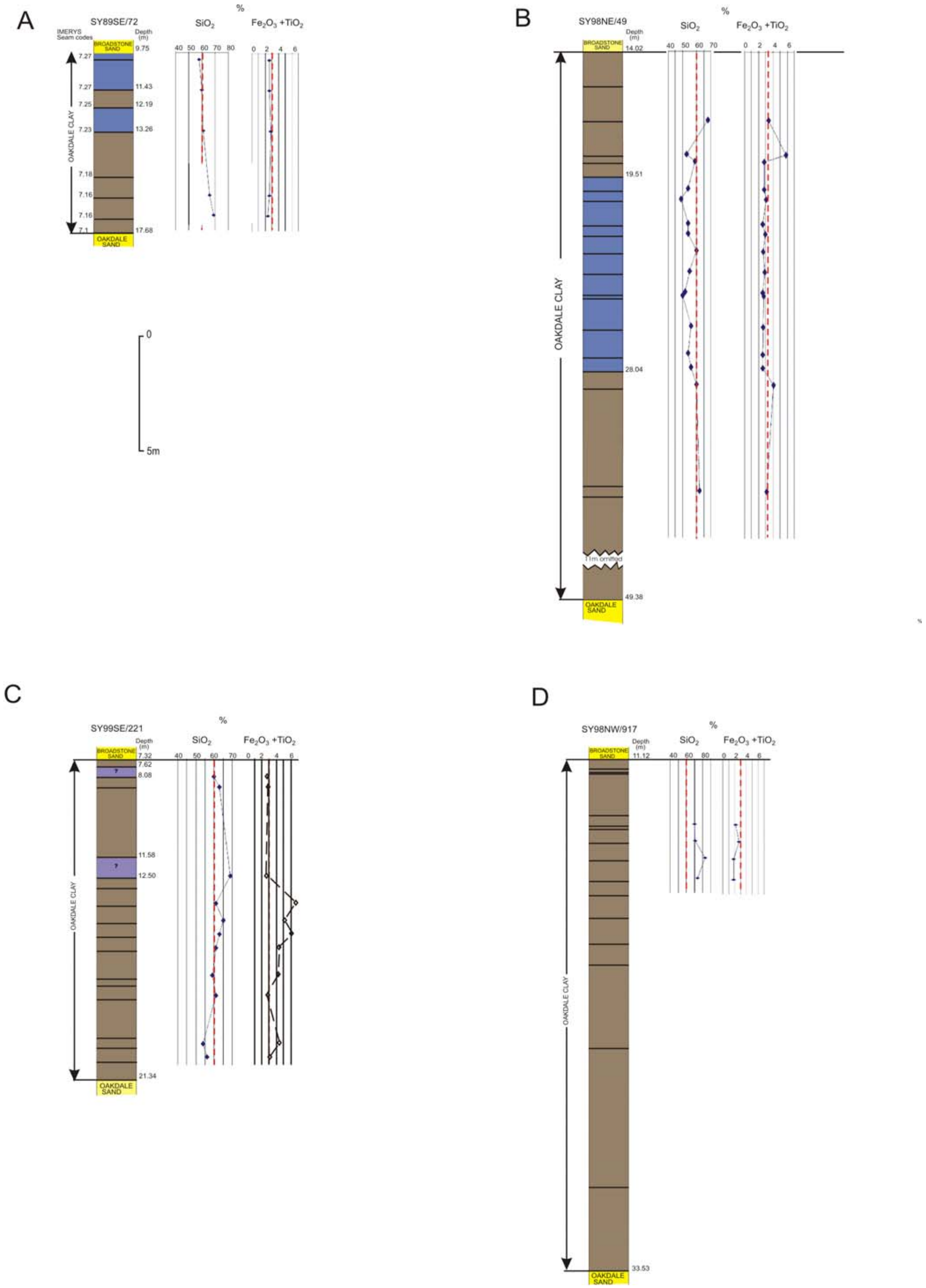


Figure 22 Generalised logs of the Oakdale Clay in boreholes SY98NE/49, SY89SE/72, SY99SE/917 and SY98NEW/221



worked, other than as small pockets of clay in the overburden at Povington. It forms the lower, unworked, part of the Trigon 'Series' north of the Frome.

- Principal occurrence in the south-east; outliers at Trigon and Bovington Heath. Average thickness 10.2 m, although there is a large range
- Second highest average kaolinite value (45.1 per cent); a belt of >40 per cent extends from Povington to the Wareham Channel. Most Trigon values between 35 and 40 per cent
- Silica values (average 61 per cent) similar to Oakdale Clay, and no clear regional trend.
- Fe-Ti oxides values are the highest of the clays (average 3.4 per cent), particularly in the south-east, and around Trigon.

Parkstone Clay (Figures 11 and 34)

Parkstone Clay has a limited outcrop. In the south, it is worked by open pit (Hawkpost and Furzeyground – in the latter the clay is very heavily iron stained) and, until August 1999, underground at Aldermoor. It forms the upper part of the Trigon 'Series' at Trigon. Parkstone Clay provides high-quality clay both north and south of the River Frome. It accounts for about 30 per cent of production.

- Thickest (average 16.3 m) host clay, but restricted to the outliers at Trigon and around Creechbarrow, where there is thick overburden
- Geochemical data from each outlier differ. Kaolinite values of 25 to 35 per cent are typical of Trigon, while values of about 40 per cent occur around Creech. Average kaolinite content (31.9 per cent) is the lowest of the clays
- Silica content (average 64.9 per cent) is distributed in the same way: Trigon clays have about 64 to 68 per cent and Creech clays about 54 to 60 per cent silica
- Combined Fe-Ti oxides (average 2.9 per cent) is the lowest of the clays, with some indication Trigon has higher values

3.2.4 Technological constraints

Modern ceramic-manufacturing technology, with the trend towards automation and fast-firing, is placing increasingly stringent demands on clay quality. In this context, the term 'quality' implies raw materials with predicable and consistent ceramic properties in which changes in raw material composition and, therefore, ceramic behaviour, cannot be tolerated. Variations in quality results in lower yields, i.e. increased production losses, which can have a major effect on the economics of a ceramic manufacturing operation.

A particular requirement of many ceramic manufacturers is the need to ensure long-period production runs, thereby enabling them to provide their customers with a regular and consistent product. This is of particular importance in tableware and sanitaryware. This requires the ball clay industry to be able to demonstrate the long-term adequacy of reserves of suitable grades of clay. That has an implication in the need to maintain a series of operating areas, and faces in operating areas, and the need to provide, through the planning process, sufficient long-term security of supply of a range of clays.

3.2.5 Extraction

Ball clay extraction is now only by opencast methods. Overburden to mineral ratios range up to 6:1. Unlike Devon, where there are many workable seams, in Dorset, extraction is usually confined to a single bed between 3 and 6 m thick. However, a single bed may contain several production grades of clay and these are comparatively easy to select and work. The clay is selectively dug by mechanical excavators and loaded into lorries for transport to a centralised storage and processing facility at Furzebrook, for blending for sale.

Underground mining, using a retreat mining method, with clay extraction by means of hand-held pneumatic spades, has declined significantly over recent years because of its high cost. The Aldermoor and Norden mines closed in August 1999, bringing to an end a long history of underground ball-clay mining in the Wareham Basin. Underground production was only some 5904 tonnes in 1998 and limited to specialised grades. However, mining never contributed a large output with a maximum of 50 000 tonnes produced in 1975. Mining was formerly carried out to the south-east and south-west of Wareham, at Trigon, and along the southern margin of the Basin between Creech and Norden. Creekmoor Clay was the principal mined horizon, with some production from the Broadstone and Parkstone clays. Because of the need to retain a minimum of 5 m of clay both above and below the mined horizon to prevent water ingress, this significantly limits extraction and sterilises part of the resource. In addition, health and safety considerations incur greater capital expenditure. As the cost of mining greatly exceeds the value of the clay produced, a resumption of mining in the foreseeable future is highly unlikely.

Operational opencast ball clay sites in Dorset are:

Trigon
Doreys
Povington
Furzeyground
Arne
Hawkpost (temporarily inactive)

IMERYS Minerals Ltd (formerly ECC Ball Clays) operate all the sites and ball clay is normally extracted as the sole mineral.

3.2.6 Processing and blending

Dorset ball clays undergo very little processing other than shredding. This process, which involves size reduction, allows ball clay to be more easily handled and, more importantly, blended and homogenised to provide a balance of technical properties. This not only smooths out variations in the properties of individual clays, but allows the desirable properties of two or more clays to be combined, for example, combining strength and light-firing characteristics. Blending, therefore, creates a combination of properties which would not naturally occur in a single clay. Some 89 per cent of Dorset ball clays are sold in shredded form and the remaining 11 per cent as a dry-milled product.

The extraction and subsequent processing/blending of ball clays is, therefore, geared to the production of homogeneous and standard grades of clay. This has a number of advantages, as it allows:

- A reduction in the variation in quality to which individual clays, as naturally-occurring raw materials, are prone
- The use of lower quality clays, thus conserving higher quality clays and optimising the use of the resource in line with the principles of sustainable development
- The production of consistent grades with reproducible characteristics over long periods and thus providing consumers with continuity and security of supply
- The development of new blends to meet evolving consumer requirements.

The properties of ball clays from different areas and seams complement each other. The availability of a wide range of clays is, therefore, an essential feature of ball clay supply. It provides the industry with a greater degree of flexibility in balancing supply and demand, and ensures a greater degree of security of supply. However, without the most versatile (high-quality) clays, blending of less versatile clays becomes difficult, if not impossible. Both high and lower-quality clays are required to sustain the industry. Specifications are generally tightening, thus reducing the options of blending away lower-quality clays.

In Dorset some 26 different production clays are extracted to produce 24 saleable blends. These blends contain between three and seven production clays, currently with an average of four, but the trend is for an increasing number of production clays to be used in blends. Dorset clays are also transported to South Devon mainly for use in sanitaryware blends and some South Devon clay is transported to Dorset. These flows emphasise the distinct character of ball clays from each basin.

3.2.7 Beneficiation of Dorset ball clay

One of the main problems of processing ball clays to remove impurities, such as colouring oxides, lignitic material and quartz, is their fine particle size with 90 per cent of particle sizes typically being less than 2 μm. In South Devon, some ball clays, being much coarser, have been successfully refined for many years for the production of valued-added products for the sanitaryware market. Refining involves a mix of wet and dry processing. Carbonaceous clays are wet screened to remove lignitic residues, whilst dried and powdered non-carbonaceous siliceous clays are air classified to remove coarse quartz. The two feedstocks are then blended with shredded clays to reduce the moisture content to allow bulk handling. A drying stage may also be involved.

The suitability of ball clay for ceramic end-uses is highly dependent on its combined Fe – Ti oxides content. If it were possible to reduce the Fe-Ti oxides content to an acceptable level (<3 per cent) through beneficiation, 'borderline' clays previously considered unsuitable might then achieve a grade suitable for blending. Whilst the processing techniques currently available are able to achieve a modest reduction in the Fe-Ti oxides content, they are incapable of removing sufficient iron to change a red-firing clay to a white-firing variety.

In ball clays from Devon and Dorset, iron usually occurs as siderite (iron carbonate), pyrite (iron sulphide), and geothite and limonite (iron oxyhydroxides). Hematite is the principal red/purple colouring component in Dorset clays. Titanium generally occurs mainly as anatase (titanium oxide). Various methods may be employed to reduce the level of Fe-Ti-bearing minerals in a clay. These include screening, wet size-classification (hydrocyclones), wet high-intensity magnetic separation and chemical leaching. Coarse-grained siderite can sometimes be removed by dry screening or air classification. All other processes involve chemically dispersing the clay in water, usually involving acid, which subsequently would need neutralising, before the water could re-enter the hydrological cycle. In ball clays with a relatively coarse particle-size distribution, hydrocyclones can be used to remove silt-grade (>10 μm) siderite particles. Wet magnetic methods may be reasonably effective in reducing the iron content of a clay by up to 0.5 per cent. Chemical leaching methods are impractical due to their effect on the rheological properties of the ball clay. However, the major drawback of all these wet methods is dewatering the clay following separation of the Fe-Ti components. Ball clays are by nature extremely fine grained, and may take almost an order of magnitude longer to dewater than refined china clay. Dorset ball clays are much finer grained than Devon clays. At these fine particle sizes, it is not practically possible to remove finely divided carbon, which is common in some Dorset clays, or fine-grained quartz. It is, therefore, impractical on a large scale to alter the fundamental mineralogical proportions present in Dorset clays. For example, the quartz:kaolinite ratio in the Oakdale Clay could not practically be reduced to that of the Creekmoor Clay.

The mineralogy, fine particle size, and relatively low intrinsic value of Dorset ball clays (compared to say, china clay) is likely, therefore, to preclude their industrial-scale beneficiation under current or foreseeable economic conditions. However, further research in this area is recommended.

3.2.8 Ball clay assessment

Ball clays exhibit variations in properties which primarily reflect variations in their mineralogical composition, carbon and Fe-Ti oxides content, and particle size. These properties vary both laterally and vertically. Other important parameters that affect the commercial viability of a specific deposit include overburden and ball clay thickness. An assessment of variations in some of these properties across the Basin, was undertaken by:

- a geochemical study of the boreholes drilled by BGS
- an analysis of the IMERYS borehole data.

3.2.9 Geochemistry of BGS boreholes

In order to provide stratigraphical control and samples in areas with poor borehole coverage away from producing sites, a small drilling programme was undertaken as part of the project. The objective was to provide not only infill information, where thickness and geochemistry data on the host clays were sparse, but also to assess the vertical variability of clay members. The geochemistry of 149 samples of host clays taken from 23 boreholes and trial pits in the Wareham area was determined and compared with

Figure 23 Geochemistry of BGS borehole samples

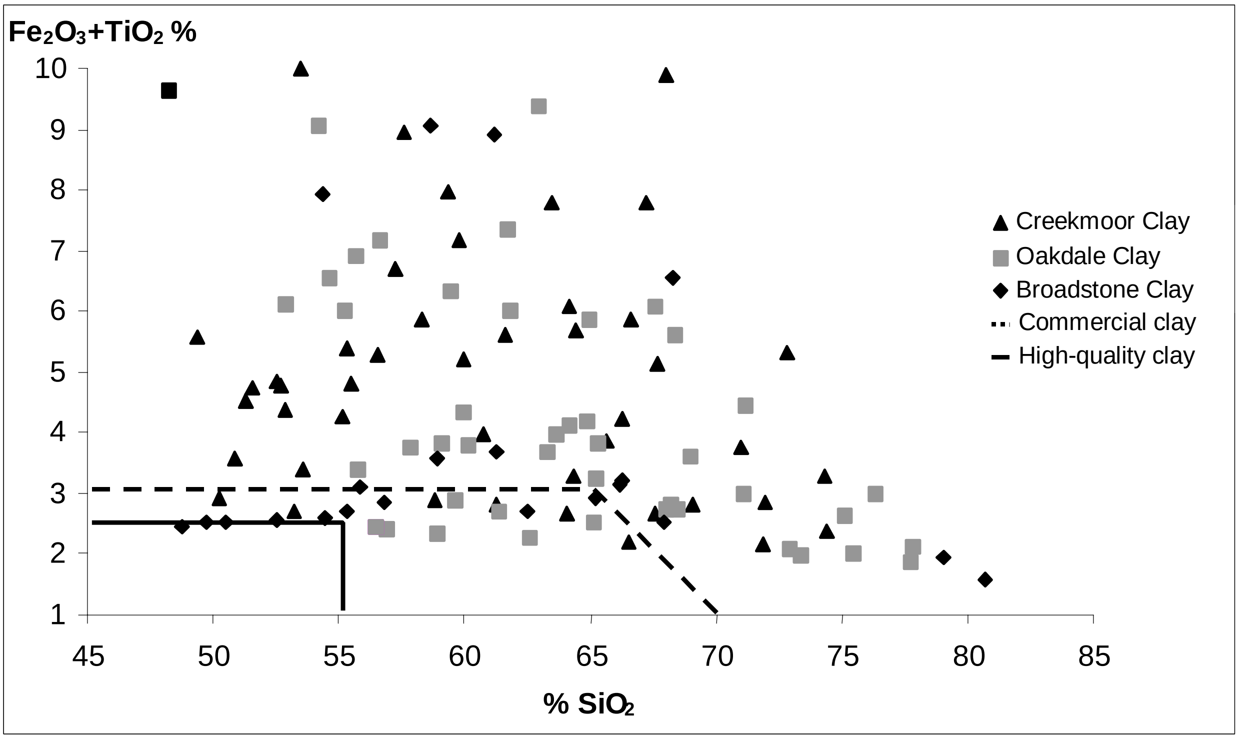


Figure 24 Geochemistry of the Creekmoor Clay in the Priory Farm Borehole

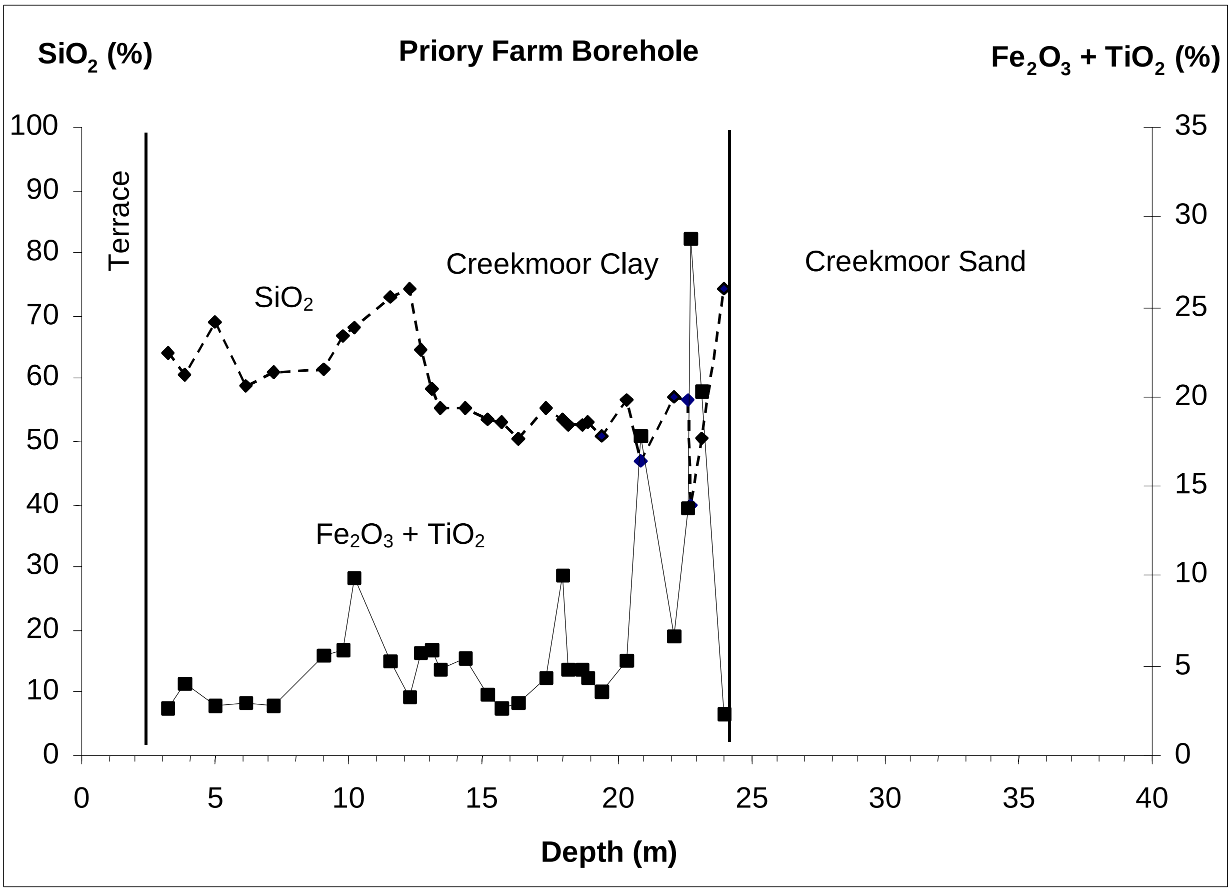


Figure 25 Creekmoor Clay: Overburden thickness (2851 records)

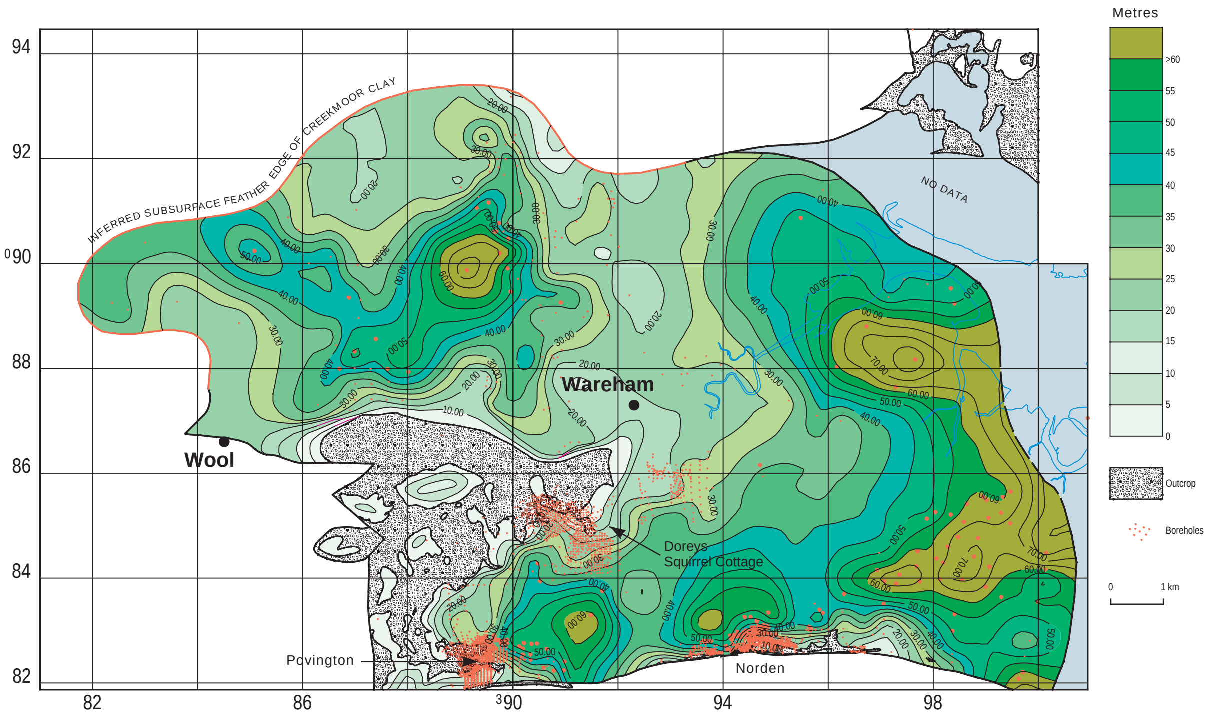


Figure 26 Creekmoor Clay: Kaolinite content (1347 records)

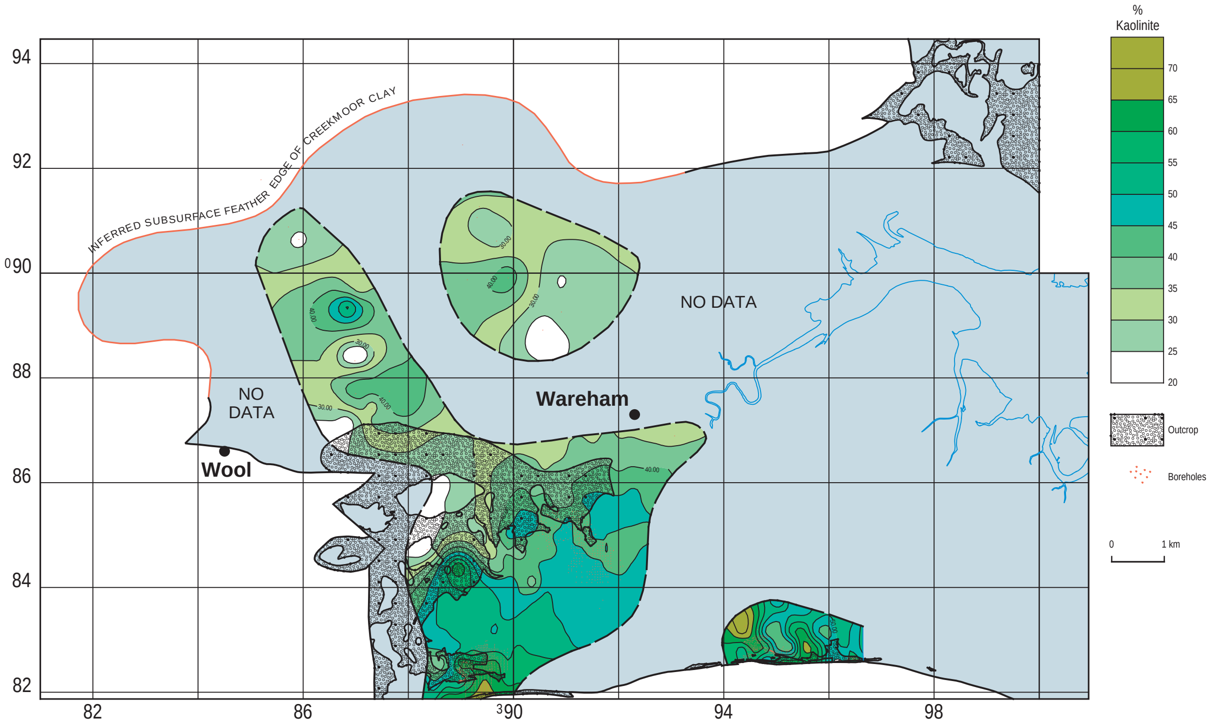


Figure 27 Creekmoor Clay: Fe_2O_3 and TiO_2 content (1858 records)

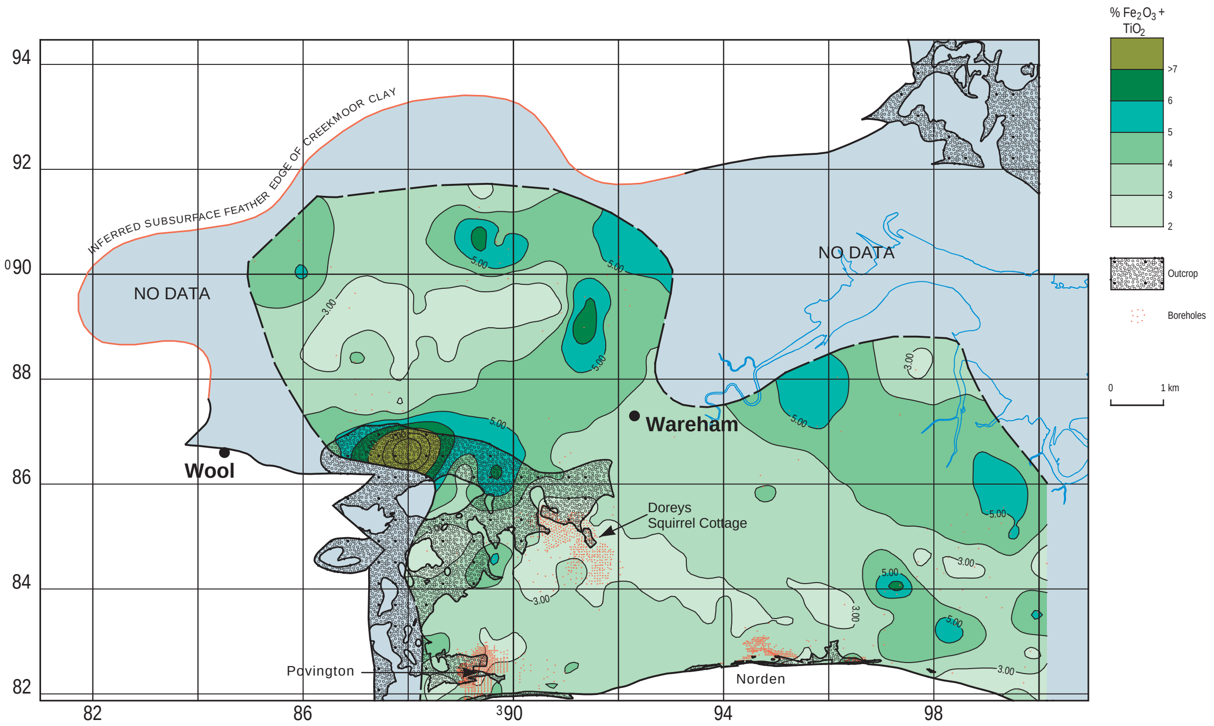


Figure 28 Creekmoor Clay: SiO_2 content (1860 records)

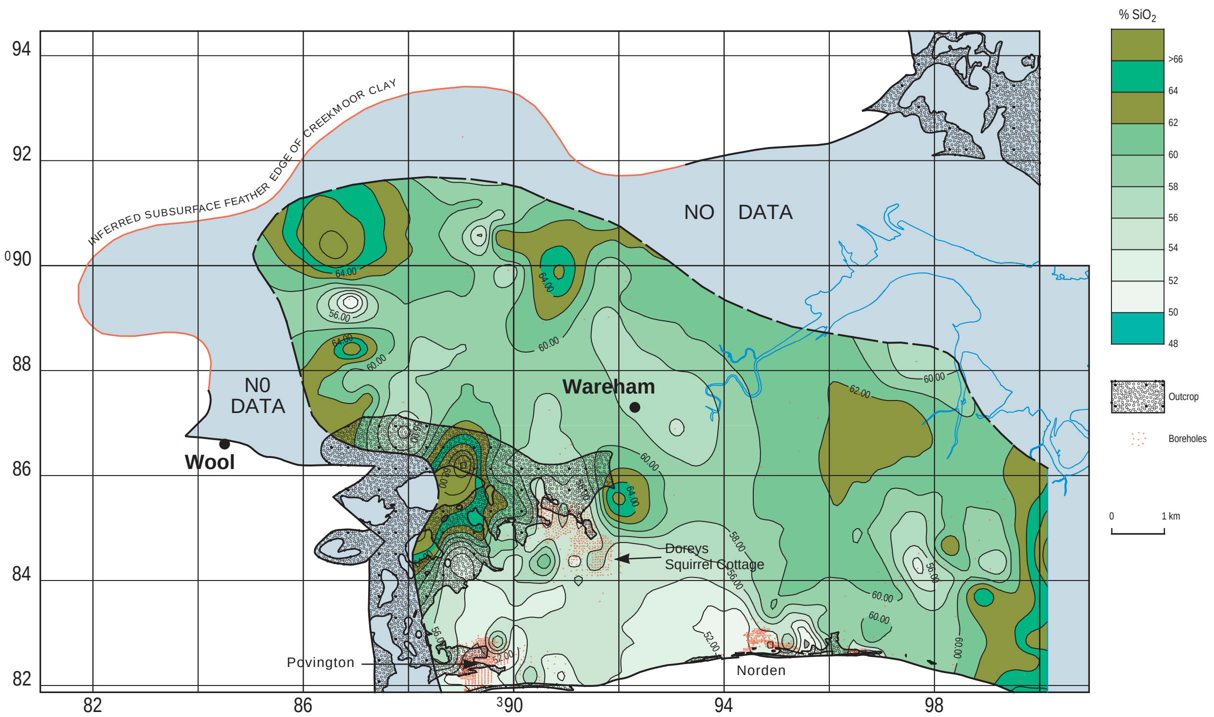


Figure 29 Oakdale Clay: Overburden thickness (947 records)

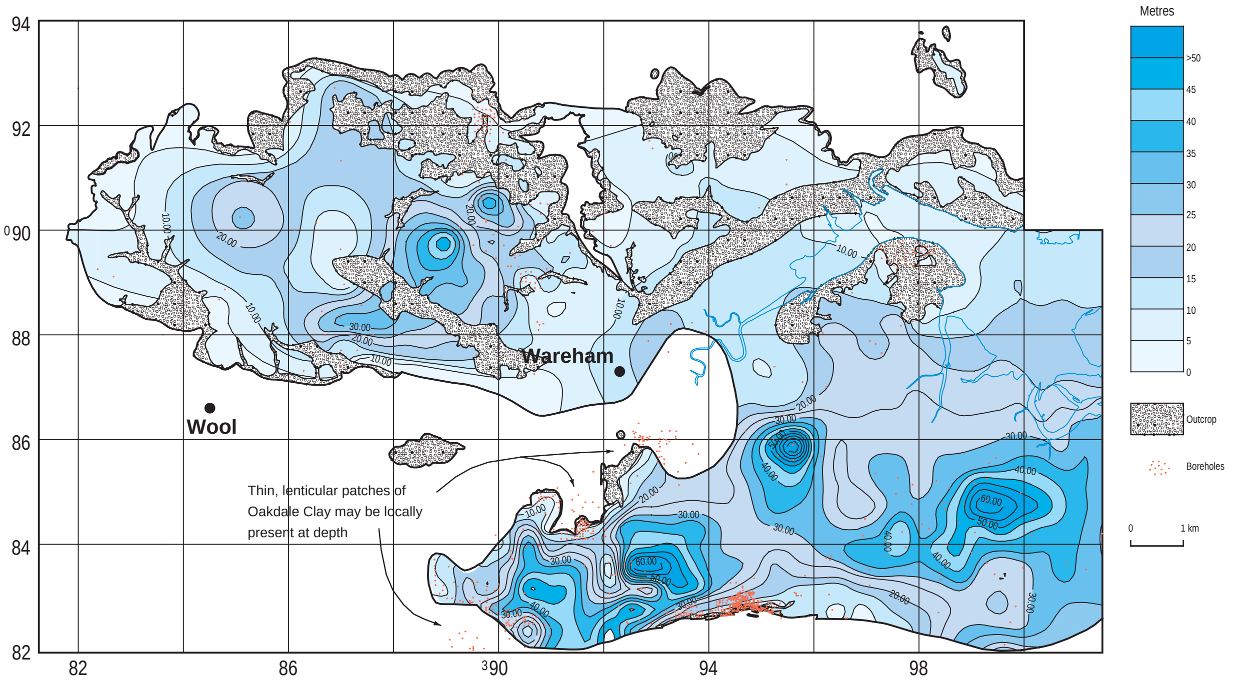


Figure 30 Oakdale Clay: Kaolinite content (176 records)

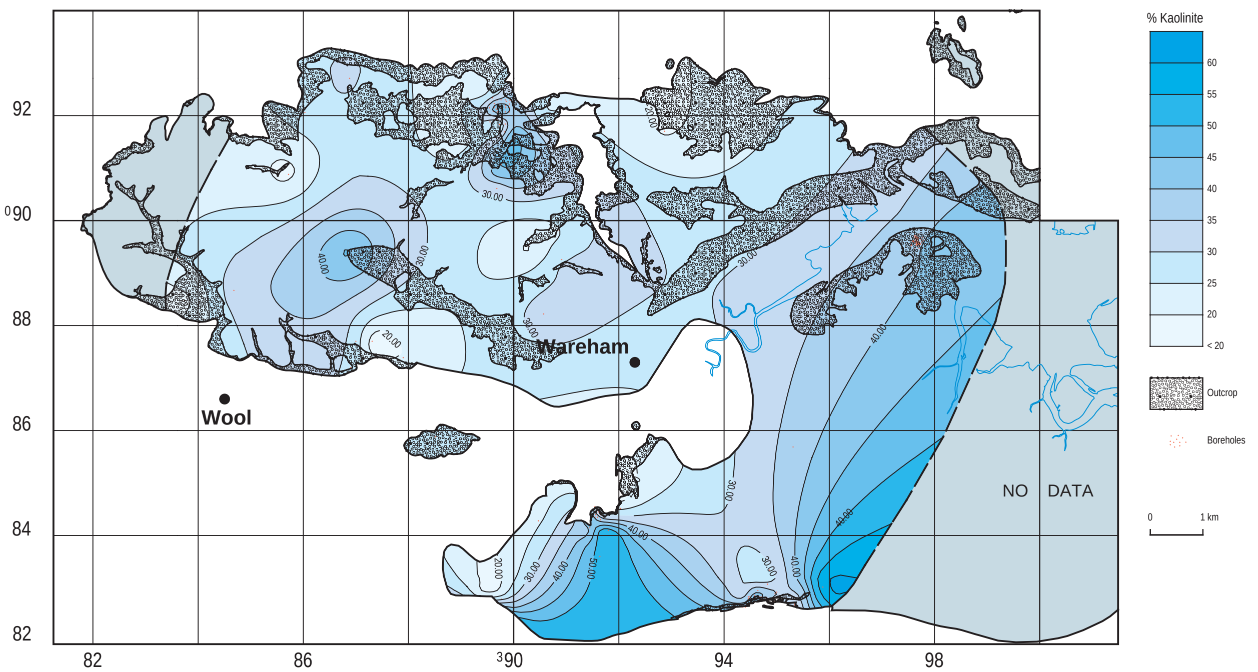


Figure 31 Oakdale Clay: Fe_2O_3 and TiO_2 content (327 records)

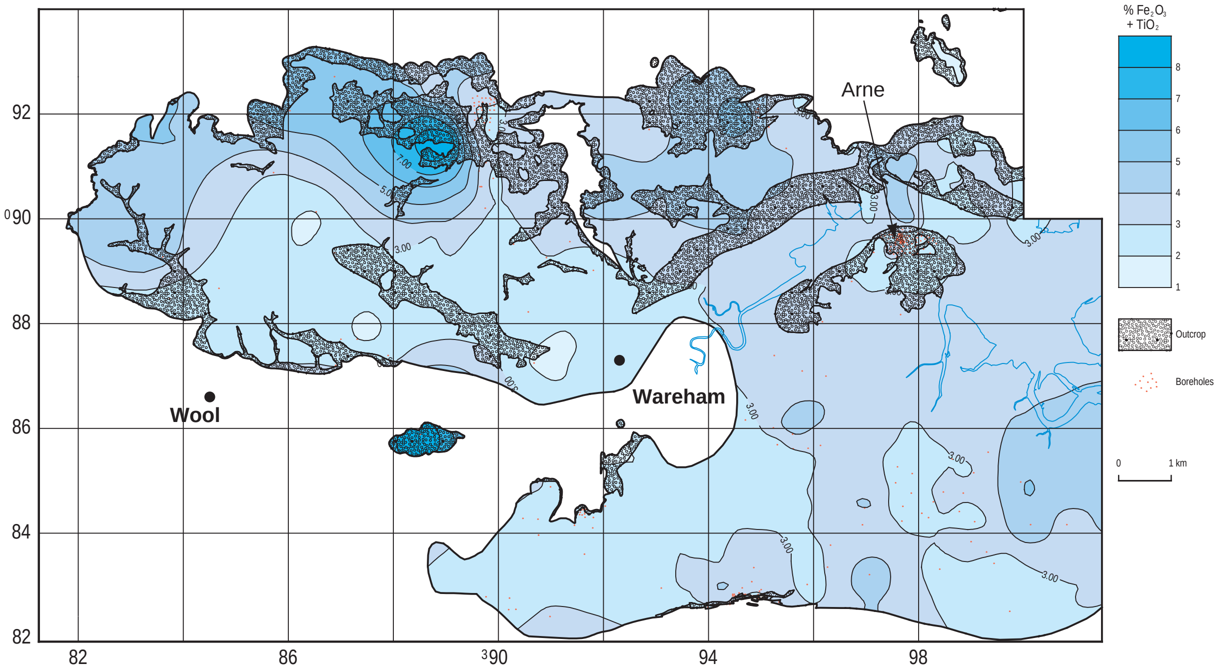


Figure 32 Oakdale Clay: SiO_2 content (327 records)

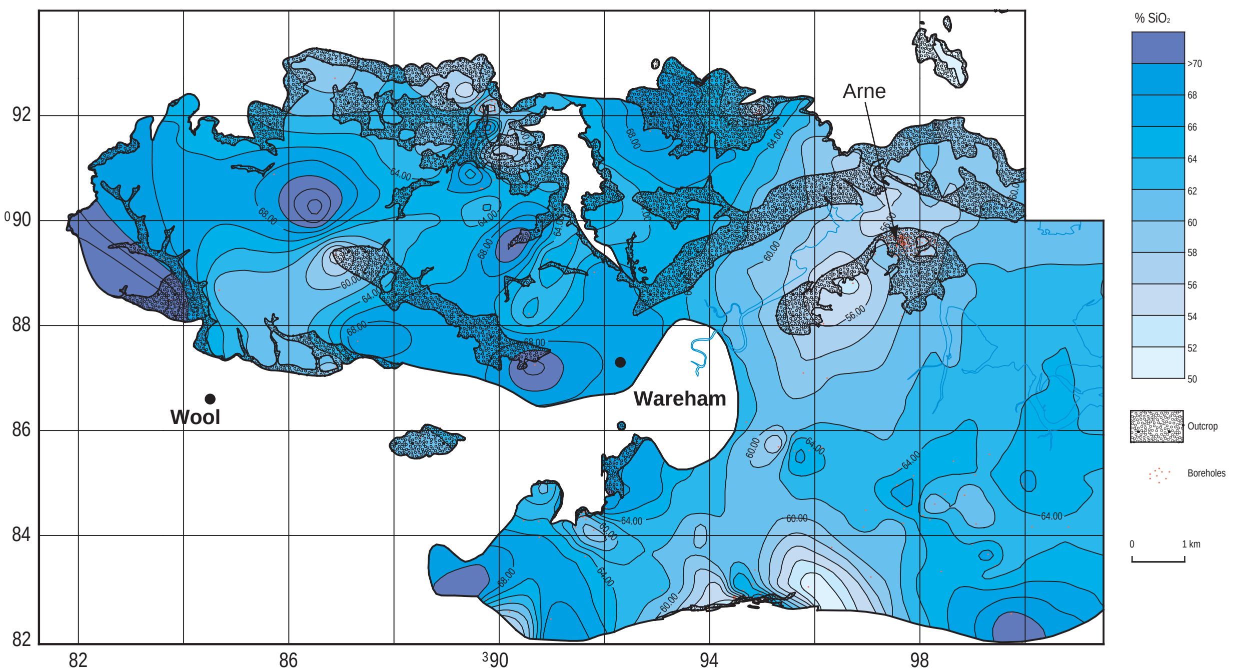


Figure 33 Broadstone Clay: Overburden thickness (928 records)

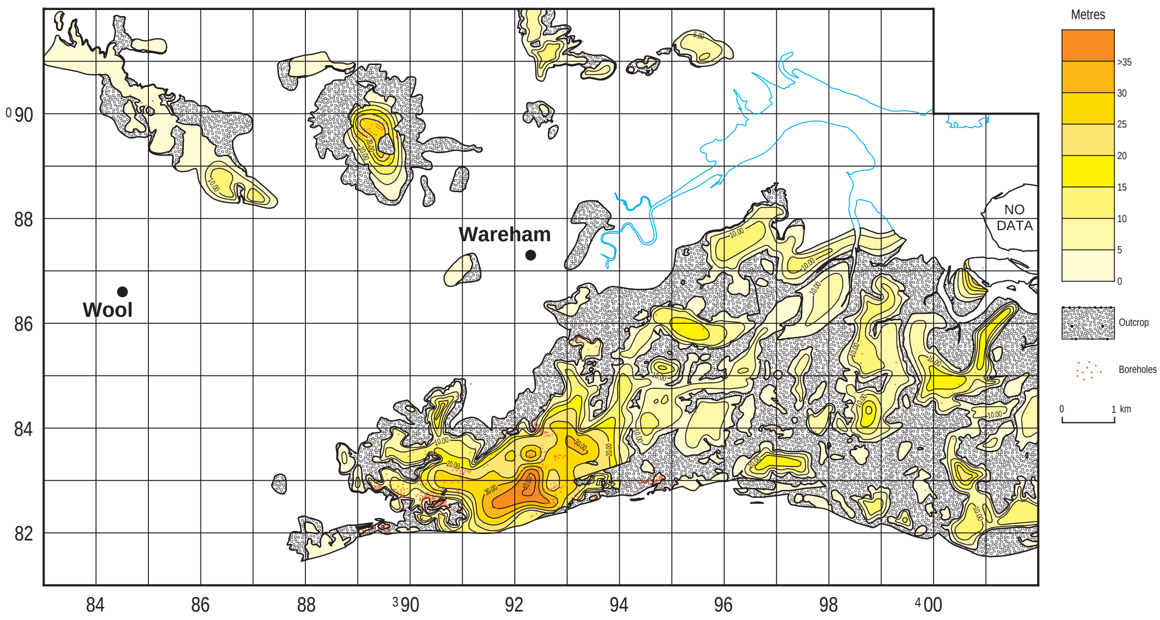
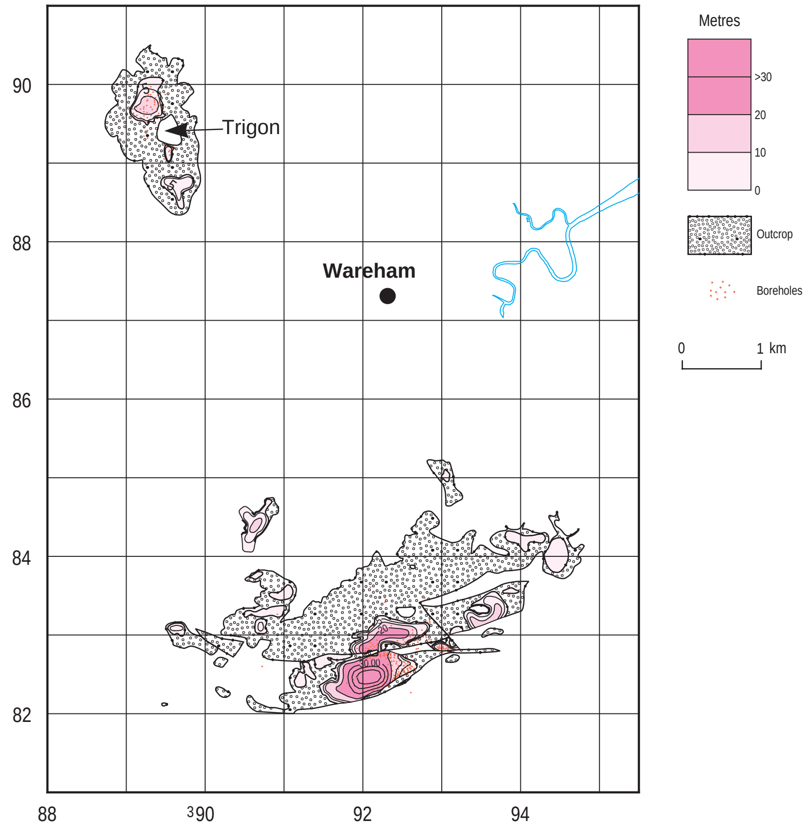


Figure 34 Parkstone Clay: Overburden thickness (350 records)



criteria used to assess commercial ball clays. Major-element geochemistry, total organic carbon [TOC] and surface area were determined following discussion with the ball clay industry regarding some of the critical parameters used to define production-grade clays. The geochemical data are reproduced in Appendix 7. The geochemistry also allowed an estimate of the kaolinite, illite (mica) and quartz contents of the clays to be calculated by rational analysis.

A scatter plot showing combined Fe_2O_3 and TiO_2 plotted against SiO_2 is shown in Figure 23. The area outlined on this plot represents the compositional limits for production grades of ball clay in the Wareham Basin. Higher silica clays are worked for tile bodies. Each host clay shows a broad scatter of compositions, although those from the Broadstone Clay show less variability in iron/titania content than samples from the underlying Oakdale and Creekmoor clays. Low iron levels tend to occur in samples with very high silica contents. No clay meets the demanding criteria set for tableware clays and only a few appear suitable for light-bodied tiles. This pattern is similar to that noted by Bristow and Freshney (1993).

There is a strong positive relationship between surface area (indicating strength and particle size) and kaolinite content. Most production grades of ball clay have a high kaolinite content. Desirable use-related properties, such as high strength, are also indicated by higher surface-area values. Although proportions of kaolinite and illite in the clay assemblage vary, it is likely that the principal control on surface area is the free silica (quartz) content. There is also an inverse relationship between kaolinite and quartz content, with high kaolinite values being associated with low quartz values, and vice versa.

To illustrate the vertical variability of a host clay (the Creekmoor Clay), a downhole plot of Fe+Ti oxides and silica is shown for the Priory Farm Borehole (Figure 24). Similar variations are seen for TOC. In conclusion, the BGS borehole and geochemical study clearly shows the heterogeneity of the host clays. Parameters critical to the commercial potential of the clays can change rapidly with depth, and the vertical extent of a clay horizon which meets the initial commercial specifications is generally very limited. On the basis of this limited study, it also appears that the clays show lateral heterogeneity, with little continuity in geochemical stratigraphy in host clays from borehole to borehole. Only a small proportion of the BGS samples meet the silica and Fe/Ti oxides criteria for commercial production grades. Low iron levels tend to occur in samples with very high silica contents. No clay meets the demanding criteria set for tableware clays. It is likely that the principal control on surface area (indicating strength and particle size) in these clays is the free silica (quartz) content. In addition, mineralogical analysis by X-ray diffraction of a broad spread of production-grade ball clays confirms that b-axis disordered kaolinite and illite dominate the clay mineral assemblage.

3.2.10 Geochemistry of IMERYS Minerals Ltd boreholes

Using the very large IMERYS Minerals Ltd geochemical data set confirms the above conclusions that host clays show considerable lateral and vertical variation in geochemistry and thickness (see also Henley et al., 1992). Although many seams can be traced across the Basin, seams can pass from commercial to non-commercial grade over a matter of metres (Figure 19). As Figure 16 shows, the productive clay (coloured blue) at Povington forms 26 per cent of the host clay (Creekmoor Clay). However, whereas IMERYS Seams 5.3 and 5.35 can be worked locally, nearby, because of high iron contents, these seams have no commercial value. Figure 20 also demonstrates how the detailed downhole geochemistry reflects the quality of the clays for use as ball clays. The highest-grade production clays all have low silica (50 to 55 per cent), high alumina (> 30 per cent), low iron and titania (< 2.5 per cent) and high kaolinite (>36 per cent) values.

3.2.11 Regional trends

To illustrate broad regional trends, variations in clay and overburden thickness, and geochemistry of the host clays across the Basin are shown in a series of contour maps (Figures 8 to 11, and 25 to 34). These were generated using Surfer 6.0, a grid-based graphics program, using the borehole database. Each data set, i.e. data from each borehole, is a weighted average. The closer the borehole is to a grid node, the more weight it carries in determining the value at that node.

Clay thickness can only be calculated for boreholes that prove both the top and base of a host clay. This excludes many thousands of boreholes proving only the top, base, or middle of a clay. Average thickness and overburden for each host clay are given in Table 3.

The boreholes are markedly clustered, with most located in, or close to, ball-clay workings. Elsewhere, the boreholes are unevenly distributed, but generalisations derived from areas of dense borehole coverage allow a reasonable prediction of resources to be made. Locally, the borehole cover may be sparse and in such areas, extrapolations may not be justified. The availability of geochemical data is critical to the evaluation of ball clay prospects. Sampling, however, may not be representative. Based on a visual examination of the core, sampling is likely to be biased towards clays with apparent potential. Clays with obviously high iron and quartz contents will not have been analysed. In marginal areas, analyses tend to be from thin, less sandy, non-stained clays which are unrepresentative of the clay unit as a whole.

Using the main parameters (see Figure 18) for determining ball clay quality, maps of silica, combined iron (Fe_2O_3) and titania (TiO_2), and rational kaolinite contents (Figures 26, 27, 28, 30, 31, and 32) have been generated. Because of multiple values for each host clay in any one borehole, these have been averaged for a specific parameter and therefore can only show general regional trends in quality. Thus, regardless of the number of analyses available for a borehole, there is only one data point for each host clay. Thin intervals of good-quality clay in a host clay may be masked as a result of this averaging. A low-quality clay seam in ground shown as having low silica, iron and titania, or high kaolinite may be similarly obscured. Where data are abundant, the maps provide useful indications and predictions of the characteristics of ground nearby. The maps help define regional trends and potentially prospective areas, but do not identify economic deposits of ball clay. They are not intended as a substitute for detailed exploration. The environmental and planning constraints relevant to potentially prospective areas is discussed in Chapter 6.

3.2.12 Prospective areas

The Surfer maps indicate that commercial ball-clay deposits occur in areas with thin overburden (<25 m), moderately thick host clays (>5 m), low silica (<60 per cent) and Fe-Ti oxides (<3 per cent) values, and high kaolinite contents. The maps show that the same parameters may occur elsewhere in the Wareham Basin and these areas are identified for each host clay below. Areas meeting overburden and thickness parameters of the host clays may be worth further investigation, although away from the existing worked deposits, few or none appear to meet the remaining criteria.

In the section following, the thickness and extent of potential ball clays in each clay host are determined using a comparison of the geochemistry of productive ball clays with the geochemical data available from various prospects identified in the Surfer plots. Intervals of potential ball clay tend to occur in the upper parts of host clays.

Creekmoor Clay

In the Area of Search areas of thick Creekmoor Clay with thin overburden are listed below. From the lithological descriptions of the boreholes and sparse geochemistry it seems unlikely that significant quantities of ball clay will be found in these areas:

Wareham Forest: a 10 km^2 area north of Wareham has overburden <25 m and the host clay typically exceeds 20 m in thickness. However, much of the Creekmoor Clay is a silty clay, clayey silt or sandy clay and commonly iron stained. Most of the few thin clay seams analysed have low alumina and high silica and combined iron oxide and titania.

Wool-Bovington: Creekmoor Clay is near surface north of Wool, an area where clay thickens markedly toward the north-east. Geochemical data are sparse or absent.

Bere Heath-Bloxworth: Creekmoor Clay on the north-west margin of the Basin has an overburden of <25 m and is >20 m thick toward the south. However, where the deposit is thickest, the clays are silty and ironstained. Analysis of the most promising (thin) seams showed that SiO_2 is mostly >55 per cent, combined iron oxide and titania >4 per cent, and with low alumina (<30 per cent).

Other prospects include extensions to existing deposits: north of Povington pit, between Holme Priory, Doreys pit and Stoborough, and either side of Norden. All have moderately thick clay near surface, that is relatively kaolinite-rich and low in silica, iron oxide and titania. The ground on either side of Norden is, however, structurally very complex. All these areas fall in the AONB.

Oakdale Clay

In the Area of Search, areas of thick Oakdale Clay and with thin overburden include:

Woolsbarrow: an area of relatively high kaolinite, low silica and low iron oxide and titania occurs in the north of Wareham Forest. Boreholes around Woolsbarrow Fort [893 925], where the host clay is about 10 m thick, have intervals of potential ball clay (20 to 34 per cent), either in several beds (e.g. Figure 22 SY89SE/72) [8963 9223] or a single interval (SY89SE/31) [8967 9212] about 2.4 m thick. The data suggest that this area has some resource potential. Just north of the fort, the clay thins to 2 m and has no ball clay.

Stokeford Heath: although boreholes around Stokeford Farm [8725 8710] prove only 2 to 3 m of Oakdale Clay with no potential ball clay, Surfer plots suggest that to the north, the host clay is 5 to 10 m thick, and may have clays with low silica and iron oxide, and high kaolinite values. However, the sparse geochemical data indicates high silica (>60 per cent) and low alumina (<24 per cent), but nevertheless, this area is worth further investigation

Cold Harbour (east of Trigon): boreholes (e.g. Figure 22; SY98NW/917) [9028 8951] show Oakdale Clay up to 22 m thick and near surface. However, the sparse analytical data suggest that the clays are relatively low in iron oxide, but high in silica. The ground is not regarded as prospective *Holton Heath:* thick Oakdale Clay occurs around King’s Bridge [9530 9238], where Surfer plots show an area of low silica and high kaolinite, but with high iron oxide values. These data are substantiated by boreholes (e.g. Figure 22; SY99SE/221) [9548 9134] and by field observations of bright red-stained clays at surface. The area is not regarded as prospective.

Unexplored ground: the area south-west of Woolsbarrow has few geochemical data and there is no borehole in kilometre square [88 90]. To the east, potential ball clays occur in the upper 2 m of a 5 m thick host, but the overburden locally exceeds 40 m. If these thicknesses are typical, then the combination of thin ball clay and thick overburden (with consequent large-scale workings necessary to reach the ball clay) precludes this as a prospective area.

Broadstone Clay

Areas of thick Broadstone Clay and thin overburden include:

Hartland Moor: thick Broadstone Clay south of Arne [centred on 955 860] has potential ball clay in the upper part. A representative borehole (SY98NE/36) [9589 8562] shows an interval 2.8 m thick with about 10 m overburden.

Newton Heath: a similar upper ball clay is present around Newton Heath in a 20 m thick sequence; the uppermost 2.6 m are low in silica and iron oxide (SZ08SW/13) [SZ0060 8471].

New Mills Heath: low-silica clays with at least 40 per cent kaolinite occur between New Mills Heath and Norden. Near Lower Bushey Farm [97 83], combined intervals of ball clay up to 4 m thick occur high in the sequence (SY98SE/26).

All three above localities fall in the AONB. Additionally, they all fall or are closely associated with SSSIs. Elsewhere in the south, the clays tend to be high in silica, except around Creech, where the overburden is much greater.

Extensions to Trigon: although Surfer plots suggest that kaolinite increases and silica decreases south-eastwards from the present Trigon workings (in Parkstone Clay), and also between Gallows Hill and Stoke Heath [85 90], there is no supporting data.

Parkstone Clay

Potential ball clay resources in Parkstone Clay occur around the existing workings at Trigon (in the Area of Search) and Creech:

Trigon: the host clay is about 20 m thick, of which about 5 m in the upper part is ball clay. The lower part is both siliceous and high in iron oxides. Extensions to the Trigon deposits occur (SY88NE/457 [8954 8914]) about 500 m south-east, where there is ball clay up to 2.3 m thick.

Creech: Parkstone Clay is 15 to 20 m thick on the north and north-east side of Creechbarrow. In boreholes SY98SW/3313 [9253 8290] and 3282 [9244 8250]), potential ball clays comprise 14 to 32 per cent of the sequence, including a thick seam near the base. Under Creechbarrow, mining has been extensively carried out, but has now ceased.

3.2.13 Summary of regional trends and prospective areas

Borehole data show that the Creekmoor Clay hosts ball clays with the most consistent thickness and geochemical properties. It has the highest kaolinite (Figure 35) and lowest silica contents of the host clays, and thus correlates well with it being the source of the highest quality ceramic clays. Consequently, ball clays in the Creekmoor Clay form an important part of most clay blends, making this clay the most important host clay economically, accounting for some 55 per cent of total output. Sparse data from the north of the Frome, where the clay mainly occurs at depth, indicates that potential ball clays are thin or absent, or of poor quality. The Creekmoor Clay is only worked south of the Frome in the AONB. This is where the promising prospects occur.

Oakdale Clay has a lower kaolinite content than the Creekmoor Clay and, therefore, is not considered as prospective for high-quality ball clay. Oakdale Clay is best developed in the north and east of the area; it is currently only worked on the Arne peninsula, in the AONB. Much of the area surrounding the current workings is constrained by international designations. The Oakdale Clay was formerly extracted at Binnegar and Holton Heath. A possible clay prospect, but of limited extent, occurs at Woolsbarrow in Wareham Forest

Broadstone Clay has kaolinite values second only to the Creekmoor Clay, although average Fe-Ti oxide contents are the highest of the clays. The main deposits are in the south, where several prospects are identified and where it was once worked. However, because of the sinuous nature of the ball clay channel fills and difficulty in locating such relatively small deposits, the clay is not now worked, except locally at Povington. Most prospects are covered by major environmental constraints .

Parkstone Clay is a siliceous clay, with the lowest kaolinite values of the host clays. Fe-Ti oxide contents are comparatively low. The highest kaolinite levels occur in the south, in the AONB. The Parkstone Clay is the second most important source of ball clay in terms of output.

A key factor of ball clay supply is access to clays with a wide range of properties for blending. All the host clays have the potential to supply commercially acceptable ball clays, but loss of production from the Creekmoor Clay with its large range of individual seam properties would make the maintenance of the blend specifications difficult, if not impossible, to achieve. Based on the large body of evidence in this study, it seems unlikely that ball clay deposits with the quality of those in the Creekmoor Clay south of the Frome will be found elsewhere in the Wareham Basin.

A detailed examination of the relationship between ball clay resources and environmental designations is given in Chapter 6 and Figures 36 and 37.

3.3 COMMON CLAY

The term 'common clay' defines clays primarily used in the manufacture of structural clay products, such as facing and engineering bricks, pavers, roofing and floor tiles, and vitrified clay pipes. The clays used in these applications normally fire to a reddish colour due to the presence of appreciable amounts of iron. Common clay may also be used as a source of constructional fill and for lining and sealing landfill sites.

Although all the host clays in the Poole Formation occur between Wareham and Poole, the evidence from former workings suggest that they are of inferior quality, are commonly red stained and no longer light firing. They have been classed as 'common' clays because they are not light-firing. However, the inherent mineralogy of these clays may make them suitable for the manufacture of facing bricks and roofing/cladding tiles.

Common clay extraction is currently only taking place at Knoll Manor, near Corfe Mullen, where clay in the West Park Farm Member of the London Clay is worked for the manufacture of red-bodied unglazed floor tiles. The raw material is always blended with other materials, principally Dorset ball clay, china clay and feldspar.

Common clay has been extensively worked in the past, in places by underground mining, for the manufacture of bricks, salt-glazed pipes and tiles and this was formerly an important industry (Bristow et al., 1991). At Beacon Hill, Broadstone Clay was formerly used in the manufacture of refractories and bricks, and at Hamworthy, Oakdale Clay was used until 1965 in the production of bricks and salt-glazed pipes. Creekmoor Clay at its type locality was also used as a source of brick clay. Until 1978, Oakdale Clay was extracted at a pit at Kingsbridge, south-west of Lytchett Minster, and blended with Devon ball clays for tile manufacture. The bed worked was of ball clay character, but apparently showed heavy specking on firing. Associated clays in the Oakdale Clay exhibit very high iron contents.

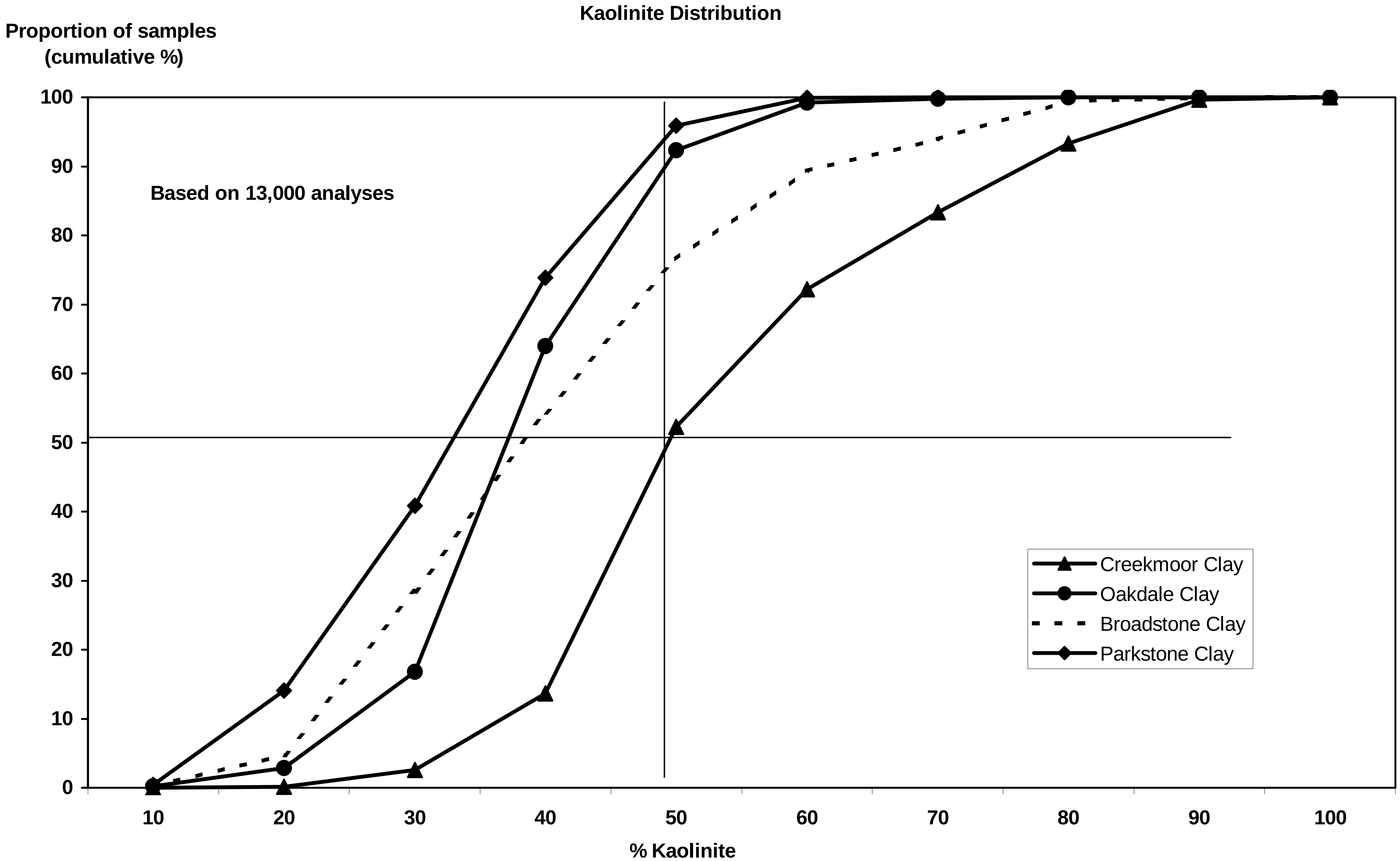
3.4 SAND AND GRAVEL

3.4.1 Introduction

The commodity 'sand and gravel' includes all sand and gravel used for construction purposes, but excludes relatively small amounts of sand used for industrial applications, which are referred to as 'silica' or 'industrial' sands. The principal uses of sand are as fine aggregate in concrete, mortar and asphalt, and the main use of gravel is as coarse aggregate in concrete. Small amounts of sand are also used in the manufacture of calcium silicate bricks. Substantial quantities of sand and gravel may also be used for constructional fill.

Total production of sand and gravel in the area is estimated to be about 2 million tonnes a year, comprising about 75 per cent sand and 25 per cent gravel. Of total sand and gravel production, 1.1 million tonnes consists of

Figure 35 Distribution of kaolinite in the host clays



concreting aggregate and 0.55 million tonnes is building sand. The remainder consists of fill and asphalting sand.

3.4.2 Specifications

Although conveniently grouped together, sand and gravel are separate commodities, defined on the basis of particle size rather than composition. In the British Standard particle-size classification (BS 1377:1975 and BS 5930:1981), sand is defined as a granular material in the size range 0.06 to 2 mm, with gravel being material in the range 2 to 60 mm. However, in current British usage in the aggregates industry, the term 'gravel,' or coarse concrete aggregate, is used for material that is coarser than 5 mm, with a maximum size of 40 mm. The term 'concreting sand,' or fine-concrete aggregate, is used for material finer than 5 mm. However, in future European standards, the division between fine and coarse aggregate is likely to be taken at 4 mm, and this is the definition used by the local industry. The division between sand and gravel in the BGS Mineral Assessment Unit reports was taken at 4 mm, and this classification has been used herein. Three sizes of sand have been defined; fine (0.075 to 0.25 mm), medium (0.25 to 1 mm) and coarse (1 to 4 mm).

Sands used in mortars (building sands) are specified in BS 1199 and 1200: 1984. Building sands are significantly finer than all but the finest concreting sands. They are often referred to as 'soft' sand, whereas concreting sand is 'sharp' sand. The description reflects differences in particle size, rather than surface texture and shape. However, British Standard specifications for building sand are not universally adhered to and resources that fall outside specification are commonly utilised.

Relatively small amounts of fine sand are used in asphalt. Requirements are specified in BS 594:1985 and, again, the main requirement is particle size.

3.4.3 Processing and blending

For the production of sand and gravel for concrete aggregate, it is usual to treat quarried material in a washing and screening plant to remove sometimes significant amounts of fines (clay and silt) and oversize material. Gravel for concrete and other uses is washed and graded using rotary or multi-deck screens. Crushing may be necessary to maximise saleable product, but increases costs. Very clayey gravel may require a greater degree of processing in specialised plant. Gravel for constructional fill may be produced 'as dug' or by dry screening.

The operation of most sand-washing plants for the production of concreting, asphalt and building sand involves the dispersion of sand in water and the separation of fines in a cyclone which delivers a partially dewatered coarser product. The unwanted fines are allowed to settle out in lagoons, from which the process water is recirculated. Building sand is also produced by passing the excavated sand over a screen, without the addition of water (dry screening) so as to retain fines, but remove coarse material.

Processing thus provides scope for adjusting the particle-size distribution of the 'as-dug' material to match market requirements of the final saleable product. Blending also allows for the adjustment of particle size to meet user requirements.

3.4.4 Resources

Sand and gravel resources of the Wareham Basin fall into two main categories:.

- bedrock, or 'solid' sand deposits (mainly the Poole Formation) and
- superficial, or 'drift,' gravel-bearing river terrace deposits.

About 1.2 million tonnes of sand is produced from bedrock deposits, almost entirely the Poole Formation; some 0.8 million tonnes is derived from river terrace deposits.

The principal resource of bedrock sands is the Poole Formation, which is extensively worked. The existing industry, which historically has also worked the superficial deposits, is centred on the Warmwell and Gallows Hill areas, with smaller operations north of Wareham and at Corfe Mullen. Subsidiary resources occur in the Branksome Sand and in sand bodies in the underlying London Clay (West Park Farm Member, Warmwell Farm Sand and Lytchett Matravers Sand). The sands in the London Clay are much finer grained than those in the Poole Formation which significantly limits their commercial use.

The Poole Formation has a wide outcrop, but beds of clay and silt, particularly in the east, means that the resource is fragmented. In the west, well-defined mappable clays are largely absent, although thin lenses and more clayey sands do occur. The resources map (Figure 7) shows those areas where bedrock sands occur at outcrop. However, extensive areas are masked by relatively thin superficial sand and gravel deposits which has allowed gravel quarries to be deepened to extract underlying bedrock sand. The sands of the Poole Formation have a buff or light colour, which is one of their valuable properties contrasting with the red sands of east Devon. Their thickness varies between 0 and 44 m (Table 2).

Bedrock sands are the main source of fine aggregate in Dorset and also are of local importance as a source of concreting and building sand. The particle size and low iron content also make them a potential source of silica sand, and they are also worked on a modest scale for industrial uses. Extraction operations are dry. Wet working would lead to a loss of fines and significant waste. The water table represents the limit of working unless active de-watering takes place, with the consequent, perhaps only local, effect on the surrounding environment.

Superficial sand and gravel deposits are the main source of coarse concreting aggregate in Dorset. The only current source is the river terrace deposits which, in places, are worked in conjunction with the underlying bedrock sands. Alluvial gravels, mostly associated with the rivers Frome and Piddle, have not been worked to any extent because of operational and restoration difficulties associated with wet working. Significant areas of superficial sand and gravel have been worked out or are already covered by mineral permissions.

The market area for construction sand covers primarily Dorset, Somerset, Wiltshire and Bristol, but extends to Chichester, Gloucester and Cardiff. The market area for concreting aggregate is Dorset.

3.4.5 Sand and gravel assessment

3.4.5.1 SAND

Production is mainly from the Broadstone Sand and the undifferentiated sands in the west of the Basin (Figure 7). Sands of less importance economically occur in the underlying London Clay and overlying Branksome Sand.

Sands in the Poole Formation

The Poole Formation is divided into four sand units, each about 10 to 15 m thick, separated by clays. The sands are typically medium-grained and moderately well sorted, although they may be locally pebbly and with thin beds of silt and clay.

West of a line between Wool and Bere Regis, the Poole Formation comprises largely undifferentiated sands, typically concealed beneath river terrace deposits. The sands range in grain-size from fine to coarse, with grains varying from subangular to very well rounded, and from well to poorly sorted. Fine, granular lignite occurs locally. Locally, gravel sheets, pebble beds or stringers also occur, comprising small sub-rounded to well-rounded flints in a clayey sand matrix. Clasts also include small white quartzite, together with lesser amounts of chalk, limestone and slate. Most sands fail to meet BS 882 and 1200G; however, selective extraction and/or processing and blending enables products to meet the above specifications (Table 4). Thickness and grading data for all four sand units of the Poole Formation are given in Table 2. Although all four units are similar, there are some slight, but not particularly significant, differences:

- Creekmoor Sand is the finest grained Poole Formation sand (average 0.4 mm); the Broadstone and Parkstone sands are the coarsest grained (average 0.6 mm)
- 38 per cent of unwashed samples of the Oakdale Sand passed BS882 and 1200G, the highest pass rate of all the sands
- sands which pass the British Standards appear to be fairly evenly distributed across the basin

Sands in the London Clay

Sands occur at three levels in the London Clay (see Chapter 2), but are described here as a single resource. Most sands in the London Clay are fine grained, locally clayey and moderately well sorted. Pebble beds, commonly composed of well-rounded black flints associated with coarse-grained sand, less than 1 m thick, occur locally. Sparse analytical data (Table 2) show that the average grain-size is 0.22 mm, in the range of fine or very fine sand. The sands are positively skewed Most unwashed London Clay sands (all Warmwell Farm and Lytchett Matravers sands) fail BS 882 and 1200G (Table 4). In general, the sands are too fine-grained for commercial use. However, the Warmwell Farm Sand is worked, together with the Broadstone Sand, in the Henbury Pit.

Branksome Sand

Branksome Sand typically has a pebbly base. The sands are medium-grained and variably sorted. Sparse data from the present area suggest that the sand has an average grain-size of 0.86 mm (Table 2;), although Bristow et al. (1991) report an average of 0.25 mm for the entire unit (range 0.11 to 0.8 mm).

[1] see footnote 4 on Table 2

Table 4 Breakdown of passes and fails for sand units in the Wareham Basin

	Number of samples	Unwashed		Washed (<75µm removed)	
		Pass[1]	Fail	Pass	Fail
Branksome Sand	BS882	2	1	2	1
	BS1200G	2	1	2	1
Parkstone Sand	BS882	28	35	24	39
	BS1200G	13	50	11	52
Broadstone Sand	BS882	42	82	36	88
	BS1200G	16	108	19	105
Oakdale Sand	BS882	61	63	61	63
	BS1200G	28	96	32	92
Creekmoor Sand	BS882	3	4	6	1
	BS1200G	6	1	3	4
Sand in London Clay	BS882	7	7	9	5
	BS1200G	5	9	4	10
Warmwell Farm Sand	BS882	0	15	0	15
	BS1200G	2	13	1	14
Lytchett Matravers Sand	BS882	0	4	0	4
	BS1200G	0	4	0	4
Sand in West Park Farm	BS882	1	6	2	5
	BS1200G	0	7	3	4

[1]Passes the relevant BS specification

3.4.5.2 GRAVEL

The principal source of gravel (>4 mm) in the Wareham Basin is the superficial deposits that form a thin layer above the solid formations. The most important are the terraces associated with the rivers Frome, Piddle and Stour, although gravel is also present beneath the alluvial spreads of these same rivers and under the marine alluvium around Poole Harbour (Figure 15). Smaller amounts of gravel also occur as thin sheets in the Poole Formation sands, but no estimate of the proportion produced from this source is available.

Terrace thickness

Gravel thickness and grading have been determined in 26 trial pits dug during the project in terraces along the Frome, from Bovington to Worgret, and south of Tadnoll Brook around Owermoigne. Average thickness is 2 m, although some pits around Bovington Camp did not prove terrace base; thicknesses around Owermoigne and along the Frome average 1.2 m and 2.2 m respectively.

The average thickness of river terrace deposits from 463 boreholes is 2.35 m (range 0.15 to 9.45 m). Earlier BGS data for south Dorset give an average thickness of the low terraces (terraces 1 to 7 and sub-alluvial deposits) in 83 boreholes of 2.7 m; and for the higher terraces (terraces 8 to 15), an average of 2.1 m thick (Mathers, 1982). Although forming a potential resource, because of their relative thinness, large areas would need to be worked to achieve the necessary volume for economic extraction.

Grain-size data

Some 63 dry-sieve determinations were performed on bulk samples (average 22.5 kg) obtained from the trial pitting (Table 5). Overall, sand (49.9 per cent) and gravel (50.1 per cent) occur in approximately equal proportions. Dominantly gravelly deposits (>65 per cent) were recorded from the Bovington Camp pits and at Rushton Farm; dominantly sandy deposits (typically >65 per cent) were recorded from the Owermoigne and Stokeford pits.

Earlier grading data (Mathers, 1982) indicates that the mean of both the lower (1 to 7) terrace deposits, located mainly along the Frome and Piddle rivers, and sub-alluvial gravel is 7 per cent fines, 39 per cent sand and 54 per cent gravel. The higher terraces have a mean grading of 10 per cent fines, 33 per cent sand and 57 per cent gravel. The sand fraction is either medium or medium and coarse grained, with some fine grained. Many terraces have a clayey or silty sand top, similar to Alluvium.

Clast composition

The mean composition of the lower terraces is 88 per cent angular or subangular flint, 3 per cent rounded flint, 4 per cent quartz, 3 per cent sandstone and ironstone and 2 per cent chalk (Mathers, 1982). Mean compositions from the upper terraces average 90 per cent angular and sub-angular flint, 2 per cent rounded flint, 6 per cent quartz, 2 per cent sandstone and ironstone and 2 per cent chalk. Locally, common large chalk clasts occur south of the Frome, and the vein quartz content increases eastwards (Mathers, 1982). The occurrence of significant quantities of chalk clasts in a deposit diminishes its economic importance.

Regional variation

Warmwell and the Upper Frome

The broad terrace flat over Crossways was extensively worked at Warmwell and Moreton, but is now largely worked out. Average gravel thickness was 1.7 m (range 0.3 to 3.1 m; mean of 33 boreholes), overlain by c.0.5 m of clayey silt topsoil with small flints, and slightly gravelly clayey sand and sandy clay. Elsewhere, the average thickness is 2.6 m, but locally, in the range 3.8 to 4.3 m. Small areas of terrace that could still be worked are typically 1.7 to 3.5 m thick, with about 50 per cent coarse gravel.

Between Woodsford Signals and Woodsford Crossing, and east toward Moreton Station, boreholes show that the gravel deposits are fine to coarse flint that average 1.5 m thick (range 0.9 to 2.3 m), overlain by about 0.7 m of topsoil, clayey sand and sandy clay, all with sparse flints. There are few data from the extensive terrace deposits around Moreton, although the few boreholes suggests that the deposits are 1.5 to 2.5 m thick and overlain by about 1 m of topsoil and sandy clay with sparse flints. There, mean grading is 2 per cent fines, 55 per cent sand and 43 per cent gravel. Gravel composition is 82 per cent angular or subangular flint, 15 per cent quartz, 2 per cent well-rounded flint and 1 per cent ironstone (Mathers, 1982).

Owermoigne and south Frome

Terrace 3 which forms extensive low flats north-east of Owermoigne and between Winfrith and East Burton, differs in thickness and composition. Boreholes between Nutley Farm and North Fossil Farm show the deposits to be relatively thin, and commonly chalk-rich. A typical section shows about 0.7 m of sandy topsoil and very clayey silty sand, both with flints, overlying 1.1 m (range 0.4 to 2.8 m) of sandy gravel (mean of 75 boreholes). The upper part of the sequence is silty sandy flint gravel, while the lower part is white to greyish brown chalk and small flint gravel. The chalk, however, can form up to 19 per cent of the deposit, which considerably reduces its economic potential.

Stokeford and Wool

This area includes the widely exploited higher terraces between Bere Heath and Worgret, and the largely unworked ground adjacent to the Frome between Bovington and East Holme. Deposits in this latter area are relatively thick (>2 m) and typically have a thin overburden. Extensive areas of coarse gravel are present around Bovington Camp.

Wareham and the Lower Frome

About 10 km^2 of terrace and sub-alluvial gravel occurs around and east of Wareham (Figure 15). Alluvial overburden thickness is locally 5 m, although gravel thickness is also above average, locally exceeding 10 m. The mean grading of the deposits is 5 per cent fines, 47 per cent sand and 48 per cent gravel (Mathers, 1982). However, much of the alluvial gravel falls in the AONB.

Table 5 Dry sieve determinations for gravel samples collected during the present study (values in per cent)

Trial Pit	BGS Registration Number	Grid ref.	Sample interval (m)	Fines[1] (<75μm)	Sand (<4 mm)	Gravel[2] (>4 mm)
A Hethfelton	SY88NE/768	[8549 8752]	0.6 – 1.2	1	76	23 (0)
			1.3 - 1.9	1	58	31 (11)
B Hethfelton	SY88NE/767	[8590 8766]	0.6 – 1.1	<1	80	20 (0)
			1.1 – 1.5	1	69	30 (3)
			1.5 – 2.1	<1	78	22 (2)
C Stokeford Farm	SY88NE/770	[8725 8748]	0.4 - 1.1	8	66	26 (4)
			1.1 – 1.9	14	74	12 (0)
D Stokeford Farm	SY88NE/769	[8710 8781]	0.4 – 0.6	12	69	19 (0)
			0.6 – 0.9	7	46	47 (15)
			2.1 – 2.8	1	44	55 (10)
E Stokeford Farm	SY88NE/771	[8682 8756]	0.9 – 1.0	<1	50	50 (7)
F Stokeford Farm	SY88NE/772	[8677 8802]	0.4 – 1.0	7	70	23 (0)
			1.4 – 2.0	10	64	26 (0)
G Stokeford Farm	SY88NE/773	[8715 8810]	0.4 – 1.1	8	68	24 (4)
			1.1 – 1.9	9	73	18 (1)
H Rushton Farm	SY88NE/776	[8799 8672]	1.3	1	32	67 (15)
			1.9	1	26	73 (11)
I Rushton Farm	SY88NE/777	[8862 8677]	1.4	1	36	63 (12)
			2.0	1	33	66 (14)
			2.4	1	31	68 (13)
J Priory Farm	SY88NE/778	[8911 8620]	1.5	1	40	59 (10)
			2.3	1	33	66 (19)
K Priory Farm	SY88NE/779	[8989 8590]	1.9	<1	39	61 (10)
			2.4	<1	39	61 (3)
L Worgret Manor Farm	SY98NW/925	[9072 8662]	1.5	1	66	33 (2)
			2.0	1	77	22 (5)
			2.6	2	84	14 (0)
M Worgret Manor	SY98NW/927	[9052 8642]	1.3	1	44	55 (4)
			1.8	1	40	59 (7)
			2.1	1	38	61 (15)
			2.8	<1	39	61 (13)
N Bindon Lane	SY88NE/775	[8566 8660]	0.8 – 1.5	<1	38	62 (13)
O Bindon Lane	SY88NE/774	[8613 8639]	0.3 – 0.7	2	44	54 (2)
			0.7 – 1.4	<1	33	67 (9)
			1.6 – 2.0	1	37	62 (10)
P Bovington Camp	SY88NW/201	[8303 8792]	0.8	1	43	56 (10)
			1.3	<1	28	72 (11)
			2.2	<1	36	64 (13)
			2.4	<1	37	63 (5)
Q Bovington Camp	SY88NW/202	[8254 8795]	0.8	<1	37	63 (8)
			1.1	<1	33	67 (20)
			1.4	<1	27	73 (17)
R Bovington Camp	SY88NW/203	[8215 8818]	1.0	<1	31	69 (11)
			1.4	<1	22	78 (25)
			2.0	<1	23	77 (19)
S Bovington Camp	SY88NW/204	[8186 8890]	1.0	1	24	75 (17)
			1.6	1	34	65 (16)
			1.8	<1	30	70 (16)
			2.0	<1	49	51 (7)

Trial Pit	BGS Registration Number	Grid ref.	Sample interval (m)	Fines[1] (<75μm)	Sand (<4 mm)	Gravel[2] (>4 mm)
T Bovington Camp	SY88NW/205	[8208 8853]	1.2	<1	27	73 (14)
			1.7	<1	25	75 (18)
			2.0	<1	13	87 (20)
U Galton Manor Farm	SY78NE/390	[7775 8568]	0.6 – 0.8	2	60	38 (12)
V Galton Manor Farm	SY78NE/392	[7831 8622]	0.7	4	58	38 (1)
W Galton Manor Farm	SY78NE/391	[7843 8596]	0.5	8	79	13 (0)
X Worgret Manor	SY98NW/926	[9075 8675]	1.5	2	69	29 (2)
			2.6	<1	57	43 (11)
			3.0	1	53	46 (8)
Y Galton Manor Farm	SY78NE/393	[7873 8671]	0.8	2	75	23 (0)
Z Moigne Court	SY78NE/394	[7708 8586]	1.0	4	61	35 (1)
			1.4	2	44	54 (11)
			1.7	3	48	49 (12)
			2.0	2	52	46 (11)

[1]Many samples were taken below the water table resulting in the loss or depletion of much of the fines fraction. The smallest sieve size of 75μm was used in the determinations.
[2]Figures in parentheses are percentages of oversize gravel (>40 mm) which may require crushing.

Poole Harbour

Sand and gravel, up to 5 m thick, forms the basal part of the marine alluvium on the west side of Poole Harbour. Little is known of the composition of the marine alluvium around the rest of Poole Harbour, but a basal gravel is likely to be present. However, much of this area falls in the AONB.

3.4.6 Summary of findings

The Poole Formation is the principal source of fine aggregate in the Wareham Basin. The average grain size is medium grained, but 'as dug', most sands do not initially meet BS 882 and 1200G. However, blending and processing successfully allows these sands to be sold for concreting and building sand. Although there is a predictable vertical variation in grain size, there appears to be little geographical variation across the basin.

High-level terraces have provided most of the gravel of the area, but most deposits are now worked out. Considerable areas of low-lying terraces, with an average thickness of 2.35 m, border the River Frome throughout the Basin; a more limited area of low-lying terraces occurs along the River Piddle north-west of Wareham. Alluvial gravel occurs along the length of both rivers, but is unlikely to provide a significant resource because of operational and restoration difficulties associated with wet working. Most of the above potential resources fall outside the AONB. The large areas around Woodsford lie in the Dorset County Council's Preferred Area of working.

3.5 INDUSTRIAL SAND

Although sands of the Poole Formation are principally valued as a source of fine aggregate, some are suitable for industrial purposes. The physical and/or chemical properties of silica sands effectively govern their usefulness and value; different applications demand different combinations of properties. These include high silica contents in the form of quartz, an absence of deleterious impurities, and typically a narrow grain-size distribution (generally in the range 500 to 100 μm); preferred sands are those that are clean, free of impurities and well sorted.

The distinction between silica sand and construction sand is based principally on application and market specifications, rather than a fundamental difference in the two raw materials. Depending on end-use application, processing of silica sands is of varying degrees of complexity and often requires a high capital investment in plant. Silica sand commands a higher price than construction sand, which allows it to serve a wider geographical market.

Industrial (silica) sand is marketed for purposes other than for direct application in the construction industry. It is an essential raw material for glassmaking and foundry casting, as well as a wide range of other products such as ceramics, chemicals and water filtration. For most industrial applications, silica sands have to conform to very closely defined specifications.

The Poole Formation is not a nationally important resource of silica sand. This is probably a function of a lack of important local markets and increased competition from other silica sand resources in more distant markets. Silica sand, including resin-bonded foundry sand, has been produced at Binnegar in the past. Dried silica sand is currently produced at Warmwell for use, after grinding, in glass-fibre manufacture. Chemical analyses of these products are shown in Table 6 which indicates the high silica and low impurity levels of the sands. Sands for semi-industrial applications, including facing bricks and sports-turf sand, are produced from sand in the London Clay at Henbury.

Table 6 Typical chemical analyses of sands produced from the Poole Formation

	Binnegar	Warmwell (Bardon Aggregates)
	Weight %	
SiO_2	99.24	99.4
TiO_2	0.05	0.03
Al_2O_3	0.28	n.a.
Fe_2O_3	0.07	0.35
CaO	0.01	0.05
MgO	<0.02	0.02
K_2O	0.03	0.01
Na_2O	0.08	0.01
Loss	0.24	0.20

3.6 SUMMARY AND CONCLUSIONS

Ball clay is a scarce resource, limited in occurrence in Europe and only found in three locations in Britain. Ball clays from these locations have different properties which tend to complement, rather than substitute for one another. In the Wareham Basin, the properties of ball clays show local and broad vertical and lateral changes in chemical and physical characteristics. This variation has led to the division of such deposits into various end-use grades, each with specific properties. This enables the separation of high-quality clays from lower quality material, thereby providing clays which meet more rigorous specifications. The combined effect of these factors impacts on the location of, and the potential for, commercial ball clay deposits. Effectively, ball clay resources are not present west of Bovington Camp.

The thickness and quality of the host clays and contained ball clays is based on data derived from a large number of boreholes. Inevitably, these are concentrated around existing operations, but, generally, there is sufficient borehole cover in the intervening areas, to allow a reasonable prediction of ball clay resources.

Creekmoor Clay hosts the highest-quality ball clays. It thins and shows decreasing qualities north from the Chalk ridge and is not considered a viable commercial prospect north of the Frome due to its general poor quality and thick overburden. This restricts the prospectivity for high-quality ball clay to deposits in the south of the Basin. There, Creekmoor Clay is at or near surface in the Povington - East Holme area, and only occurs at depth approximately east of the Wareham-Corfe road.

South of the Frome, significant deposits of Oakdale Clay only crop out in the Arne Peninsula, but do occur at depth south of that area. Some commercial deposits (Binnegar) are known north of the River Frome, and other prospective areas are known (Woolsbarrow). However, in this northern tract, such deposits will mostly be thin and of limited extent.

The Broadstone Clay has an extensive surface crop south of the Frome and a limited crop north of the Frome (around Trigon). In the south, the clay has been worked for ball clay in the past and is still considered to be prospective in that area.

In the Area of Search, the Parkstone Clay has a very restricted outcrop around Trigon where it is currently worked.

The principal host clay in the Area of Search is, therefore, the Oakdale Clay; possible areas of interest have been identified during this study. However, Oakdale Clay is of lower quality than Creekmoor Clay and it is not considered as a potential source of high-quality ball clay. There would appear, therefore, to be no available substitute for the high-quality ball clays produced from the Creekmoor Clay in the south of the Basin.

Although deep mining has been carried out for many years, this method of extraction is now not economically viable. The last remaining mines closed in August 1999. In the foreseeable future, ball clay extraction will be by surface workings.

Processing and/or blending can increase the size of a mineral resource base, which may also expand if specifications become less restrictive or consumers are willing to accept an inferior product. There is no indication that ball clay-user specifications are being relaxed, and current sales and exports show that consumers require light-firing clays with consistent properties.

Extending ball clay resources by blending lower and higher quality clays is standard commercial practice to optimise resource use. However, because of the scarcity of higher quality clays, there are limits to the extent that this can be undertaken without the risk of diluting higher quality clays so that they no longer meet current commercial parameters.

The mineralogy, fine particle-size, and relatively low intrinsic value (compared to china clay) is likely to preclude industrial-scale beneficiation of Dorset ball clays in the present economic climate to remove Fe-Ti oxides and organic carbon or to increase kaolinite content. Such beneficiation processes require considerable investment and involve complex processes leading to a major industrial development and difficulties in waste disposal. This is not a viable option in the foreseeable future. Such a process would give rise to environmental costs directly by processing and waste disposal, and indirectly in additional energy consumption.

The Poole Formation is the principal source of fine aggregate in the Wareham Basin and also provides a modest source of industrial sand. Resources are large. Relatively thin river terraces deposits have provided almost all of the gravel produced in the area. Higher-level terraces are mostly worked out and extensive areas of lower terrace gravels are believed to be of lower quality.

4 Planning & Land Use Considerations

4.1 THE PLANNING PROCESS

The planning policies which apply in the area have an important historical context, reflecting the early recognition of both the importance of the mineral and other resources, particularly flora and fauna and their associated habitats.

In the late 1940s, the area was confirmed as of major national environmental importance for both nature conservation and the landscape. The Dower (1945), Huxley (1947) and Hobhouse (1947) reports noted that large parts of the area were of major scientific interest and identified the importance of the area's landscape in national terms. Dower proposed, unsuccessfully, that the area should be designated a National Park. However, the designation of much of the area as an Area of Outstanding Natural Beauty confirmed its national importance for its landscape qualities. The perception of the high quality of the landscape and the success in preserving and enhancing its character is also reflected in the Council of Europe award for the Heritage Coast.

The importance of ball clay as a valuable national asset and essential raw material for the pottery industry was recognised by the Enquiry on the Ball Clay Industry (Anonymous, 1946). The Enquiry was set up by the then Board of Trade to consider what measures should be taken to increase ball clay production to meet expanding post-War requirements for the clay and to ensure that future demand could be met.

In the early 1950s, the Ball Clay Standing Conference, constituted by the then Minister for Town and Country Planning in 1949, undertook an assessment of the potential conflict of resource objectives (Anonymous, 1953). The objective was to make provision for the future working of ball clay in the Development Plans being prepared under the Town and Country Planning Act 1947.

The Conference recommended that, in view of the national importance and comparative scarcity of ball clay, means should be found to safeguard from conflicting development, as far as possible, the foreseeable land requirements of the industry. The conclusions of that process helped to resolve problems at the time, leading to the allocation of areas for ball clay working in the County Development Plan and confirmation of the extent of major conservation designations.

The need to protect deposits of ball clay from sterilisation by other development was also identified. This led to the adoption of a consultation process, applied in the general geographical limits of ball clay (the Ball Clay Consultation Area) which has helped to protect ball clay resources from sterilisation. The Consultation Area covers some 147 km^2 in Dorset (Figure 16). The consultation process still operates, but neither the process, nor the Consultation Area, has been reviewed since that time. Similarly, the report on sand and gravel supply (Waters, 1948) provided guidance on provision and this was also reflected in allocations in the Development Plan. The Plan made no provision for onshore oil or industrial sands. However, requirements for additional resources of sand and gravel, and certain clays, subsequently gave rise to the need for industry to develop new sites or extend existing operational areas. At the same time, conservation designations were extended and/or new designations confirmed. These separate processes reduced the extent of non-contentious areas available, leading to more difficulties in decision making.

Since the 1970s, significant developments relating to both mineral and conservation issues have taken place. In the mineral resource sector, there has been a continuing growth in demand and a significant increase in ball clay production. This has been accompanied by a reduction in the size of the permitted reserves, the development of a considerable part of the unconstrained gravel resource and, with specific regard to ball clay, a decline in underground mining (ceased in August 1999) and a commensurate rise in surface working. There has also been a heightening and a reinforcement of the perceived value of, and the need to protect, the environmental resources of the area.

The conflict between mineral development and environmental protection was highlighted by three developments in the early 1970s. These were the proposal to extract ball clay at Russell Quay on the Arne Peninsula, the proposal to extract sand and gravel from Bestwall, Wareham, and the proposal to develop onshore oil at Wytch Farm adjoining the southern shores of Poole Harbour.

These proposals involved significant mineral development in or adjoining areas of major conservation interest. All developments were in the AONB and adjoined significant SSSIs. The proposal at Arne was granted on appeal in 1977. In his decision letter, the Secretary of State noted the continuing conflict between ball clay production and the need to protect the environment. He proposed that the County Council prepare a Ball Clay Subject Plan indicating areas where ball clay could be worked with the least environmental damage.

This request caused difficulties for the County Council because of the limited knowledge regarding the location and quality of the ball clay resource. Some progress on the preparation of a Ball Clay Subject Plan was undertaken, but this was subsequently subsumed in the Minerals and Waste Local Plan which was adopted in April 1999 (Dorset County Council, 1999). However, the preparation of that local plan was still hampered by the lack of data on the extent, characteristics and variation of the mineral resources in the Basin.

The conflict between the development of mineral and other resources in the area has been a real, if limited, factor to date. In practice, a fair proportion of decisions involving apparent conflicts between mineral and other resource objectives have been resolved by the planning process without significant negative impact. Diverse competing demands between minerals and other resources have generally been balanced. Recognition of that achievement is exemplified by reconfirmation of the Council of Europe Award for the Heritage Coast area, despite the development of mineral resources in the area. This achievement of the planning process over the last few decades precisely accords with sustainability objectives and is to be commended.

However, very recent policy developments relating to international nature conservation designations primarily related to the 'heathlands' and 'wetlands' of the area, have heightened the degree of actual and potential conflict at all levels in the short term. The impact of these developments in the medium and long term have also been identified and appear to lead to conflicts which may be extremely difficult to resolve in accordance with sustainability objectives given current arrangements.

4.2 NATURE CONSERVATION INTERESTS OF THE WAREHAM BASIN

4.2.1 Introduction

The diverse mosaic of semi-natural habitats and associated ecosystems in the Wareham Basin form a continuous interacting linkage. For example, the shallow waters and mud flats of Poole Harbour adjoin and grade into reed bed and mires, wet heathland and ultimately dry heath and woodland.

Many of these habitats had been severely reduced in extent over the last decades, mainly by agricultural improvement, forestry and urbanisation; mineral extraction has had only a minor impact.

4.2.2 Heathland

4.2.2.1 DEFINITION OF HEATHLAND

Heathland is a term which describes both a landscape and particular assemblage of plants and animals. In its widest sense, heathlands are open, uncultivated tracts of treeless land, usually covered with low herbage or dwarf shrubs, that are difficult to cultivate and with low agricultural productivity (Gimingham, 1972; Webb, 1986). These heaths depend on a temperate climate with cool moist summers and warm moist winters. Annual precipitation is 600-1000 mm.

4.2.2.2 SOILS

Lowland heathland is dependent on chemically poor and acidic soils. Characteristically, heaths form on podsols and the growth of heath vegetation assists podsolization. In places, wind-blown sands may cover calcareous strata to varying depths resulting in greater biological diversity. In other areas, heaths form on decalcified dune sands.

4.2.2.3 TOPOGRAPHY AND HYDROLOGY

Topography, which in turn affects hydrology, produces considerable local variation in heath vegetation. There is a clearly marked series of inter-related types. In **dry heath**, the water table is well below the surface and soils, typically podsols, are free draining throughout the year. **Humid heath** occurs where the water table is within 40 cm of the surface and drainage is impeded giving rise to gley soils. In **wet heath**, drainage is impeded and the water table is very close (<10 cm) or even at the surface. **Valley mires** occur where the water level is at or above the surface resulting in peat formation (Chapman et al., 1989).

4.2.2.4 EXTENT OF HEATHLAND

In Britain, heathland occurs in the Scilly Isles, on the coasts of Cornwall and north Devon, on the pebbly and sandy commons in south Devon, Dorset and the New Forest, northern Hampshire, Surrey and Sussex, with small areas in Kent. In East Anglia, there are heathlands in the Breckland, on the Sandlings in Suffolk and in north Norfolk. Further north, heathland occurs in the Vale of York. Scattered heathlands still occur in Leicestershire and Nottinghamshire, and there are good areas in Shropshire. There are extensive coastal heathlands in west and north-west Wales. Most of northern Britain contains moorland, but there are scattered areas of lowland heathland.

4.2.2.5 CHANGES IN EXTENT

In Europe, there has been a startling decrease in heathland over the last two centuries and only 10-15 per cent remains: a decrease from several million hectares to about 350 000 ha (Diemont et al., 1996; Webb, 1998). In Britain, about 58 000 ha now remain (Farrell, 1993). The national biodiversity action targets are to maintain this area and, through restoration, increase it by 6 000 ha (Anonymous, 1995).

In Dorset, where changes are well documented, heathland has declined from about 40 000 ha in the mid-18th century to about 7 000 ha (Webb and Haskins, 1980; Webb, 1990; Rose et al., 1999). Most remaining heathland is subject to legislation designed to protect, conserve, and manage biodiversity. Almost everywhere, traditional uses of heathland have ceased and, as a result, heathlands disappear under scrub and trees. To conserve them, they must be actively managed, but commonly, the management has been insufficient.

4.2.2.6 PRESSURE ON HEATHLANDS

In Dorset in the 19th century, the major loss was to urban development. In the 1920s, planting by the Forestry Commission began, and there was further expansion in the 1950s and 60s. The loss of heathland has continued until the present time, but the losses are now small (Moore, 1962; Webb, 1990).

Veitch et al. (1995) found that of the former heathland in Dorset, 7 769 ha (21 per cent) had been converted to arable land, 7 290 (20 per cent) to grassland, 5 760 ha (16 per cent) to coniferous woodland, and 3 642 ha (10 per cent) to deciduous woodland. Urban land now occupies 4 429 ha (12 per cent). Between 1978 and 1987, losses to farming and forestry were small and the main losses were to various forms of development which fell outside the control of planning or wildlife legislation (Webb, 1990). Since that time, with a more rigorous application of the legislation, the losses have been small.

However, losses due to inappropriate or inadequate management and public pressure have increased. In the past, heaths were part of the agricultural system. This involved grazing, regular burning, cutting of vegetation for fodder, animal bedding and fuel, and the cutting of peat and turf. All of these activities prevented scrub and tree invasion and helped to deplete nutrients. To maintain heathland, these activities must continue. Nevertheless, conservation agencies have been slow to implement the necessary management and, since 1978, the rate of scrub and tree invasion is estimated as approximately 1.7 per cent per year (Webb, 1990; Rose et al., 1999), with further loss of heathland.

Public pressure, especially fires, arising from the local population and tourists can be a problem. This is particularly the case on the urban-fringe heathlands.

4.2.2.7 Potential for Restoration

Introduction

Clay extraction in Dorset was formerly small scale and many old pits now have a diverse topography with small pools and regeneration of heathland, and several are notified as SSSIs. In recent years, the area worked has increased with mechanisation. This difference in work necessitates active measures if heathland is to be re-instated.

Dorset heathland is described by Moore (1962) as "the whole complex of plant communities which are associated with the poorer sandy soils…". "It not only includes areas dominated by *Calluna* and *Erica* species, but also valley bogs, pine heath, thickets of *Ulex*, and *Agrostis setacea* and *Molinia* grasslands". Within this range, there is a smaller scale pattern resulting from variations in topography and soil moisture. Reproducing this topographic variation is important to ensure a full range of heathland species, and should be a feature of all reconstruction schemes. Some key species which are a feature of the Dorset heathlands require mixtures of different heathland elements. For instance, the Grayling butterfly requires both hot bare sandy areas, which are a component of dry heath, and also a proportion of fine-leaved grasses in the heathland vegetation as the larval food plant. Similarly, Dartford Warblers require both gorse scrub and open mature heather to provide their full habitat, and while Nightjars nest on heathland with scattered trees, the birds seek food over adjacent woodland.

The Potential for Reconstruction in Dorset

There is now considerable potential for increasing the area of heathland and reducing its fragmentation. English Nature has drawn up a re-creation plan (Rose and Webb, 1995) in order to assess the contribution that Dorset could make to the National Biodiversity target of 6000 ha of new heathland. In an area of 20 819 ha of former heathland, Rose and Webb (1995) identified 2091 ha to improve the continuity and quality of existing patches of heathland. In Dorset, some 332 ha of heathland are adjacent to active workings, and nearly 100 ha of heathland are abandoned workings.

Methods of restoration

There are two components to a restoration scheme. First the creation of an appropriate topography and its associated hydrological regimes. This establishes the underlying landscape form. This element has been neglected in many restorations where unimaginative schemes have tended to use flat or uniformly sloping surfaces. Secondly, there is the establishment of the plant and animal community. This may meet broad landscape objectives with the establishment of a mosaic of heather, gorse scrub, pine heath, grasslands and wet heath areas similar to Moore's (1962) definition. Or, it may be a more active attempt to enhance biodiversity and create communities of significant conservation value. In some instances, reconstructed areas may be of the former type, but in biological-rich south-east Dorset, the emphasis should be on the latter, with restoration of both landscape and its biodiversity.

To date, most restorations have been to dry heathland because it is possible now to grow dwarf shrubs, particularly *Calluna*, relatively easily (Putwain and Rae, 1988). However, a sward of *Calluna* is not a heathland. It may be acceptable in landscape terms, but may make a small contribution to biodiversity. Many components of the vegetation and fauna will be lacking. Often, it is assumed that animals will colonise once the plant community has been established. However, the success of establishing the plant community may depend on animals at an early stage, for instance as pollinators or seed dispersers. What are also important are the topographic relationships in heathland systems.

Throughout the area, there are many examples of large and small-scale, mostly *ad hoc*, restorations, but few have been set up as properly designed experiments from which statistically valid conclusions can be drawn. The wide range of examples shows an equally wide range of successes and failures. There has been no thorough review of these trials and most conclusions are anecdotal and lack generality.

In a replicated series of plots at Master Pit South, Pywell et al. (1996) tested applications of topsoil at three rates, and heather, together with a fertilizer application and a locally grown nurse grass mixture. Both sources of propagules, collected nearby from South Heath, contained a range of dry heath species and after 30 months, the topsoil provided the best cover of heathland species. Both propagules contain the main heathland species, but some species were poorly represented in the harvested shoots. Low applications of fertilizer were beneficial to heather growth. The companion grasses did not appear to enhance the early establishment of heather, but where native grass was included, the appearance of the site improved. Significantly, the presence of nurse grasses suppressed the establishment and growth of Purple moor grass (*Molinia caerulea*) (Pywell and Webb, unpublished data).

In restoration, the important stages are: defining the community to be restored, site preparation, selection and sources of propagules, methods of application, and aftercare. Failure may occur at any stage. Furthermore, success or failure may depend on year-to-year variations in the weather. Inappropriate site preparation, often in combination with the weather, may prevent the germination of heather seed. Failure to germinate needs to be distinguished from a failure to establish, when seeds germinate, but seedlings soon die, often due to drought. This may be a result of the weather conditions or inadequate site preparation.

On some sites, invasive species such as gorse, purple moor grass and soft rush may become a problem. Once established, they may be difficult to control. It is not certain why these species dominate in some sites and not in others.

On most lowland heathland, botanical diversity is greatest in wet areas, yet we have little experience of re-creating wet-heath vegetation. However, IMERYS Minerals carried out a wet-heath translocation experiment in 1993, with the removal of about 1000 m^2 from Doreys pit to Gadle Knap, a ball clay pit last worked in 1977. Monitoring indicates that it has responded well to the new hydrological regime and shows the importance of hydrology in relation to topography.

In some instances, reconstructing heathland on disused workings may not be the best option. It might be better to restore other types of vegetation, such as forestry, grassland or agricultural land, and to restore heathland elsewhere to compensate for that lost during mineral working. Existing forestry, especially conifers, and abandoned farmland are the most likely areas for this activity.

Coniferous woodland on former heathland produces few detrimental soil changes. The soil remains predominantly acid and has a similar nutrient status to the original heathland soil. A substantial seed bank of *Calluna* often remains beneath conifers, even after 70 years.

The method of restoration is simple and has been pioneered by the RSPB (Auld et al., 1992; Woodrow et al., 1996). Trees are cut close to the ground and removed. Leaf litter is swept up and sold to offset management costs. This exposes the soil surface and sufficient seed bank remains to produce good regeneration of heather after about 5-6 years. The RSPB showed that in 1996, areas restored had a cover of some 21.5 per cent of *Calluna* and 18.3 per cent of *Erica cinerea*. Sites restored some 10 years before had cover respectively of 72 per cent and 11 per cent.

Early stages of succession are often dominated by bryophytes and over the first 5 years or so, estimates indicated a bryophyte cover of about 20 per cent. Problems were caused by the introduced species *Campylopus introflexus* which produces a dense carpet which inhibits heather seedling regeneration. Only when this carpet breaks up does heather establish.

RSPB management has shown a substantial increase in rare heathland birds. There is less information on plants, but species such as *E. ciliaris* have established in some areas.

Little is known about restoring heathland on areas of deciduous woodland. Many heathlands in southern England have been invaded by birch, with consequent soil changes. Any restoration will first have to create the correct soil conditions for heathland. In other areas of deciduous woodland, trees such as oak are likely to be long-lived and no heathland seed bank will remain.

Chapman et al. (1989) showed a clear relationship between phosphorus and vegetation change on these heaths. Where phosphorus adsorption capacity was low, there was a tendency to remain as open heath, but where it was higher, there was a tendency for birch invasion. Mitchell et al. (1997) have shown that there is increasing phosphorus where birch has established. However, once phosphorus has been elevated, after clearance, such sites may be prone to reinvasion by birch.

With farmland, we need to know when was it converted from heathland and how was the land managed; in particular, what fertilizers and minerals were added. In some instances, pH and phosphorus will decline with time if not too high initially.

The next step is to determine whether propagules of heathland species still exist, whether they occur nearby and could colonise naturally or whether they must be introduced. Pywell et al. (1997) showed that after 20 years of arable cultivation, an appreciable heathland seed bank could remain. This, as expected, is predominantly *Calluna,* but other species may occur, including *Erica cinerea*, *E. tetralix*, and *Agrostis curtisi*; *Ulex minor* often abounds. The seed banks are small and distributed more uniformly down the soil profile than in intact heathland soil, but are adequate for natural regeneration of heathland.

If such fields are left, some 12-15 years after abandonment, heather and other heathland species begin to appear. Gradually, a mixture of heather and grassland develops which can have a high conservation value of its own. This relatively uncommon community is particularly attractive to many heathland invertebrates.

4.2.3 Wetlands

Wetlands include those areas fringing Poole Harbour and comprise shallow waters, mud flats, salt marsh and reed beds which gradually grade into one another, and inland, wet heath and mires. Poole Harbour extends to some 3800 ha, including 1755 ha of inter-tidal mud flats and about 700 ha of salt marsh.

In Poole Harbour, the extent and diversity of wetland habitats and numbers of associated species have experienced some dramatic changes. These changes and losses have been caused both by human activity and natural processes. For example, *Spartina* salt marsh, which now forms a significant environmental resource, was unknown until 1890, following which it rapidly expanded to its peak in the 1920s. Subsequently, its extent has reduced, probably due to the species reaching equilibrium in the environment.

Reed beds of the area are significant. They have a diverse wildlife interest and are amongst some of the most important habitats for birds in the UK. Reed beds suffer problems from natural succession to scrub and can be affected by grazing and salinity changes.

Poole Harbour, with its extensive intertidal areas and graduated change from sea water to fresh water, provides numerous habitats. The disposition of bays and channels with islands and the small tidal range with double tides and limited flushing conditions enhances the habitat variety.

Apart from reed beds, which frequently will naturally regenerate in wet mineral workings, re-creation of these habitats is impracticable.

4.2.4 Woodlands

Broad-leaved trees, many of which are over 250 years old, occur in the area as scattered woods or as individual stands and are important in extending the range of habitats in the area. According to the level of management, they provide environments for many animals and plants. Woodlands are particularly important for epiphytes and fungi, saproxylic invertebrates and can provide roosts for bats and hole-nesting birds. Woodland may also moderate climate and provide shelter in severe conditions for non-woodland species. Species which roost in woodlands may rely on adjacent heath and grassland for feeding. This relationship is important and reflects the need to assess the total habitat and any changes.

Restoration of woodland in terms of providing a mature diverse fauna and flora is a long-term process. While planting techniques are well known, more than 200 years may be required to produce a mature stand with fauna and flora ecosystems of nature-conservation value.

4.2.5 Rivers

The area is traversed by two of the highest quality chalk rivers in southern England – the rivers Frome and Piddle. These rivers rise high on the Chalk and flow across the

Palaeogene deposits to discharge into Poole Harbour. They are classic chalk streams with stable flows and a constant year-round temperature. This results in them being warm in winter and cool in summer. The filtration of surface run-off through the chalk results in water of great clarity. The higher reaches of these rivers and their tributaries are winterbornes with seasonal variations in their spring sources. The Frome and Piddle are fed by several chalk streams, but where they cross the Palaeogene deposits, they receive surface run off which is acidic and less clear. This results in more rapidly changing water levels and variations in turbidity. Surface run off is modified where there is mineral extraction and development adjacent to the rivers. Suspended solids may be removed in settlement ponds, but colloidal clay may remain and affect water quality. In the past, water from these rivers was diverted into floodplain 'water' meadows to increase their fertility. Where they have not been agriculturally improved, these derelict meadow systems and associated wetlands are now botanically diverse and rich in insects and other arthropods. The rich insect fauna gives rise to a rich avifauna which may be supplemented seasonally by migratory species for which the riverside vegetation is important. The Frome and Piddle are noted fish rivers, particularly for salmon and trout. Over the last years, both the numbers of fish migrating in to these rivers and the numbers caught have declined. Salmon and Migratory Trout occur in the middle and lower reaches, while Brown Trout occur in the upper reaches. The proportion of coarse fish is greatest in the lower reaches and some marine species may occur in the lowest reaches. Otters, which declined dramatically due to the effects of pesticides and habitat loss, occur on both rivers, and numbers are slowly increasing following active conservation measures.

The River Frome and its flood plain in the area is notified as an SSSI.

4.2.6 Grasslands

In the area, a range of grasslands exist. Besides agriculturally managed grasslands, the semi-natural grasslands fall into three main groups: dry acid grasslands associated with heathland, grasslands in the flood plains of the rivers, and wet grasslands in the lower reaches of the flood plains and margins of Poole Harbour.

Dry acid grasslands are a biotope closely associated with heathland and may contain a small proportion of heathland species. These grasslands are scarce, both locally and nationally. Many have been lost as a result of agricultural reclamation. Paradoxically, the recent decline in agriculture has resulted in the abandonment of these reclaimed heathland areas and their reversion to acid grassland or heathland. In some cases, these grasslands will be included in heathland SSSI boundaries. Many of the rare plant species of dry sandy acid soils are more associated with these grasslands than with dry dwarf-shrub heath. There are several such species (Byfield and Pearman, 1996) which have suffered severe declines largely as a result of habitat loss. Protection of the remaining grasslands of this type, together with habitat-creation schemes, is a conservation priority. Associated with these dry acid grasslands are wet-flushed areas noted for their flora which occur on the fringing Palaeogene clays.

The grasslands of the flood plains are significant. They tend to be neutral, over which seasonal irrigation was managed to take advantage of the nutrient-rich, relatively warm, water from chalk streams. The drier areas may contain hay meadows and, where not 'improved', have an extremely rich and attractive flora. Particularly good examples occur along the Corfe River. The lowest reaches of these rivers and areas surrounding Poole Harbour contain wet grasslands maintained by grazing. These may also be floristically rich and, where not 'improved', their varying degrees or wetness results in significant invertebrate populations which provide food for wildfowl and wading birds. These grasslands are important both as breeding areas and for feeding, particularly outside of the summer. These feeding areas for shore birds are an important supplement to the intertidal feeding areas in Poole Harbour, because the double tide in the Harbour often restricts the use of intertidal areas.

4.2.7 Open Water

Naturally occurring open water is rare in Dorset. Most is derived from human activity, especially mineral extraction. Many old clay pits have regenerated into attractive areas, often showing considerable diversity due to differences in soil type and topography. Many have a rich flora and invertebrate fauna and have been notified as SSSIs. Open water around Poole Harbour may be important for wildfowl and waders.

5 Current Planning Policy

5.1 BACKGROUND

Current policies relating to mineral conservation and development, and the protection and enhancement of the environment, other resources and amenity are primarily contained in planning legislation. This mainly has national and local components, although international and regional structures and policies may have an increasing impact. The objectives of statutory environmental agencies and landowners may significantly influence the development pattern. However, it is the planning process which integrates all these interests and is required to make a balanced decision on the development of land in the public interest and in accordance with sustainability.

5.1.1 Sustainability

Sustainability objectives (Anonymous, 1999), are a key concept which underpin the whole approach of the UK's planning system at both local and national level. The objectives stress the importance of integrated policies in meeting four broad objectives which need to be addressed equally:

- social progress which recognises the needs of everyone;
- effective protection of the environment;
- prudent use of natural resources; and
- maintenance of high and stable levels of economic growth and employment.

Thus economic growth needs to take place in a way that ensures effective protection of the environment and prudent use of resources. Meeting this challenge is not easily achieved and it is often difficult for the planning system to balance economic objectives with societal-environmental demands. The UK cannot consider its sustainability actions in isolation and decisions must take account of implications on the economy and environment of other nations. Sustainability, therefore, requires us to ensure an adequate provision of minerals to support downstream manufacturing industries in the UK and, where relevant, to industry in other nations dependent upon resources available in the UK. Developing our indigenous mineral resources to support British industry is important not only in producing value-added output and supporting jobs, but also in providing essential raw materials for downstream industries. Exports of both minerals and mineral-derived products also assist the balance of payments. However, mineral resource development options may become more constrained and sustainability objectives will be more difficult to maintain in the future

5.1.2 Biodiversity

The objectives of local, national and international policies with regard to nature conservation is to conserve and manage habitats and associated species, both to maximise conservation objectives and increase biodiversity. In that context, several habitats in the area have been identified as being biodiversity priority areas. This requires action to increase the extent of habitats and thereby assist the viability of the habitat type and associated species. Given sufficient time and resources, it may be possible to re-create a number of the valued habitats in the area.

The requirement to increase biodiversity land is not formalised and there is no guidance as to what land should be given priority. If land is subsequently developed for biodiversity re-creation, then it would not benefit from current statutory protection during this process. Management provisions would normally prevent such land being made available for development, including mineral extraction, but it may be desirable to ensure that such areas are identified and protected through policies, otherwise targets may not be achieved.

5.1.3 National Planning Guidance

At national level, the Town and Country Planning Act 1990 is the primary legislation which, together with associated Acts, defines the process and considerations to be taken into account in determining broad objectives and also decisions on particular proposals. Section 54A of the Act makes it clear that planning applications for development are to be determined in accordance with the development plan, unless material considerations indicate otherwise. In addition, sustainability objectives must be addressed in planning policies.

Supporting and clarifying these objectives are Statutory Instruments, Circulars and Planning Guidance (PPGs), which may relate to aspects of all development, Regional Planning Guidance (RPGs, which will be developed further to assist new regional planning structures) and Mineral Planning Guidance (MPGs), which are specifically focused on mineral planning.

Requirements and advice in several PPGs have a bearing on mineral and other development or conservation objectives. Of overall importance is PPG1 General Policy and Principles (Anonymous, 1997) which defines the key roles of the planning system and refers to the need to provide development consistent with the principles of sustainable development, the need for the process to promote competitiveness and for consistent, predictable and prompt decision making. The significance of the 'plan led' system in defining decisions is explained, as is the need for the development plan to be up-to-date. Other PPGs refer to matters such as Green Belts (PPG2), The Countryside (PPG7), Nature Conservation (PPG9) and provide detailed advice on such matters.

MPG1 'General Considerations and the Development Plan System' (Anonymous, 1996) sets out the principles and main planning objectives for all minerals. It requires MPAs to recognise the importance of maintaining, through development plans, a continuing supply of non-energy minerals for the plan period, and such defined landbank period, the need to safeguard and conserve mineral deposits as well as other associated matters. MPG1 also identifies the availability of advice for specific minerals, either in separate MPGs or in MPG1 itself. Development plan and landbank periods vary. A plan period must cover at least 10 years and a review should be completed every 5 years. Landbanks vary according to the mineral and may relate to a ‘shire’ county area, a group of planning authorities or may be site specific.

In relation to the project area, advice on aggregates supply is contained in MPG6 ‘Guidelines for Aggregates Provision in England’ (Anonymous, 1994), which identifies the anticipated requirements by regions, the necessary landbank of 7 years, (normally for a ‘shire’ county), and takes account of imports, exports and recycled aggregates. MPG15 ‘Provision of Silica Sand in England’ (Anonymous, 1996) also identifies future requirements but, due to the nature of the deposits and their locations, specifies a more flexible approach to landbanks, although a minimum of 10 years should be maintained at each site.

There is no specific guidance on ball clay, except general guidance contained in MPG1 which states that the mineral has a limited occurrence. It is important, therefore, that adequate reserves are provided for the long term and that ball clay bearing-land is not unnecessarily sterilised. Landbanks for ball clay are not defined in MPG1.

MPG1 identifies that common clay ("brick clay") resources and products vary widely and that MPAs should have regard to these variations and the aesthetic qualities of products.

5.1.4 Local Planning Policy

In the area, the development plan consists of the Structure, Local (prepared by district councils), and Minerals and Waste Local plans. Normally, where there is conflict between provisions in these plans, the latest adopted plan has precedence. Poole Borough Council, now a unitary authority, will follow the existing Local Plan and Structure Plan. Policies for minerals and waste will continue to be included in a minerals and waste local plan covering the whole of Dorset. Development plans should be generally consistent with national and regional policy.

The Structure Plan sets out broad strategic guidance in relation, *inter alia,* to the provision and protection of minerals, and protection and enhancement of the environment. Detailed mineral issues are dealt with in the Minerals and Waste Local Plan (Dorset County Council, 1999). This sets out policy and allocation issues for minerals, and confirms the desirability of ensuring that mineral development does not harm the environment or amenities. Provision for future supplies are identified alongside policies to encourage the development of alternative sources, recycling and the prevention of sterilisation of mineral deposits. Local Plans may have a bearing on mineral development decisions by allocations for other development, and by policies to protect the environment and other resources.

Government policy also supports the prevention of sterilisation of mineral resources. Of primary significance in relation to ball clay is the provision for consultation on development which may sterilise ball clay in the Ball Clay Consultation Area. Aggregate and industrial mineral consultation areas have also been defined.

The main thrust of policy at local level reflects considerations for each mineral. There is no specific policy requirement at local level in relation to industrial sand and common clays. However, general policies would restrict the potential for their extraction in the AONB or in other major designations. The policy towards sand and gravel reflects the size of the landbank and the relationship to the development plan timescale. There is a continuing shortage of available gravel, and policies are directed towards maintaining a reserve in accordance with national guidelines. The situation for construction sand is different, in that reserves are significantly larger and, therefore, the policy framework is not to provide for further reserves.

In the Minerals and Waste Local Plan, specific proposals are set out for ball clay. This takes the form of a strategy with the long-term objective of moving ball clay extraction from the AONB to north of the River Frome, subject to detailed assessment of other designations and impacts. This is a long-term strategy and, in the interim, provision is made through Preferred Areas for some extensions in the AONB. The strategy itself is not set out in a policy, but forms the reasoned justification for the policies and allocations in the Plan. The Strategy, but not a policy, also identifies the desirability of maximising resources in the area outside the AONB by beneficiation and the potential for the reduction in specifications. These objectives are supported by a policy allocating all the Ball Clay Consultation Area outside the AONB as an Area of Search, and seeking to ensure that high-quality ball clays are restricted to uses requiring such quality material.

5.1.5 Planning constraints

The major planning constraints in relation to the development of the mineral resources in the area are the statutory nature conservation and landscape designations at national and international level.

Guidance in the definition of certain planning constraints indicates that it should include land which may, by association, relate to the purposes of the designation. The extent of an SSSI should, for example, include all that land which may lead to impacts on the designated interest, such as by groundwater flows. It is unclear if that position currently always applies in the area.

5.1.5.1 NATURE-CONSERVATION DESIGNATIONS

The area has an exceptionally high concentration and coverage of statutory national and international nature-conservation designations (see Table 1 and Figure 2). These include Priority SAC, SACs, SPAs, Ramsar sites, NNRs and SSSIs. In addition to the national and international nature-conservation designations, there are local, non-statutory, designations. These are principally Sites of Nature Conservation Importance (SNCI) identified by the Dorset Wildlife Trust and form relevant considerations in planning policies. Many are of a limited extent and may cover, for example, narrow belts of heathland adjoining forest roads. It is recognised that these areas may be important as planning constraints, but principally at a level of detail not considered in this report.

Figure 2 demonstrates the concentration of the main national and international designations over extensive areas around Poole Harbour. North of the Frome, significant areas are found running westward on the eroded plateau between the Sherford, Piddle and Frome rivers. There are also important areas on the Chalk ridge to the south.

Development which may impact on international designations would only be permitted after a rigorous examination of the proposal, and after it has been demonstrated, either that the development would not adversely affect the interests, or where there are imperative public-interest reasons why it should be permitted. There should be no acceptable alternative site. Where a priority site is affected, development will only be permitted if it is shown to be necessary for public safety, human health or where other environmental benefits may accrue.

In national designations, a proposed development will also be rigorously examined and must demonstrate that the social, economic or other environmental benefits of the proposal outweigh any impact on the purposes for which the area was designated.

Development in non-statutory designations is subject to the provisions of a local policy, but generally will not be permitted unless the benefits of the proposal outweigh the nature conservation interests

5.1.5.2 Landscape Designations

The landscape qualities of the area are nationally important and a major consideration in the planning process. Nearly all the area south of the River Frome downstream from Wool forms part of the Dorset AONB. This includes the southern shores of Poole Harbour, and the dunes and lagoons around Studland.

The primary objective of the AONB designation is the conservation of the landscape. Policies in relation to the AONB are, therefore, concerned with its conservation, having regard to social and economic considerations.

The qualities of the coastal landscape in the AONB have been recognised by their inclusion in the Heritage Coast, parts of which in the area include the Frome/Piddle confluence below Wareham and the southern shores of Poole Harbour from the Wareham Channel to the Wareham-Corfe road. The planning objectives of the Heritage Coast are focused on conserving and enhancing the landscape qualities and encouraging the adoption of management practices to assist those objectives.

Local landscape designations are defined by the local planning authority and should represent areas of landscape which have a local value over and above that of the countryside as a whole, which itself is required to be protected. The definition of these local areas is not consistent between authorities; one authority, Purbeck District, has chosen not to define such areas. Due to the varying basis for their definition, such areas are excluded from this study, but nevertheless, they are a relevant consideration in policy and decision processes.

The area forms the western half of the East Dorset and Poole Basin Landscape Character Area based on advice in PPG7 to help to describe a broad area so as to ensure that development relates to, or enhances, that character. That part of the area in the Purbeck District south of the A35 falls in the Purbeck Heritage Area where the District Council has developed a strategy which includes provisions to preserve and enhance landscape and environmental qualities. Neither area forms further planning designations, but they provide a context for evaluation of the countryside and subsequent reviews of designations.

Development which may impact upon the AONB will only be permitted after a rigorous examination; in general, major commercial development would be inconsistent with the designation. The lack of alternative sites and requirements of national interest can justify permission, but subject to appropriate operational and restoration standards.

Local designations carry less weight than national ones and local authorities should only maintain such designations when normal planning policies cannot provide protection as part of the general countryside conservation. It is important that these designations do not unduly restrict development, without identifying the particular features of the local countryside which need to be respected or enhanced

Landscape and environmental-management strategies are not planning designations, but requirements of such strategies should be reflected in development proposals.

5.1.5.3 Green Belt

Most of the area north-east of Wareham is included in the South East Dorset Green Belt. Mineral extraction need not be inappropriate development in the Green Belt, provided that high environmental standards are maintained and the site is well restored. Extraction operations should, where possible, contribute to the achievement of the objectives for the use of land in the Green Belt (as set out in PPG2, para 1.6).

5.1.5.4 Scheduled Ancient Monuments

There are numerous Scheduled Monuments in the area (Figure 3) which may produce potential constraints on mineral working. In the environmental assessment of a mineral site, the largest single expenditure is commonly archaeology. The possibility of acquiring consent to remove a monument depends upon the significance of the monument and the value of the mineral resource constrained. Excavation and removal of a monument is a last resort, but the impact on mineral resources may be significant. There is no major pattern to the distribution of these features, except linear structures such as Battery Bank along the plateau between the rivers Piddle and Frome and which may form a major limit to working in that area.

5.1.5.5 Conservation Areas

The Planning (Listed Buildings and Conservation Areas) Act 1990 requires local planning authorities to consider which parts of their areas are of special architectural or historic interest, the character or appearance of which is desirable to preserve or enhance. These areas are then designated as Conservation Areas. Such areas mainly occur around settlements, but may also include surrounding open land to reflect their setting. Mineral operations may accord with these objectives as they may be temporary activities leading to a long-term enhancement. The position of more extensive long-term operations may be more difficult.

5.1.5.6 Agricultural Land

Agricultural land is classified according to the extent to which its physical or chemical characteristics impose long-term limitations on agricultural use. Limitations may affect the range of crops that can be grown, the level and consistency of yield and the cost of obtaining it. Flexibility of cropping is an important consideration, and the ability of some land to produce consistently high yields of a relatively narrow range of crops is also taken into account.

The principal physical factors influencing agricultural production are climate, site and soil. In some situations, chemical properties, such as high levels of toxic elements, or extreme subsoil acidity, can influence the long-term potential of land and are taken into account. These factors, together with interactions between them, form the basis for classifying land into one of five grades (the Agricultural Land Classification); Grade 1 land being of excellent quality, to Grade 5 land of very poor quality. Grade 3, which constitutes about half the agricultural land in England and Wales, is divided into Sub-grades 3a and 3b. Lower grade land may be significant in terms of farm structure or viability, or for its environmental value.

Government policy provides protection from development for Grades 1, 2 and 3a agricultural land. This is set out in PPG7, paragraphs 2.17 – 2.18 (Anonymous, 1997), which states that within the principles of sustainable development, the best and most versatile agricultural land (defined as Grades 1, 2 and 3a) should be protected as a national resource for future generations, and development should be steered away from such land. However, MPG7 paragraph 3 (Anonymous, 1996) indicates that the achievement of high standards of restoration may lead to the release of the best and most versatile land for mineral working.

The Agricultural Land Classification Grades shown on Figure 3 are based on provisional data and are only suitable for strategic purposes to provide a broad indication of likely grade. They do not show Grades 3a or 3b, as the data upon which they are based do not include a breakdown of Grade 3. Figure 3 shows that, based on provisional data, there is only Grade 2 and apparently no Grade 1 land in the area.

Grade 2 and 3a agricultural land is restricted to the lower gravel terraces of the Frome, but detailed site assessment in the West Knighton area has indicated some Grade 1 land. This assessment was undertaken in accordance with proposals for the shallow extraction of terrace gravels. Those proposals included provisions for the restoration of the land to pre-existing grades and therefore complied with the provision that the best and most versatile agricultural land should not be lost. Restoration has been successful and has increased the availability of high-grade land and agricultural productivity.

While such temporary and shallow mineral workings may not harm an agricultural resource, more extensive and long-term operations, and those which may alter ground levels significantly in relation to the permanent water table, may not comply with the requirement to maintain and protect agricultural land.

5.1.5.7 GROUNDWATER PROTECTION ZONES

The area is not an important source of groundwater, although the fringes of the area are underlain by groundwater sources. Aquifers are vulnerable to contamination from many human activities (agriculture, urbanisation, industry, waste disposal and chemical spillages) making groundwater resources increasingly threatened. The protection of aquifers from pollution is therefore very important, as restoration of contaminated groundwater to its original quality is difficult and expensive.

Protection zones have been defined around sources, in which some activities or processes are prohibited or restricted. Source-protection zones vary in size and shape according to the nature of the aquifer, rainfall, land use and amount of water pumped. Three zones have been defined for each source: an inner protection zone, an outer protection zone, and the total catchment area (the entire area from which the groundwater source derives its supply) (Downing, 1998). There are several large water supplies from Chalk sources around the margins of the project area, although only parts of the zones fall in the study area and tend not to coincide with the Poole Formation crop.

However, protection is required for all aquifers, not just the parts falling in source-protection zones of currently operating abstractions. Groundwater vulnerability maps indicate where groundwater is potentially at risk from polluting activities.

Numerous solution-collapse hollows occur on Palaeogene strata overlying Chalk at shallow depth in the Lytchett Matravers area (Bristow et al., 1991, fig. 27) and farther west near Bere Regis, on Affpuddle Heath, and in Puddletown Forest. In those areas, the potential for pollution to reach the Chalk is higher than normal.

In Protection Zone areas, restrictions may apply to the depth of working and may require the provision of balancing lakes to take account of any reduction in recharge into the Chalk aquifer. This consideration currently affects workings in the solid sands around the northern and western sections of the area and may provide a fundamental restriction on deepening existing quarries or opening new deep quarries in these areas.

5.1.5.8 FORESTRY

Commercial forestry and woodland does not represent a planning constraint, but may represent an economic and land-use constraint. However, mineral working and forestry can be incorporated into a mineral development programme, such that workings will be restored to forestry. Large parts of the area are commercially forested. This includes a significant part of the host clays in the north. Forestry, basically, replaced poor quality agricultural land or heathland and would revert, in many cases, to heathland if clear felled. Figure 3 shows the extent of Woodland Grant Schemes and Closed Schemes administered by the Forestry Commission, and also commercial forestry managed by Forest Enterprises for the Forestry Commission.

6 Resolving the Planning Issues

The research has identified the extent and nature of the mineral, environmental and other resources in the Wareham Basin. For the first time, it provides a basin-wide strategic baseline from which planning structures and policies can be prepared, and against which nuances of policy and consideration of mineral-extraction proposals can be tested in relation to developing national and local environmental objectives for sustainability and, of particular importance to the area, biodiversity.

6.1 RESOURCES AND THEIR RELATIONSHIPS

The assessment of the economic minerals in the Basin shows the following broad situation.

- There appears to be no significant variation in the properties of the sand deposits across the Basin, although there are significant local variations
- There are significant variations in the characteristics of the host clays and the contained ball clays across the Basin. The main variations are:
  (a) thinning towards the north and west
  (b) increased staining to the north, east and west
  (c) lowering of kaolinite content to the north, east and west
  (d) variations in quality between ball clays in each host clays
- There are significant local variations in the terrace gravels, but no particular trend across the basin
- The common clay resources thicken eastwards

Mineral resources and their potential for development may be considered in relation to the outcrop of specific resources, e.g. Creekmoor Clay, and any planning constraint over their outcrop. However, some mineral resources may be overlain by other deposits, (e.g. a host clay may be overlain by terrace gravels) and the relationship between mineral extraction and the potential for conflict with other objectives also includes consideration of the subcrop. The inter-relationship between the various mineral resources and the main statutory designations are shown in Tables 7 and 8 and Figures 36 to 39.

6.1.1 Creekmoor Clay

Virtually all the main outcrop is in the AONB and much of it is in major conservation designations and Ministry of Defence ranges. The northern part lies beneath the flood plain of the River Frome. Parts of the outcrop are currently under commercial forestry, but no significant high-grade agricultural land is thought to be affected.

Three broad subcrop areas of marginal exploration prospects are identified in Chapter 3 north of the River Frome and outside the AONB: Wareham Forest, the Wool-Bovington area, and Bere Heath. However, nature-conservation designations (from local to international level), other land-use and resource considerations affect these areas to varying degrees. Prospects north of the Frome have no less impact on environmental considerations than areas in the AONB.

The areas identified above lie at a relatively shallow depth. However, overburden, which will include waste, Oakdale Clay, and possible saleable mineral (construction sand) still exceeds 20 m, placing the deposit at or beneath OD. Similar considerations apply to the Creekmoor Clay south of the Frome and south-east of the outcrop between Wareham and Creech. There, however, the size of extraction operations to gain access to the generally deeper (>35 m) host clay, would be significantly more extensive and thus have a greater visual and environmental impact.

It appears, therefore, that due to quality and operational requirements, the main potential for developing Creekmoor Clay is at or near outcrop south of the Frome and west and south west of Wareham in the AONB.

6.1.2 Oakdale Clay

The Oakdale Clay forms the main surface and shallow subcrop clay in the area north of the Frome and outside the AONB. Much of this area is overlain by forestry and generally poor-grade agricultural land, but the extent of overburden is variable. The remaining area includes land designated as of international nature-conservation importance which precludes most mineral operations and may inhibit the extraction of mineral on adjoining land because of impacts on groundwater. Chapter 3 has identified prospective areas at Woolsbarrow, Stokeford Heath, Coldharbour and Holton Heath, and around the currently dormant operations at Binnegar. The data, however, indicate that the Stokeford, Coldharbour and Holton Heath deposits are of poor quality, although sites at Woolsbarrow and Binnegar have been proven at a level which indicate encouraging prospects. However, nature-conservation designations and physical constraints may inhibit the full development of these prospective areas.

Oakdale Clay also crops out at Arne and occurs at subcrop in the south and east of the area. There, the clay occurs at depths exceeding 20 m, but displays better quality characteristics. However, as the area is overlain by numerous designations, the potential for working is severely constrained.

The main prospective areas are, therefore, north of the River Frome, but operations would be relatively extensive and may impact upon designations. Current policy for this area, while supportive of ball clay operations due to the Area of Search allocation, also seeks to limit the landscape impact of such operations. This may conflict with extensive operations.

6.1.3 Broadstone Clay

Broadstone Clay is mainly found in the AONB between Creechbarrow and Studland along the southern boundary of the Basin. There, limited areas unconstrained by nature-conservation designations may be found. Where the host clay is at or near outcrop, operations may not need to be extensive. North of the Frome, there are outliers at Trigon and Stokeford Heath. The Trigon deposit represents a prospective area, but is subject to nature-conservation designation constraints.

Table 7 Inter-relationship of mineral resources and selected statutory designations in the Wareham Basin (to High Water Mark)

Mineral Resource	Total Area	Area covered by AONB		Area covered by SSSIs		Area covered by AONB or SSSIs	
	(ha)	(ha)	%	(ha)	%	(ha)	%
Ball clay host clay at surface							
Parkstone Clay	617	467	76	210	34	479	78
Broadstone Clay	3310	2513	76	1416	43	2633	80
Oakdale Clay	2247	387	17	659	29	835	37
Creekmoor Clay	1464	1223	84	577	39	1274	87
Ball clay host clay at subsurface							
Parkstone Clay	377	301	80	211	56	317	84
Broadstone Clay	3166	2421	76	1311	41	2640	83
Oakdale Clay	4140	653	16	1000	24	1213	29
Creekmoor Clay	1745	1080	62	645	37	1322	76
Poole Formation sands	15014	4722	31	3794	25	6294	42
Sub-alluvial sand and gravel	3317	1392	42	1492	45	1890	57
River terrace sand and gravel	7868	1582	20	803	10	1995	25

Table 8 Environmental constraints on resource areas

Host Clay	Prospective area	Environmental constraints
Parkstone Clay	• Trigon	• Outside AONB
	• Creech	• Within AONB
Broadstone Clay	• Hartland Moor	• In AONB, and SPA/SAC
	• Newton Moor	• In AONB, adjacent to SPA/SAC
	• New Mills South	• In AONB
Oakdale Clay	• Woolsbarrow	• Outside AONB but adjacent to and fragmented by SPA/SACs and Scheduled Monuments
	• Stokeford Heath	• Outside AONB and largely unconstrained (a)
	• Cold Harbour and Trigon	• Outside AONB and largely unconstrained (a)
Creekmoor Clay	• North of Povington pit	• In AONB and SPA/SACs
	• Holme Priory, Doreys pit to Stoborough	• In AONB and fragmented by SPA/SACs and Scheduled Monuments
	• East and west of Norden	• In AONB
	• Wareham Forest	• Outside AONB, partly fragmented by SPA/SACs
	• Wool-Bovington	• Outside AONB, partly fragmented by SPA/SACs
	• Bere Heath - Bloxworth	• Outside AONB, largely unconstrained (a)
(a) Largely unconstrained by national designations. Other constraints may also occur.		

6.1.4 Parkstone Clay

This host clay has a restricted outcrop, with significant deposits located at Creechbarrow and Trigon. The deposit at Creechbarrow is in the AONB, but is not constrained by nature-conservation designations.

6.1.5 Solid sands

There is no significant systematic variation in the physical characteristics of the sands across the Basin. They are subject to similar planning constraints to host clays. However, major areas around Warmwell and north-east of Wareham, which are in agricultural or forestry use, represent significant unconstrained resources. Other parts of

Figure 36 Potential ball clay resource areas in relation to major environment designations

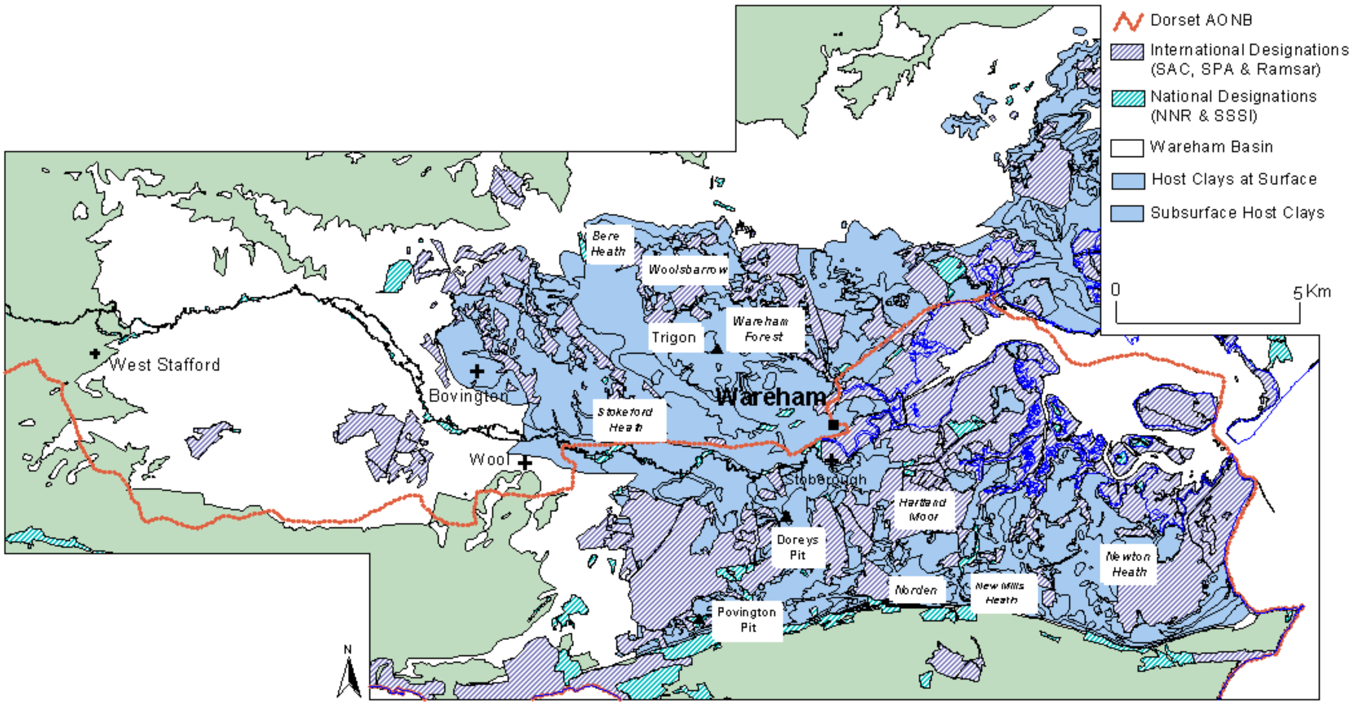


Figure 37 Host clays not constrained by international and national nature conservation designations and AONB

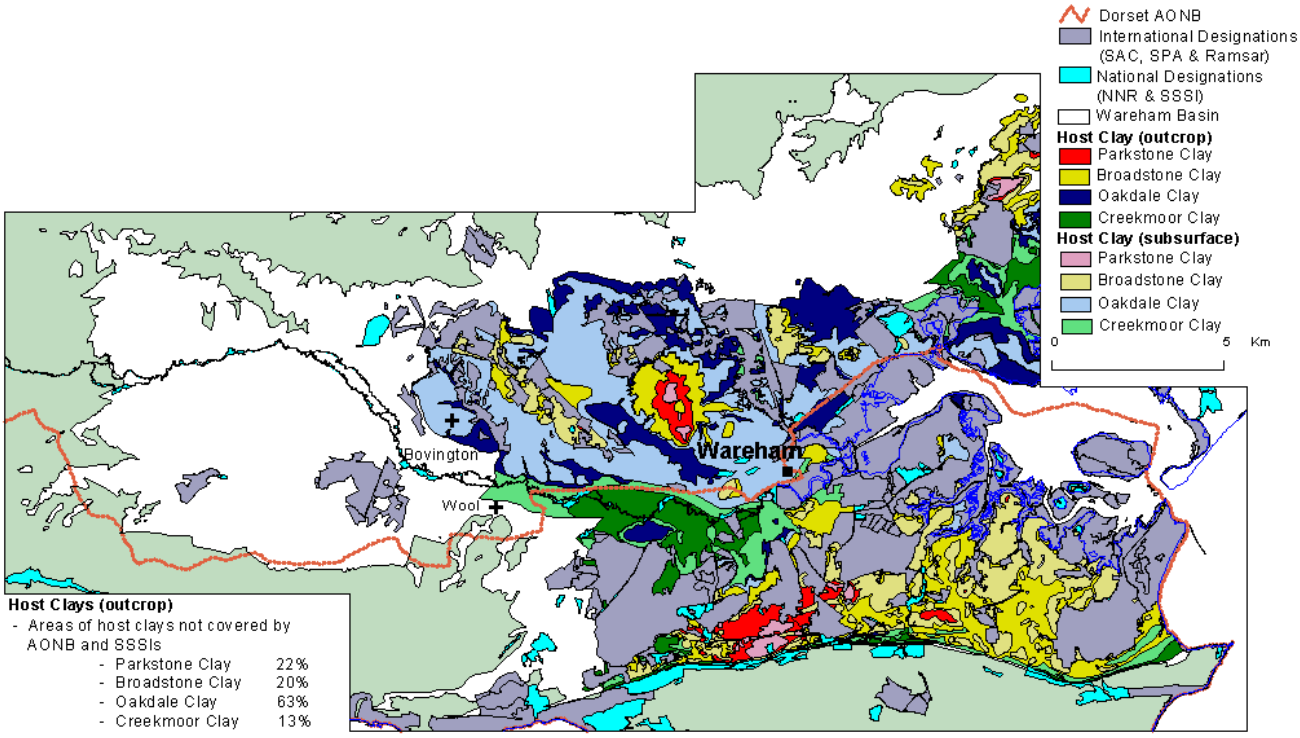


Figure 38 Bedrock sand deposits in the Poole Formation not constrained by international and national nature conservation designations and AONB

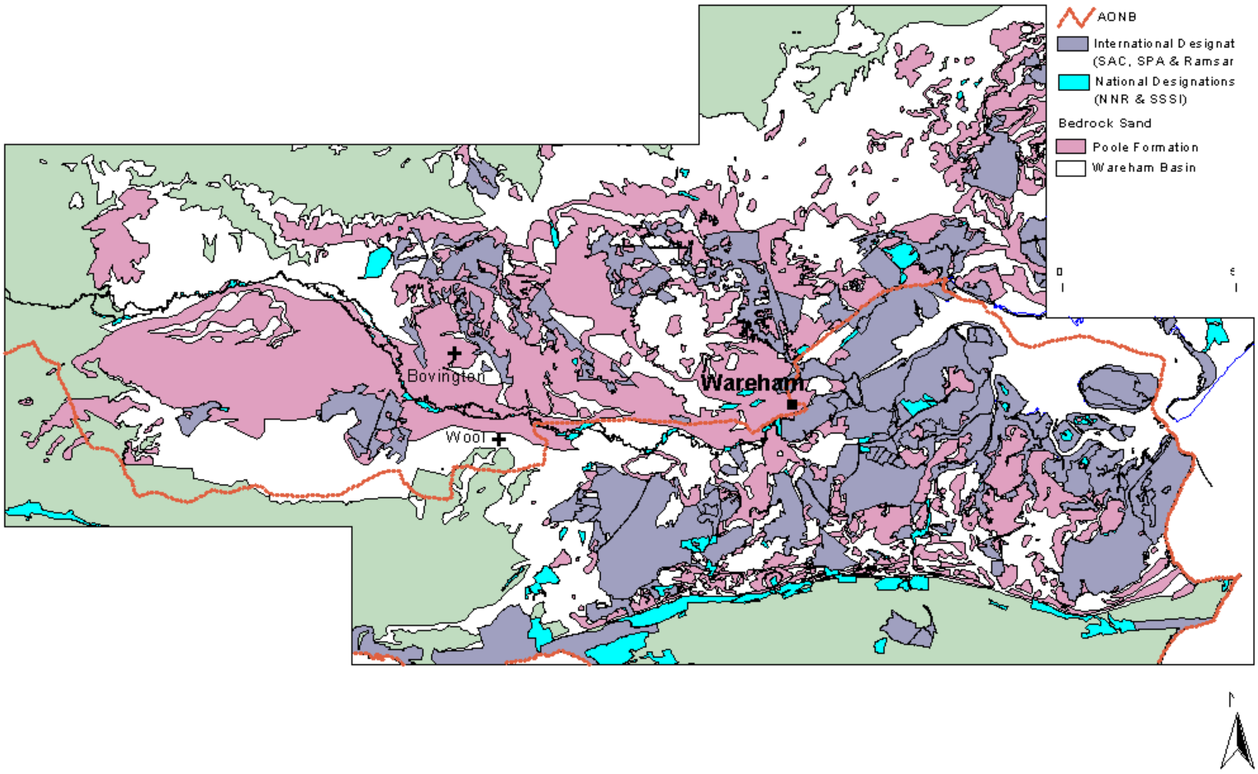
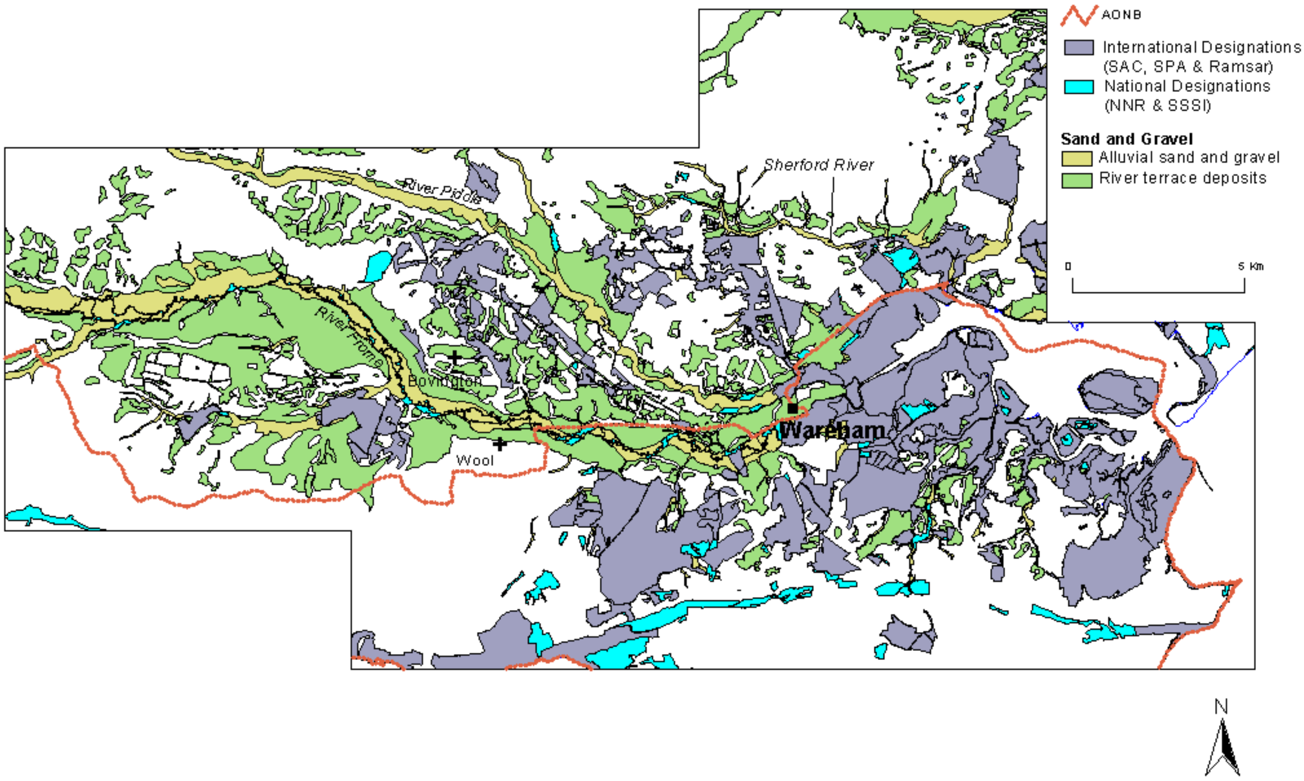


Figure 39 Superficial sand and gravel deposits not constrained by international and national nature conservation designations and AONB



the outcrop are subject to nature-conservation designations which already restrict the potential for extraction (Figure 38).

Extraction operations may, however, be subject to limitation due to groundwater issues and, in the west of the Basin, of overlying terrace gravels, which underlie high-grade agricultural land. Deep working of these deposits may remove groundwater storage capacity and prevent agricultural restoration, and conflict with groundwater quality issues and the requirement to protect the best and most versatile agricultural land.

The solid sand outcrop south of the Frome is subject to the AONB constraints and major international nature-conservation designations. In view of the large resource north of the River Frome, working of these deposits is unlikely to be needed in foreseeable future.

6.1.6 Superficial sand and gravel deposits

Much of the remaining higher terrace gravel is in very small outcrops and may be included in nature-conservation designations. The extensive lower terraces may be thin and of poor quality. A large proportion of the terrace gravels are overlain by high-quality agricultural land, and that part of the Frome outcrop downstream from Wool is in the AONB (Figure 39).

Where groundwater, agricultural and archaeological considerations combine, terrace gravel deposits may be severely constrained. Alluvial gravel beneath marine alluvium surrounding Poole Harbour, besides falling in the AONB, is covered almost entirely by intertidal nature-conservation designations and is unlikely ever to be worked.

6.1.7 Common Clays

Common clay is found in the south-west of the Basin in the AONB, but elsewhere is mainly excluded from major designations. However, the outcrop is associated locally with woodlands of national conservation importance and this consideration will constrain the potential for working the clay resources in such areas.

6.2 SUMMARY

A significant proportion of the ball clay resources of commercial interest lies in major environmental designations, principally the AONB and nature conservation sites. Resources outside these areas are mainly of lesser commercial interest.

There are extensive areas of sand and terrace gravel resources outside the AONB. However, significant areas are subject to other planning constraints. Some resources, particularly terrace gravel, may be of limited commercial interest

It would appear from available borehole evidence that the area currently identified in the Minerals and Waste Local Plan as an Area of Search for ball clay, does not contain significant resources of high-quality ball clay.

The current extent of the Ball Clay Consultation Area includes areas without host clays and excludes areas with host clays.

6.3 RESOLUTION

6.3.1 The issues

The current research has clarified the extent and qualities of the mineral resources in the Basin and enables all interested parties to see their relationship with the environmental resources. It provides the factual basis for the development of future planning policy. The planning system will need to take account of this new information and prepare policy which properly reflects the limitations and opportunities identified.

Given the nature and extent of the constraints, the potential for the development of some mineral resources appears to be uncertain and might suggest the need for the relaxation of planning constraints so as to enable, for example, the extraction of suitable grades of ball clay. Alternatively, the importance of the planning constraints may be so great as to entirely preclude the working of minerals in some areas.

Current mineral policy generally seeks to prevent mineral extraction harming major conservation designations. There is a long-term objective of moving ball-clay workings from the AONB, where possible, to eliminate the visual impact of extraction.

However, evaluation of the impacts may demonstrate that some conflicts can be resolved or mitigated. This may be on a case-by-case basis, or following a broad strategy defined and programmed in a structured manner, by modification to procedures, such that acceptable quantities of mineral can be provided with an acceptable level of impact on other resources. Such a procedure would be led by the MPA, with input from other interested parties.

Where impacts on environmental assets are unavoidable, it may be possible to demonstrate that environmental costs during operations can be counterbalanced by environmental gains or the protection of environmental assets elsewhere. In addition, at cessation of operations, a net long-term environmental gain might be achieved through high-quality restoration providing an increase in biodiversity (e.g. more wetlands) or the diversion of otherwise harmful, in nature-conservation terms, activities (e.g. forestry or landfill) from a virgin to brownfield site.

While detailed considerations of the acceptability of mineral extraction can only be assessed on a site-by-site basis, it is undesirable to let policy be determined by individual decisions. That would prevent an adequate assessment of the impacts of such decisions on the environmental or mineral resources. It is, therefore, desirable to identify what options might assist in developing an overall policy structure for the planning of the basin's resources.

The definitive form of particular policies will need to be addressed in any review of Planning Guidance and the development plan.

Such a review needs to assess how security of supply of minerals can be assured, how safeguarding of valuable deposits will effectively be achieved and how sustainability objectives of meeting the demand for mineral can be achieved.

6.3.2 Possible solutions

The primary concern is to identify options for the provision of ball clay because the degree of conflict between possible extraction and planning constraints is so acute. There is also a lesser conflict with other mineral resources, and solutions which enable production of these minerals to be maintained are also desirable.

Solutions need to be practical and reflect the requirements of the minerals industry and their customers (access to and a continuing production of a range of grades), as well as acceptable to environmental and sustainability considerations, and public concerns about protection of the landscape and wildlife.

6.3.2.1 MODIFICATION TO EXTRACTION AND PROCESSING

Modifications to extraction methods or processing could maximise recovery of mineral at least environmental cost or could assist in overcoming or mitigating constraints.

Surface Working

Surface working now accounts for all ball clay production. Some prospect areas for ball clay lie at a relatively shallow depth. Others, are thin or of lesser quality (therefore with lower yields per unit area) and lie beneath thick overburden, the costs of removal of which may preclude their extraction.

However, overburden may also include saleable mineral (construction sand), which, if extracted as part of a combined operation (which may have to be extensive due to low yields per unit area) might generate sufficient income to enable the ball clay to be extracted. Extensive operations outside the AONB, including in the Area of Search, may therefore increase rates of ball clay production, and also incidentally of sand, from unconstrained areas. Where such a range of deposits underlie unconstrained land, this may offer the potential to maximise mineral resource recovery at least environmental cost.

However, the extent to which this is practicable depends on various factors, including; the level and degree of planning constraint, both on site and on adjoining areas (few significant areas have no constraints); the acceptability of more extensive working (in time and area); and the justification in terms of ability to extract and market the additional, perhaps marginal, resources made available.

Such operations are not technically difficult, but require either an adjacent, and possibly extensive, area for tipping or a suitable market for saleable material and groundwater control measures. Although the Area of Search is outside the AONB, it is subject to other planning constraints which may prevent extensive operations. To reach target, host clays may require large-scale open pit working to or below OD and the permanent water table. This may not be feasible or acceptable. The extent of operations may also impact on landscape or adjacent nature-conservation interests.

Bringing deposits at depth in unconstrained areas into production, therefore, requires major development which may harm other interests. Current policy does not specifically preclude extensive operations, although they may be difficult to locate, given the need to protect landscape interests. The uncertain environmental impacts and the need to increase sales of other minerals (sand and inferior clays) to reach ball clay, together with the associated implications of overburden disposal, transport and groundwater effects, are major planning considerations.

Given the desirability and current policy objectives at national level to reduce mineral operations in an AONB, which is confirmed in specific local policies, a policy to maximise resources, including ball clay, from a perhaps modified Area of Search to include all possible host clays outside the AONB, should perhaps be investigated further and encouraged, with due regard to the environmental constraints present.

However, current evidence in this research indicates that while the sand produced may be saleable, any ball clay produced would generally be of lower quality. The deposits are thus unlikely to satisfy all demand for higher quality ball clay, and development of such prospects may not be possible in the short term.

Underground extraction

Both ball clay and common clay have been produced by underground mining, although always on a modest scale. For example, peak production of ball clay in 1975 from 9 mines was only some 50,000 tonnes. Mining of ball clay ceased in August 1999, due primarily to economic considerations, and common clay mining ceased in the 1950s. Physical limitations arising from the nature of the unconsolidated and water-bearing sediments created operational and safety difficulties which had a major impact on the economics of mining. They also fundamentally constrain recovery rates, such that host clays that can be mined need to be of the order of 15 m thick, of which only one third could be worked. Underground extraction generally gave rise to only limited visual impact, although some mineheads, associated loading areas and operations (for example at Creechbarrow) were intrusive. Due to this possible limited visual impact, mining might be acceptable in planning terms for working the higher quality ball clays generally only found in the AONB. However, this would probably need to be at a different scale to historical mining operations. To maintain current production levels, several new mines working a range of grades would be needed. Each would require sufficient workable reserves to justify development costs and each should have sufficient production capacity to provide the necessary total annual production.

However, while mining generally does not cause significant visual impact, it may create other conflicts. With the relatively shallow depth of feasible mining, extraction quickly causes an almost equal degree of subsidence, the impact of which extends beyond the underground take. This settlement disrupts local groundwater systems, changes vegetation, may cause die back of trees and permanent or temporary flooding. These effects may have an unacceptable impact on designated areas. Mining may also produce problems to infrastructure (roads and pipelines). All these considerations may further limit potential mining areas.

A policy to encourage mining might assist in ensuring that grades and qualities of clay found only in the AONB are brought forward. However, the practicalities of such actions, the probable extensive nature of such works and the possibility of significant harm to other interests, indicates that there is only very limited potential for mining. Economic considerations alone are, however, likely to preclude any resumption of mining for the foreseeable future.

Beneficiation and blending

Mineral resources *in-situ* rarely equate directly with saleable products. *In-situ* properties of minerals must, therefore, normally be modified to match specifications of mineral products or customer requirements. Blending sands with different characteristics from one or more quarries can enable them to meet British Standards specifications, which they may not if worked and sold separately. Blending may also help to ensure continuity of supply of particular grades.

Beneficiation, involving the removal of impurities, may similarly create a saleable or better quality product. Removal of silt and clay from gravels by washing and screening produces a product which is then suitable for a range of end uses.

However, as the quantity and form of impurities increases and more energy-intensive benefication is required (e.g. scrubbing or use of a log washer in gravel production), processing costs, including the treatment and disposal of wastes, and the quantity of saleable mineral recovered, ultimately limits further processing.

Processing has the potential to extend or increase the value of the resource base. Beneficiation may enable clays of limited commercial value to be upgraded. In the long term, this may enable resources in areas unconstrained by planning designations to replace resources in heavily constrained areas.

Blending of higher quality with lower quality material may also extend the resource base. However, there are practical limitations, which would be wasteful for high-quality ball clays.

Blending and beneficiation may assist planning objectives. The economic thresholds for blending and beneficiation may shift in the future enabling their greater use and a consequent increase in the resource base. There are, however, fundamental technical, and thus cost, limitations and beneficiation is unlikely to resolve supply and planning objectives in the short and medium term.

6.4 ADOPTION OF A RESTORATION AND BIODIVERSITY STRATEGY

Nature-conservation resources are generally fixed in location owing to their isolation by other land uses, but are rarely fixed in state. Where the resources are semi-natural habitats, as in the project area, and derived in part from mankind's historic and current land-management practices, they can be considerably modified by management, to either their disadvantage or advantage.

There is now experience to demonstrate the ability to re-create elements of such habitats, although the re-creation of complete ecosystems is less certain. Simplistically, we can re-create the landscape and *Erica*-vegetation cover of dry heathland, but may not be able to ensure the complete diversity of associated fauna and flora. Nevertheless, small-scale habitat and ecosystem re-creation of some old mineral workings can, in a relatively short time (circa 20 years), be so successful that the site may be designated as an SSSI and included in a proposed SAC and SPA. However, such areas are relatively small in relation to the virgin heathland in which they are situated.

However, timescales for re-creation may vary considerably. For example, oak woodland will not achieve its nature-conservation qualities for over 200 years. Other habitats, such as a reed marsh and acidic grasslands may be re-created over 20 years. In general, therefore, successful restoration of habitats and ecosystems will require management over timescales not generally adopted by the planning process.

The main habitats and ecosystems of nature-conservation importance in the Basin have been reduced in extent, as well as generally in the UK and Europe. Biodiversity objectives seek to reverse this process (the County Structure Plan sets out a figure of 500 ha to be re created in Dorset in the plan period). The potential for an increase is considerable, either by broad shifts in land-use practice (e.g. by reducing the area of coniferous forest) or, on a larger scale, by moving recreational and tourism facilities outside the Basin, or by site-specific actions to create new habitat on worked-out mineral sites.

The use of mineral sites may assist biodiversity targets and could comply with sustainability objectives, but there is, as yet, no evidence that the complex conditions necessary for diverse habitats can be re-created in old mineral workings. These objectives need to be considered with care. Heathland restoration may not be the preferred option on all old mineral workings. Such sites may be isolated or, while ultimately covered with heathland vegetation, they may be species poor and the costs of achieving this condition may have been considerable. In these circumstances, it might be of greater value to biodiversity if such areas were used as compensatory land, e.g. for forestry, with the forestry land re-created as heathland.

Deep excavations may considerably alter landscape and habitat during and after operations. The excavations will affect local groundwater flows and require the discharge of drainage water. This may impact on adjacent and distant areas and associated habitats. Restoration of such sites will require a long-term strategy, possibly involving adjacent land. Whilst this may provide important opportunities for replication of complete ecosystems, it remains a distant goal.

The current Heathland Strategy and biodiversity action plans for the Basin set out a range of objectives. However, methods to achieve these are somewhat imprecise and *ad hoc*. A strategy for old workings which seeks the re-creation of biodiversity habitats, or to use them as compensatory areas, may assist overall biodiversity objectives, and also demonstrate that a sustainable level of mineral extraction can be achieved. There is also the possibility of 'trading' of mineral, agricultural and environmental resources. For example, coniferous woodland on former heathland could be restored to heathland, ball clay under heathland could be worked, with the old pit restored and planted with coniferous woodland. Such a strategy could assist the planning process. However, this would, due to the nature and timeframe of habitat re-creation, need to be both general and specific, and would also have to take a view over a longer period (perhaps >20 years) than normal in the planning process. The development and timeframe of such a strategy will probably need to be reflected in a parallel sustainable development strategy to ensure that mineral extraction and restoration maximise environmental gains and minimise environmental costs, while providing adequate supplies of mineral.

6.5 A SUSTAINABLE DEVELOPMENT STRATEGY FOR THE BASIN

The importance and close relationship of both the environmental and mineral resources of the area has meant that the planning conflicts are as severe in the Wareham Basin as anywhere else in the country.

Current mineral policy and guidance recognises the importance of mineral resources and possible conflict with environmental resources, but may not fully reflect the inter-relationships between isolated decisions for other specific resources.

This situation is mirrored in planning and other policy and strategies for nature conservation, where policy and actions are either defined in isolation or take limited account of the inter-relationship between two broad policy objectives. An example of the latter is the consideration by English Nature and the Forestry Commission of the potential to maximise nature conservation resources on forestry land.

Given the significance of the range of resources, the absence of a land-use and environmental strategy for the Basin, which reflects the inter-relationships and values of those resources, may inhibit the potential to maximise both economic and environmental gains. As the degree and extent of possible conflicts between different objectives is expected to increase, this is not a satisfactory situation.

The limited knowledge of the mineral resources has previously severely inhibited an overall evaluation of development options. With the completion of this research, the situation has changed and the preparation of an overall integrated sustainable development strategy, identifying opportunities and limitations, could considerably aid the planning process both for minerals and other resources. However, such a strategy needs to properly reflect that some mineral resources, as well as environmental resources, are limited to this area and that their location and presence are the principal factors in any overall strategy.

6.6 A SUSTAINABLE MINERAL-DEVELOPMENT STRATEGY

Sustainable development of non-renewable mineral resources may seem contradictory. Where the resource is narrowly defined areally, qualitatively and quantitatively, a sustainable level of extraction is difficult to achieve. However, sustainability objectives are concerned with maximising economic and environmental gains and, in relation to minerals, seek to ensure that demand is met as far as practicable at the least environmental cost. Policies should be formulated accordingly.

Areas in the Basin where such objectives can be achieved could not previously be defined. Previous decisions on mineral development and allocations in Local Plans reflected the resource data available at the time.

The research has identified the disposition of the mineral resources and it is now possible to assess the potential value of deposits against a hierarchy of planning constraints and the degree of possible environmental gains or losses. Such an assessment could identify the most favourable working prospects in a manner consistent with sustainability.

Development of a such a strategy in the framework of a wider sustainable strategy could form the basis for mineral planning and provide broad objectives for the long term and more specific guidance for the near future. The findings of a such a strategy would be an important consideration in the process of Local Plan Review.

6.7 PROTECTION OF MINERAL RESOURCES

Extensive areas of the Basin are covered by planning designations to protect them from harmful development. The level of protection varies according to the importance of the site. The designations draw attention to the Basin being an area of international and national nature conservation and landscape importance and are referred to in policy and defined on maps in the various documents of the development plan.

The Basin’s mineral resources are fixed in place and cannot be replicated. They also need protection from development that would sterilise them.

Currently, the main ball clay resource area is protected by the provisions in the Ball Clay Consultation Area. Other mineral deposits may be protected by consultation areas defined under the Local Government, Planning and Land Act 1980.

However, in neither case do the areas defined relate to the now known extent of the resources and therefore may not ensure that sufficient protection is given to them. Modification of the defined areas to include the known resources will help to ensure that the planning process has the maximum flexibility to both develop necessary mineral resources and protect the environment.

However, these procedures need to be strengthened to ensure that the mineral potential of possible development sites is fully evaluated in the application determination process. This will require that mineral resources are evaluated in the planning process in a similar manner to other planning constraints, and that the costs of such evaluation, including drilling and testing, will need to be covered by the prospective developer.

Neither the ball clay nor other mineral consultation areas are identified in the district local plans, although they are referred to in the Mineral and Waste Local Plan. This exclusion prevents the full consideration of the implications of development which might sterilise mineral and which might lead to unnecessary environmental costs. A review of the current procedures and consultation areas would assist overall planning policy and help to ensure the most sustainable mineral development pattern.

6.8 SUMMARY

- Seek to maximise recovery of mineral from outside constrained areas, but recognise the limitations of supply and grades from such areas, and the economic and environmental constraints that may still apply.
- Support actions, which, through blending and beneficiation, may increase the mineral resource base and enable inferior material to become of commercial interest, but recognise that there are likely to be

fundamental limitations of an environmental or economic nature to such actions.

- Support the concept of mining of ball clay, but recognise that physical, environmental and economic constraints, and safety concerns make this highly unlikely in the foreseeable future.
- Adopt a coordinated restoration and biodiversity strategy for old workings so as to maximise environmental gains, minimise habitat loss and thereby help create an environmentally sustainable level of mineral extraction, but recognising the long-term nature of that strategy and impact on the mineral development timeframe.
- Prepare an integrated sustainable development strategy for all resources and development recognising in that strategy, the significance of those resources restricted to, or of major importance, in the Basin.
- Adopt procedures which effectively protect and identify the mineral resources so as to maintain development options and prevent actions which may lead to unnecessary harm to other resources.

7 Conclusions & Recommendations

7.1 CONCLUSIONS

The Wareham Basin of east Dorset contains mineral and other resources that are of national and international importance, the development and management of which give rise to conflicts of interest.

Mineral resources are fixed in place and cannot be moved or replaced. The impact of working minerals on natural resources, such as groundwater and high-quality agricultural land, may be minimised through the adoption of 'best practice' methods of working and restoration.

High-quality, light-firing ball clays have a limited distribution both nationally and internationally and the Wareham Basin is one of only three sources in Britain. The area accounts for some 20 per cent of national production. Production has increased in recent years due to a buoyant export market, and sales were some 237,000 tonnes in 2000, of which some 83 per cent was exported.

The area is also an important source of sand and gravel, mainly for aggregate use, although industrial sand is produced on a modest scale. Of about 2 million tonnes a year production of sand and gravel, some 1.2 million tonnes consists of sand derived almost entirely from the Poole Formation. These deposits are the main source of aggregate in Dorset and are of subregional importance as a source of concreting and building sand. There is a comparative scarcity of gravel, which is obtained from river terrace deposits. In some cases, these are worked in conjunction with the underlying bedrock sands. Large areas are already worked out or are covered by permissions. A small output of 'common' clay is used in the manufacture of red-bodied floor tiles.

The Wareham Basin is also highly valued for its landscape and nature-conservation importance. The Dorset AONB and the Purbeck Heritage Coast cover extensive parts of the Basin, and very large areas have also been designated for their international and national nature-conservation importance. These are Ramsar sites, Special Protection Areas, Special Areas of Conservation, National Nature Reserves and Sites of Special Scientific Interest, most of which are coincident with one another. In addition, large areas of land are used for military training, extensive areas are owned by the National Trust, there are numerous archaeological sites and Conservation Areas, and some areas of high-grade agricultural land. The area is also important for tourism and adjoins one of the fastest growing conurbations in the country. These all represent, to varying degrees, constraints on mineral development and there are only very limited areas in the Wareham Basin free of constraints. Any development in the SPAs and SACs must be of overriding public interest/public safety/ and human health.

The potential for conflict between mineral development and other resource interests is, therefore, considerable. To date, some conflicts have, in contrast to other forms of land-use development, been largely accommodated without major negative impact. However, there are areas where the heathland loss has occurred as a result of mineral extraction. Legislation is in place to protect such habitats from development.

Whilst mineral resources are fixed in location, there is growing evidence that some nature-conservation resources can be expanded, enhanced and replicated. Indeed, some extensive old mineral operations have been restored in a manner in which habitats have been re-created. Some of these now fall in areas of international nature-conservation importance. The restoration of mineral workings can also assist in meeting biodiversity targets. However, using compensatory land may be a quicker and more effective method of achieving such targets.

Some 70 per cent of ball clay production in Dorset is located in the AONB. Almost all the higher quality ball clays are also located in this area. There is now considerable geological evidence for concluding that the ball clay potential of the area north of the River Frome and outside the AONB is much less than that to the south. The Creekmoor Clay, in particular, is the source of the highest quality ball clays, but is largely confined to the southern part of the Basin in the AONB. This fact has an important bearing on both local policies in the Dorset Minerals and Waste Minerals Local Plan and also national policies relating to mineral working in AONBs and nature-conservation designations, in particular, in international nature-conservation designations (Ramsar/SPA/SAC).

Recent mapping has shown that the limit of potential ball clay-bearing strata, defined by the outcrop of the host clays, is not coincident with the Ball Clay Consultation Area. In the north, the consultation line extends beyond the limits of the host clays, whilst in the north-west, the host clays are more extensive than the consultation area. South of the Frome, host clays do not extend to the western limits of the consultation area. To the north-east, host clays occur beyond the limits of the consultation area. However, a deterioration of the quality of the clays to the north-east of Wareham makes it difficult to draw a definitive boundary.

The review of the local plan will look at all policies and proposals, including the existing Area of Search, and propose any changes that are considered necessary and appropriate in the light of the new information.

7.2 RECOMMENDATIONS

It is recommended that the following actions should be adopted to assist mineral planning.

- Consider the options for producing an integrated sustainable development strategy for all resources and development and relate this to an integrated restoration and biodiversity strategy so as to maximise environmental gains and minimise habitat loss.

- Review the boundaries of the Ball Clay Consultation Area and other mineral consultation areas based on the latest geological information and adopt procedures which effectively protect and identify those mineral resources so as to maintain development options.
- Carry out research to determine best practice for the creation of biodiversity targets and other habitats, giving priority to lowland wet heath and mire habitats in the restoration of mineral workings. (A scoping study on Dorset heath re-creation has been carried out by the Centre for Ecology and Hydrology and further research is being proposed).
- Identify in the strategy, the opportunities for maximising mineral resource recovery and use through options such as increased blending and benefication, more operations in least constrained areas and the potential for mining.
- Carry out further research on the beneficiation of ball clay, starting with a review of current and developing technologies, the economics of processing and a market analysis of the ceramic industry to establish the level of cost that would be viable for a refined Dorset ball clay.
- Most importantly, however, Government needs to take a view on the national importance of ball clay and in what, if any, circumstances mineral resources have a higher priority than environmental designations.

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Appendix 1 Sources of Information and Methodology

The project involved a team of field and economic geologists, database and GIS designers, mineralogists and geochemists, together with a mineral planner and ecologists. The main elements of the work programme and sources of information to meet the objectives were as follows: geological mapping and sampling, data acquisition (boreholes, mineral planning permissions, environmental designations, hydrogeological data), borehole drilling and sampling, development and population of a borehole database, and the design of a Geographical Information System (GIS).

Geological mapping

Delineation of the mineral resources of the area depended initially on the availability of accurate geological base maps. The BGS geological mapping programme was, therefore, prioritised to complete mapping of the Wareham Basin at 1:10 000 scale. This work, for the first time, allowed the detailed stratigraphy of the Basin to be defined and, in particular, to delineate the extent of the economically important clay and sand units. Digital capture of nineteen 1:10 000 geological maps forms the basis of the mineral resource maps produced.

Borehole database

A major part of the project was the development and population of a borehole database with about 8500 boreholes. About 87 per cent of the boreholes were obtained from IMERYS Minerals Ltd and most of the remainder are commercial sand and gravel boreholes. Much of the information held in the database is, therefore, classified as 'Commercial: In Confidence.' However, a synthesis of the information has been invaluable in modelling the distribution of the sands and clays. Many of the IMERYS boreholes are accompanied by geochemical data representing several tens of thousands analyses. Interrogation of the database has allowed the thickness, depth and subsurface distribution of the host clays to be defined and also regional variations in the quality of the clays to be assessed.

We gratefully acknowledge the borehole data provided by many organisations, and in particular IMERYS Minerals, which has greatly enhanced the results of the project.

Drilling and sampling programme

In order to provide stratigraphical control and sampling in areas of poor borehole coverage, the BGS drilled 17 shell and auger and 5 Minuteman holes (see Appendix 6). Clays were sampled where appropriate and analysed for major-element geochemistry, total organic carbon and surface area in BGS and external laboratories. The object of this work was to determine the vertical and lateral variability of the host clays in areas away from ball clay producing areas.

In addition, particle-size analyses were determined on 344 sand samples from working quarries and exposures across the Basin. Additionally, bulk samples of sand and gravel for assessment of particle-size distribution were taken from 26 trial pits.

Evaluation of planning and environmental data

The Wareham Basin contains habitats of international and national importance, together with a wide range of other environmental constraints. An important part of the project was the collation of information on these key designations and relating them to the distribution of mineral resources (see Table 7). Data were also collected on the extent of mineral planning permissions, together with preferred areas for mineral extraction and the ball clay Area of Search.

Design of a Geographical information system

A key objective of the project was the design of a Geographical Information System (GIS) to facilitate the integration and analysis of the large amount of spatially-related datasets that have been collected. The software used was ArcView GIS Version 3.2a.

Appendix 2 Mineral Designations

The extent of all known mineral planning permissions (other than oil) in 1999 is shown in Table 9. They include all permissions granted since 1st July 1948 and all Interim Development Order permissions. Planning permissions cover active mineral workings, former mineral workings and, occasionally, unworked deposits. They represent areas where a commercial decision to work minerals has been taken in the past and where the permitted mineral reserve may have been depleted to a greater or lesser extent. Within the overall site boundary, there may be a number of planning permissions at various stages of development and restoration. All planning permissions data were obtained from Dorset County Council.

The present physical and legal status of individual permissions is not qualified in detail although a distinction is made between valid and expired permissions. The areas shown in the GIS may, therefore, include inactive sites, where the permission has expired due to the terms of the permission, i.e. a time limit, and inactive sites where the permission is still valid. Sites, which have been restored, have not been separately identified. A planning permission may extend beyond the mapped resource as it may make provision for operational land, including plant, overburden tips and landscaping, or it may extend to an easily identified or ownership boundary. Information on the planning and operational status of each planning permission is available on the GIS. The area of these permissions is shown on Table 9. Permitted reserves of mineral that contribute to the landbank are confined to valid permissions. Information on the precise status and extent of individual planning permissions should be sought from Dorset County Council.

Table 9 Extent of mineral planning permissions and preferred areas

Type of permission	Area of valid permissions (hectares)	Area of expired permissions (hectares)	Total (hectares)
Ball clay (surface)	231	60	291
Ball clay (underground)	284	60	344
Common clay	73	53	126
Sand and gravel	904	293	1,197
Preferred areas for ball clay	-	-	135
Preferred areas for sand and gravel	-	-	188
Area of search for ball clay	-	-	4,731

Definitions of the mineral designations described in this report are given below.

Mineral Planning Permission Areas of land in which permission for extraction of mineral(s) has been granted. Extraction may be limited to parts of the permitted area. Planning permissions for all minerals, active or inactive, valid or expired, except hydrocarbons, are available. Some of the permissions may have been restored or developed for other purposes. The overall site boundary shown in the GIS may represent the outer limit of a number of consents.

Landbank A landbank is the sum of reserves of a specific mineral, or minerals, in valid planning permissions, including reserves in both active and inactive sites. Landbanks are assessed in relation to demand. Development plans should demonstrate the commitment of the MPA to the maintenance of the landbank.

Preferred Areas Areas of land which are precisely defined in the development plan. The extent of the mineral resource may not be known in detail, but there should be reasonable evidence for the existence of viable mineral deposits. There should be no significant planning considerations which would prevent the grant of permission for extraction. Subject to resolution of details, there is a presumption that permission for extraction might reasonably be granted.

Area of Search Broad areas of land defined in the development plan which are believed to contain significant mineral resources, but whose extent is uncertain. Planning permission for extraction may be granted in appropriate areas to satisfy any shortfall in supply from Preferred Areas. Planning considerations may indicate that mineral extraction is not appropriate throughout the area.

Ball Clay Consultation Area An area of some 15,400 ha defined in the 1950s in which certain planning applications for development, other than associated with extraction of ball clay and which could prevent the extraction of any underlying ball clay, are the subject of a consultation procedure with the Kaolin and Ball Clay Association, the relevant planning authority and the developer.

Appendix 3 Environmental and other Designations

The Wareham Basin is highly valued for its landscape and nature-conservation importance. Various national and international designations cover extensive areas, as do other constraints and land-use and land-ownership factors. A wide selection of these is shown on the thematic maps is this report and is held within the GIS. The various designations are briefly described below.

Area of Outstanding Natural Beauty

The southern part of the area lies in the Dorset AONB designated in 1959 in accordance with the National Parks and Access to the Countryside Act 1949. Planning policies seek to preserve and enhance the natural beauty of the AONB. Mineral development in AONB's is rigorously examined and must demonstrate that it is in the public interest.

Heritage Coast

The area contains part of the Purbeck Heritage coast designated to protect the character and provide positive management of unspoilt coastal areas. The Council for Europe Diploma was conferred on the area in 1984 and reconfirmed in 1994 in recognition of the success in achieving those objectives.

International Nature-conservation Designations

The project area contains sites designated for their international nature conservation importance. In chronological order, such designations are Ramsar sites, Special Protection Areas (SPAs) and Special Areas of Conservation (SACs). In general, the areas coincide with one another. Minor differences reflect the detailed objectives of the designations. The relevant legislation requires that areas of international designation be given greater protection from development in comparison with national designations.

Ramsar sites

Ramsar sites are areas of wet lands and wildfowl habitats, designated in accordance with the Ramsar Convention, Ramsar, Iran, 2nd February 1971. Contracting governments are required to conserve the sites and to restrict harmful development. Alternative habitat may need to be designated if development takes place in a designated area.

Special Protection Areas (SPAs)

SPAs are designated in accordance with European Directive 79/409/EEC, adopted 2nd April 1979, to provide measures to conserve wild birds, their eggs and habitats. This directive is commonly known as the 'Birds Directive.' On 1st October 1998 and March 31st 1999 respectively, the two proposed SPAs in the area, the Dorset Heathlands SPA and the Poole Harbour SPA were confirmed by the UK Government. Member states are required to take appropriate action to avoid damage to habitats and species in the designated areas. Any development which would have a harmful effect should not normally be allowed and any development which is allowed may have to provide compensatory measures.

SPAs, together with SACs (see below), will form part of 'Natura 2000,' a European-wide network of areas of special nature conservation interest.

Special Areas of Conservation (SACs)

SACs are designated in accordance with European Directive 92/43/EEC, adopted 21st May 1992, to provide measures to conserve natural habitats and associated fauna and flora. The directive is commonly known as the 'Habitats Directive.' Any SAC which contains habitats or species identified as of 'priority status for conservation within Article I of the Directive' is designated as a 'priority' SAC. On 1st October 1998, two candidate SACs in the area, the Dorset Heaths (Purbeck & Wareham) and Studland Dunes Priority SAC, and the Dorset Heaths SAC, proposed by the UK Government, were forwarded to the Commission for final confirmation. Candidate SACs should be treated as confirmed SACs for planning purposes and, in relation to development proposals, are subject to the same considerations as apply to SPAs. However, in priority SACs, more stringent considerations apply.

National Conservation Designations

The area includes extensive areas designated as of national nature-conservation importance. These designations may cover similar areas to the international designations and may also overlap each other.

Sites of Special Scientific Interest (SSSIs)

Within the area are a large number of SSSIs designated in accordance with the Wildlife and Countryside Act 1981 so as to conserve areas of special interest due to their flora, fauna, geological and geomorphological interest. Mineral applications which may affect SSSIs should be subject to the most rigorous examination.

National Nature Reserves (NNRs)

SSSIs considered to be of national importance and which are managed by way of a legal agreement as a nature reserve may be designated in accordance with the Wildlife and Countryside Act 1981 as NNRs. That legal agreement will normally ensure that land is used as a nature reserve and will preclude other development. There are five NNRs in the area.

Scheduled Monuments

Scheduled Monuments are defined in accordance with the Ancient Monuments and Archaeological Areas Act 1979 as structures, excavations or sites of national archaeological importance. There are a number of scheduled monuments in the area. Mineral operations which affect such monuments may not be permitted.

Other designations

A wide range of other constraints may impinge on mineral development. A selection of these are described below.

Conservation Areas

Conservation Areas, defined in accordance with the Planning (Listed Building and Conservation Areas) Act 1990, are areas of special architectural or historic interest which it is desirable to conserve or enhance. Development which does not conserve the area will normally be unacceptable. Most settlements in the area are in or contain conservation areas.

Green Belt

The north-east part of the area falls in the South East Dorset Green Belt designated in the development plan. Development which is inappropriate to the maintenance of openness in the area would not normally be approved. Mineral extraction may not conflict with that purpose and may be acceptable.

National Trust

The National Trust is a registered charity, set up in 1895 to promote ‘the permanent preservation, for the benefit of the nation, of lands and tenements (including buildings) of beauty or historic interest.’ The Trust is unique in being able to declare property ‘inalienable’ – a provision in The National Trust Act 1907. This means that protection of the open countryside, as well as historic houses and gardens, are guaranteed protection.

Groundwater Protection Zones

Protection zones have been defined around sources used for public supply or other human consumption, in which some activities or processes are prohibited or restricted. For each source, three zones (Inner, Outer and Total Catchment Area) have been defined. Restrictions may also apply to areas outside the marked zones.

Ministry of Defence Land

Land used for military training.

Agricultural Land

The Agricultural Land Classification provides a framework for classifying land according to the extent to which its physical or chemical characteristics impose long-term limitations on agricultural use. Limitations may affect the range of crops that can be grown, the level and consistency of yield and the cost of obtaining it. Flexibility of cropping is an important consideration, and the ability of some land to produce consistently high yields of a relatively narrow range of crops is also taken into account.

The principal physical factors influencing agricultural production are climate, site and soil. In some situations, chemical properties, such as high levels of toxic elements, or extreme subsoil acidity, can influence the long-term potential of land and are taken into account. These factors, together with interactions between them, form the basis for classifying land into one of five grades; Grade 1 land being of excellent quality, to Grade 5 land of very poor quality. Grade 3, which constitutes about half the agricultural land in England and Wales, is divided into Sub-grades 3a and 3b.

Figure 3 is based on provisional data and are only suitable for strategic purposes to provide a broad indication of likely grade. It does not show Grades 3a or 3b, as the data upon which they are based do not include a breakdown of Grade 3. The maps show that there is only Grade 2 and apparently no Grade 1 land in the project area.

Government policy provides protection from development for Grades 1, 2 and 3a agricultural land. This is set out in Planning Policy Guidance Note 7, paragraphs 2.17 – 2.18 (Anonymous, 1997), which states that within the principles of sustainable development, the best and most versatile agricultural land (defined as Grades 1, 2 and 3a) should be protected as national resource for future generations, and development should be steered away from such land. MPG7 paragraph 3 (Anonymous, 1996) indicates that the achievement of high standards of restoration may lead to the release of the best and most versatile land for minerals working.

Pipelines

The major oil and gas pipelines in the area are available in the GIS.

Commercial Forestry

Commercial forestry and woodland are not environmental designations that might preclude mineral extraction, but represent an important land use in the area (see Section 5.1.5.8 and Figure 3). The Forestry Commission, through the Forest Authority, provides advice and grant-aid to woodland and potential woodland owners, sets environmental standards for forestry and promotes the forestry industry. It consults local planning authorities on grant and felling applications and will advise on forestry issues. The Commission also manages a large woodland estate.

Appendix 4 Mineral Resources of East Dorset Database

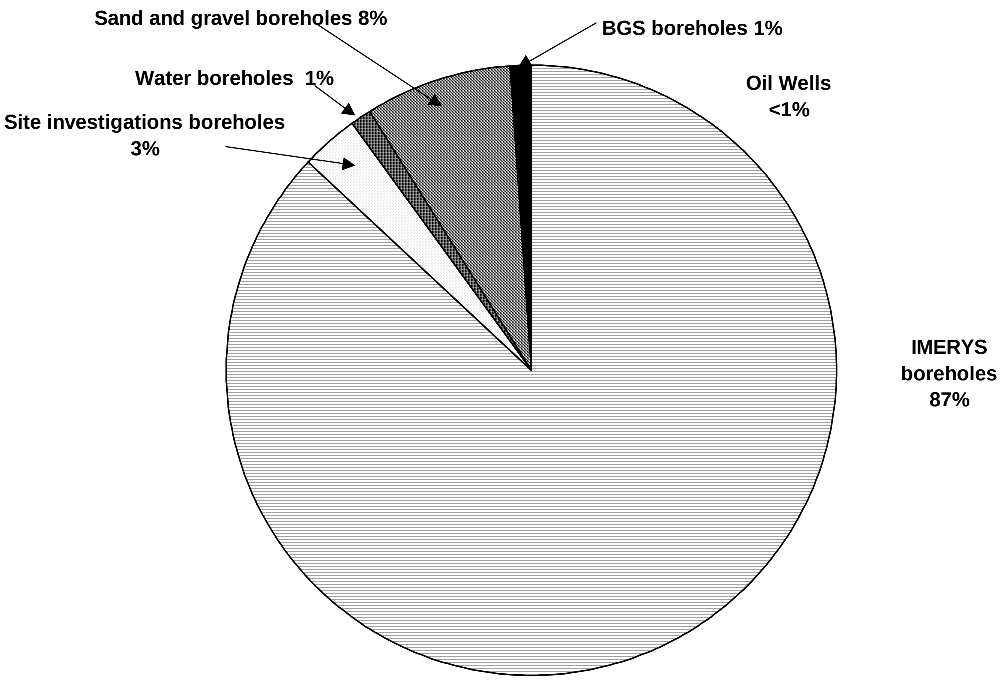
The database associated with the Mineral Resources of East Dorset Project comprises the following types of data.

1. Borehole index data
2. Stratigraphy/lithology data
3. IMERYS lithology codes along with sample numbers
4. Geochemistry data
5. Mapped heights of member and formation bases
6. Sand grain size data
7. ASCII datasets for log plotting.
8. Wellog data

The data in 1-4 above is held as a relational database in Microsoft Access.

Borehole Index Data

Data is held for approximately 8450 records. This includes IMERYS ball clay exploration boreholes (87 per cent), together with boreholes for sand and gravel (both commercial and BGS sand and gravel assessment), site investigation, water, oil and BGS boreholes drilled for this project. About 96 per cent of the boreholes in the database are confidential.



ORIGIN OF BOREHOLE DATA INDEX

Most of these data were encoded from paper record sheets, mainly obtained from IMERYS Minerals. Approximately 1500 records were obtained digitally as ASCII output from their DATAMINE system. These records contain the IMERYS borehole number, grid reference and OD level. After assignation of BGS borehole numbers, they were integrated into the project database. Existing BGS borehole data were also included where applicable.

Stratigraphy and Lithology Data

Lithostratigraphical data (61000 records) are recorded against depth for 5166 boreholes. These data were obtained from two sources. Firstly, from manual entry from paper records (mainly IMERYS) classified by BGS at Exeter, and secondly, digitally by correlating the IMERYS seam code with lithostratigraphy. There was some overlap of information from these sources, and some differences in classification had to be resolved. Because of lack of time, almost no lithology data were entered, and most meaningful output from the database comes from the geochemistry, rather than lithological descriptions. Some lithology data are available from IMERYS digital data (see below). The resultant database was mainly used to allow the selection of geochemical, depth and thickness data for the various lithostratigraphical members.

Lithology Codes

A listing of 13 427 codes was obtained as ASCII output from IMERYS's DATAMINE system, which was then imported into Microsoft Access. Their lithology descriptions are encoded into an alpha-numeric code which can be decoded using an IMERYS dictionary table.

Geochemical Data

Some 48 937 elemental analyses from 2923 boreholes were obtained. Some (5675) records were input manually from IMERYS paper records and the rest (43 262 records) were imported into Microsoft Access from ASCII tables output from IMERY's DATAMINE system. The records came attached to the IMERYS borehole number and top and bottom depths. It was possible to allocate the BGS borehole numbers to these records by relating the IMERYS borehole number to the borehole information (described in 1 above) using the relational database.

Not all records contain full analyses of the major elements such as SiO_2, Al_2O_3 etc., but most have a Quality Code entry. Approximately 26 000 records have fairly complete analyses. Using the same method applied to the BGS borehole geochemical data, it has been possible to calculate rational analyses for kaolinite, mica and quartz for 18 000 IMERYS geochemical records.

Seam Code attributes in the IMERYS data consists of a decimal code, the first digit of which corresponds to the BGS host clay and intervening sand member. It was possible to translate and add this to the downhole stratigraphy information in the database. The digits to the right of the decimal express finer divisions not translatable into BGS map units, but these are useful for retrieving data for thinner units over limited areas.

Map Height Levels

Data on 828 reduced height levels for the bases of the Palaeogene and various members were determined by inspection of the 1:10 000 maps. The records contain the grid references of the chosen points and each record is tagged with the appropriate stratigraphy code. Selections of these data can be appended to data obtained for the same level in the borehole database to provide data for contouring the base of the Palaeogene and the various members.

Sand Grain Size Data

Sand-sieving data derived from sands in the area includes 273 samples collected during the present project, and 132 samples collected in 1983-1986 during a BGS Land-use Planning project carried out for DOE. The samples were sieved at Exeter. The sample number, grid reference, stratigraphical and weight data is held in an Access table, the older data having been imported from Dbase IV. Sample numbers, with attendant stratigraphical and weight data, were exported to Sivpro for assessing the sands commercially against various BS specifications. Original weight data has also been used to generate a table containing Folk and Ward mean size, sorting and skewness data.

ASCII files for Log Plotting

ASCII file output from IMERYS's DATAMINE system is used to print out paper copies of graphic, lithological and geochemical logs of boreholes using DRILLOG5. This is material incorporated in the Microsoft Access database.

Wellog Data

Geophysical logs of some of the more recent ECC boreholes have been digitised from paper copies at Keyworth and loaded on Wellog, together with logs from selected oil wells and BGS boreholes.

Appendix 5 Geographical Information System

A key objective of the project was the design of a Geographic Information System (GIS) to facilitate the integration and analysis of the large amount of spatially-related datasets that have been collected. A GIS is a computer-based software application for mapping and analysing georeferenced spatial data. GIS technology integrates common database operations, such as query and statistical analysis, with visualisation and spatial analysis of geographic data. The software used was ArcView GIS Version 3.2a.

Key software components of a GIS are tools for the input and manipulation of geographic information, a database management system (DBMS), tools that support geographic query, analysis, and visualisation, and a graphical user interface (GUI) for easy access to tools.

A GIS stores information as a collection of thematic layers linked together by geographic co-ordinates. The information can be stored either as vector or raster data. With vector data, information about points, lines, and polygons is encoded and stored as National Grid (Easting and Northing) co-ordinates. A point feature, such as a borehole, is described by a single co-ordinate. Linear features, such as roads and rivers, are stored as a collection of point co-ordinates joined by a line. Polygonal features, such as land use constraints, are stored as a closed loop of co-ordinates. Raster data is stored as a collection of grid cells rather like a scanned map.

Information Layers included for this project

1 Km Grid
10 Km Grid
Provisional Agricultural Land Classification
AONB
Ball Clay Area Of Search
Ball Clay Consultation Area
BGS boreholes drilled for the project
Boreholes (other)
Ball Clay Host Clays and other Clay Resources
Coastline
Conservation Areas
Mineral Planning Authority boundaries
Heritage Coast
Mines and Quarries
Ministry of Defence Land
National Trust Land
NNR
Ordnance Survey backdrop (1:25000)
Planning Permission Ball Clay Surface
Planning Permission Ball Clay Underground
Planning Permission Clay
Planning Permission Oil
Planning Permission Sand and Gravel
Preferred Area Ball Clay
Preferred Area Sand and Gravel
RAMSAR sites
SAC
Sand and Gravel Resources
SPA
Scheduled Monuments
SSSI

Appendix 6 Outline Stratigraphy of Boreholes Drilled for the Project

Name	**BGS number**	**Grid reference**	**OD (m)**	**Drift (m)**	**Parkstone Clay (m)**	**Parkstone Sand (m)**	**Broadstone Clay (m)**	**Broadstone Sand (m)**	**Oakdale Clay (m)**	**Oakdale Sand (m)**	**Creekmoor Clay (m)**	**Creekmoor Sand (m)**	**London Clay (m)**
Allenby 1	SY88NW/198	8361 8927	41	9.0					4.6	4.9	0.4	3.9	11.2
Allenby 2	SY88NW/199	8734 8848	35.5	1.7					2.9	18.2			15.2
Drove Hill	SY88NW/200	8016 8598	34	2.7								3.3	24.0
Primrose Farm	SY88NE/780	8670 8769	22	1.4					5.4	3.2			
Trigon House	SY88NE/781	8896 8895	20	1.1			3.4	3.5					
Priory Farm	SY88NE/782	8953 8612	8	2.0							22.2	0.8	
West Holme	SY88NE/783	8851 8858	21	1.5				4.0	4.3	1.2			
Five Tips	SY88SE/1540	8836 8472	23	2.5						12.2	0.95	2.15	14.2
Earl's Kitchen	SY88SE/1541	8743 8322	30							15.8	3.35	2.3	20
Wareham Forest 1	SY99SW/97	9287 9170	15	0.7				8.7	10.6				
Wareham Forest 2	SY99SW/98	9202 9032	37	1.8				1.5	7.0	10.0	15.7		
Wareham Forest 3	SY89SE/251	8960 9234	27					10	11.05	5.95			
Wareham Forest 4	SY89SE/252	8700 9132	43	3.5				15.5	2.5	8.5			
Wareham Forest 5	SY89SE/253	8688 9271	47					19.4	13.4	3.2			
Snaggs Farm	SY98SE/500	9546 8430	15	1.5	2.5	5.3	12.7	10.5					
Studland 1	SZ08SW/37	0195 8371	22	1.5		5.6	9.7	5.7					
Studland 2	SZ08SW/38	0256 8320	30	0.6			12.2	1.2					

Appendix 7 Geochemistry of Samples from BGS boreholes

Name	BGS number	NGR	Mean depth (m)	Strat	Description	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	Mn_3O_4 %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	Cr_2O_3 %	SrO %	ZrO_2 %	BaO %	LOI %	Total %	Fe_2O_3 +TiO_2 %	Surface area m^2/g	TOC %
Allenby 1	SY88NW/198	8361 8927	9.5	OC	Pale grey silty clay (mottled orange clay)	61.82	0.93	22.06	5.08	0.00	0.35	0.07	0.30	2.03	0.05	0.02	0.01	0.03	0.05	6.89	99.69	6.01	84.0	0.11
			13.2	OC	Grey silty clay	76.37	1.11	13.34	1.87	0.01	0.69	0.07	0.22	1.95	0.03	0.01	0.01	0.06	0.04	4.07	99.85	2.98	42.8	0.46
Allenby 2	SY88NW/199	8734 8848	3.225	OC	Pale grey silty/sandy clay	75.42	1.17	15.56	0.84	0.00	0.42	0.01	0.26	2.18	0.03	0.02	0.01	0.05	0.05	3.91	99.93	2.01	38.8	0.06
			3.725	OC	Pale grey silty/sandy clay	75.12	1.19	15.16	1.43	0.01	0.55	0.01	0.25	2.19	0.04	0.02	0.01	0.05	0.05	3.81	99.89	2.62	36.1	0.06
Drove Hill	SY88NW/200	8016 8598			Not sampled																			
Primrose Farm	SY88NE/780	8670 8769	1.5	OC	V red clay	71.12	1.14	17.69	1.86	0.00	0.34	0.06	0.27	2.14	0.04	0.02	0.01	0.03	0.05	4.84	99.61	3.00	42.33	0.07
			3	OC	Pale grey, red stained clay	63.64	1.33	21.90	2.64	0.00	0.40	0.15	0.32	2.57	0.06	0.02	0.01	0.03	0.06	5.99	99.12	3.97	52.31	0.10
			3.5	OC	Pale grey, red stained clay	56.92	1.27	28.16	1.16	0.00	0.49	0.19	0.46	3.35	0.07	0.02	0.02	0.02	0.08	7.37	99.58	2.43	57.06	0.11
			4.225	OC	Pale grey clay	56.45	1.23	28.23	1.21	0.00	0.50	0.21	0.43	3.16	0.07	0.02	0.02	0.03	0.08	7.58	99.22	2.44	67.33	0.14
			4.45	OC	Pale grey clay	56.43	1.23	28.25	1.21	0.00	0.52	0.20	0.45	3.35	0.05	0.02	0.01	0.02	0.07	7.62	99.43	2.44	82.05	0.22
			4.8	OC	Pale grey clay	58.91	1.25	26.73	1.11	0.00	0.50	0.20	0.40	3.05	0.06	0.02	0.01	0.03	0.07	7.23	99.57	2.36	78.76	0.16
			5.4	OC	Brown clay	62.55	1.17	22.02	1.10	0.00	0.42	0.19	0.32	2.51	0.04	0.02	0.01	0.03	0.06	9.09	99.53	2.27	83.41	2.05
			6	OC	Brown clay	72.89	1.21	15.72	0.89	0.00	0.32	0.11	0.25	1.96	0.03	0.01	0.01	0.05	0.05	5.67	99.17	2.10	49.09	0.93
			6.5	OC	Brown clay, sandy	73.38	1.22	16.47	0.77	0.00	0.32	0.10	0.25	1.99	0.04	0.01	0.01	0.04	0.05	4.67	99.32	1.99	44.91	0.66
Trigon House	SY88NE/781	8896 8895	1.55	BC	Grey sandy clay	66.20	1.91	21.16	1.24	0.00	0.24	0.03	0.29	1.77	0.05	0.02	0.01	0.04	0.05	6.05	99.06	3.15	60.65	0.06
			2.05	BC	Pale grey clay	66.31	1.81	21.04	1.42	0.00	0.27	0.04	0.28	1.81	0.05	0.02	0.01	0.04	0.05	6.23	99.38	3.23	63.47	0.14
			2.3	BC	Pale grey clay + staining	58.68	1.32	21.90	7.75	0.00	0.29	0.03	0.29	2.01	0.05	0.02	0.01	0.03	0.05	6.84	99.27	9.07	65.94	0.12
			2.75	BC	Pale grey clay + staining	61.22	1.28	20.37	7.64	0.00	0.30	0.03	0.29	2.04	0.05	0.02	0.01	0.03	0.05	6.33	99.66	8.92	65.07	0.11
			3.25	BC	Pale grey clay + staining	68.26	1.21	17.11	5.34	0.00	0.27	0.02	0.22	1.72	0.04	0.01	0.01	0.04	0.04	5.30	99.59	6.55	49.97	0.09
			3.75	BC	Pale grey clay + staining	79.06	1.19	13.14	0.77	0.00	0.20	0.01	0.18	1.21	0.03	0.01	0.01	0.07	0.03	3.79	99.70	1.96	31.93	0.05
			4.25	BC	Pale grey clay + staining	80.69	0.95	12.26	0.63	0.00	0.19	0.01	0.14	1.06	0.04	0.01	0.01	0.06	0.04	3.57	99.66	1.58	26.55	0.04
Priory Farm	SY88NE/782	8953 8612	3.2	CC	Pale grey clay	64.07	1.21	22.84	1.45	0.00	0.47	0.13	0.36	3.06	0.05	0.02	0.01	0.03	0.07	5.86	99.63	2.66	60.59	0.11
			3.875	CC	Dark brown clay	60.78	1.15	22.29	2.82	0.01	0.42	0.15	0.20	1.99	0.05	0.02	0.01	0.03	0.05	9.17	99.14	3.97	84.59	1.21
			4.95	CC	Medium grey clay	69.10	1.23	18.61	1.57	0.01	0.40	0.14	0.21	1.79	0.04	0.02	0.01	0.04	0.04	6.09	99.30	2.80	67.15	0.32
			6.15	CC	Pale grey clay	58.87	1.27	25.73	1.62	0.01	0.58	0.24	0.26	2.54	0.05	0.02	0.01	0.03	0.06	7.82	99.11	2.89	94.56	0.28
			7.125	CC	Pale yellowish brown clay	61.27	1.36	24.21	1.46	0.01	0.53	0.22	0.26	2.54	0.05	0.02	0.01	0.03	0.05	7.41	99.43	2.82	84.47	0.39
			9.025	CC	Yellowish brown clay	61.59	1.23	20.72	4.38	0.02	0.52	0.20	0.19	2.06	0.05	0.02	0.01	0.03	0.05	8.07	99.14	5.61	75.84	0.62
			9.725	CC	Pale grey clay	66.64	1.28	17.54	4.57	0.02	0.36	0.17	0.32	2.15	0.04	0.02	0.01	0.03	0.05	6.22	99.42	5.85	68.17	0.16
			10.225	CC	Pale grey clay	68.00	1.15	12.65	8.74	0.04	0.28	0.13	0.23	1.54	0.03	0.01	0.01	0.04	0.04	6.95	99.84	9.89	46.58	0.43
			11.525	CC	Pale grey clay	72.86	1.03	14.19	4.30	0.01	0.31	0.13	0.21	1.67	0.03	0.01	0.01	0.04	0.04	5.16	100.00	5.33	47.47	0.16
			12.275	CC	V sandy pale grey clay	74.35	1.10	15.21	2.20	0.01	0.37	0.12	0.23	1.96	0.03	0.02	0.01	0.04	0.05	4.24	99.94	3.30	46.27	0.08
			12.625	CC	Pale grey clay	64.46	1.20	19.92	4.49	0.03	0.47	0.16	0.31	2.72	0.04	0.02	0.01	0.04	0.06	5.64	99.57	5.69	61.37	0.12

Name	BGS number	NGR	Mean depth (m)	Strat	Description	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	Mn_3O_4 %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	Cr_2O_3 %	SrO %	ZrO_2 %	BaO %	LOI %	Total %	Fe_2O_3 +TiO_2 %	Surface area m^2/g	TOC %
			13.1	CC	Pale grey clay	58.29	1.15	24.35	4.73	0.04	0.57	0.20	0.41	3.29	0.06	0.02	0.01	0.03	0.07	6.85	100.07	5.88	71.81	0.11
			13.45	CC	Pale grey clay	55.46	1.13	27.48	3.69	0.01	0.59	0.25	0.40	3.29	0.07	0.02	0.01	0.02	0.07	7.32	99.81	4.82	105.57	0.11
			14.3	CC	Pale grey clay	55.34	1.21	27.03	4.19	0.00	0.54	0.25	0.40	3.19	0.07	0.02	0.01	0.02	0.07	7.43	99.77	5.40	100.69	0.11
			15.15	CC	Pale brownish grey clay	53.58	1.05	29.73	2.34	0.00	0.59	0.29	0.42	3.20	0.06	0.02	0.01	0.02	0.07	8.25	99.63	3.39	120.22	0.10
			15.725	CC	Pale brownish grey clay	53.27	0.98	30.62	1.73	0.01	0.60	0.30	0.44	3.27	0.05	0.02	0.02	0.02	0.07	8.29	99.69	2.71	125.92	0.10
			16.325	CC	Pale brownish grey clay	50.27	0.85	32.61	2.06	0.01	0.63	0.37	0.44	3.16	0.06	0.02	0.02	0.02	0.07	9.17	99.76	2.91	142.17	0.11
			17.35	CC	Pale brownish grey clay	55.19	1.53	28.68	2.75	0.01	0.27	0.29	0.23	1.52	0.04	0.02	0.01	0.03	0.05	9.15	99.77	4.28	124.21	0.18
			17.925	CC	Banded pale grey clay (+ nodules)	53.53	1.07	23.72	8.93	0.08	0.49	0.24	0.30	2.41	0.04	0.02	0.01	0.02	0.06	9.98	100.90	10.00	85.84	0.82
			18.2	CC	Dark brown clay	52.71	1.01	29.05	3.76	0.02	0.56	0.30	0.39	2.99	0.06	0.02	0.01	0.02	0.06	8.62	99.58	4.77	124.77	0.26
			18.7	CC	Medium grey clay	52.50	1.01	29.53	3.82	0.01	0.59	0.30	0.41	3.24	0.06	0.02	0.01	0.02	0.07	8.36	99.95	4.83	121.48	0.19
			18.9	CC	Brownish grey clay	52.88	1.11	29.86	3.26	0.01	0.50	0.31	0.33	2.62	0.06	0.02	0.01	0.02	0.06	8.85	99.90	4.37	124.53	0.18
			19.425	CC	Brownish grey clay	50.87	0.86	31.61	2.71	0.00	0.62	0.34	0.42	3.11	0.06	0.02	0.01	0.02	0.07	8.86	99.58	3.57	143.89	0.12
			20.4	CC	Medium grey clay	56.56	1.43	26.80	3.85	0.01	0.27	0.27	0.22	1.57	0.05	0.02	0.01	0.02	0.04	8.78	99.90	5.28	122.61	0.18
			20.925	CC	Medium grey clay	46.87	1.01	22.39	16.75	0.04	0.24	0.23	0.22	1.42	0.08	0.02	0.01	0.02	0.04	10.21	99.55	17.76	102.61	0.52
			22.125	CC	Brownish grey clay	57.29	1.12	25.39	5.56	0.01	0.24	0.26	0.21	1.31	0.05	0.02	0.01	0.03	0.04	8.26	99.80	6.68	115.99	0.14
			22.675	CC	Pale grey clay	56.80	0.90	16.96	12.96	0.10	0.24	0.18	0.19	1.28	0.03	0.01	0.01	0.03	0.03	10.00	99.72	13.86	67.41	0.98
			22.8	CC	Pale grey clay	39.76	0.66	13.63	28.10	0.24	0.22	0.19	0.15	1.06	0.05	0.01	0.01	0.02	0.03	15.70	99.83	28.76	45.62	2.01
			23.2	CC	Pale grey clay	50.29	0.78	15.44	19.46	0.14	0.24	0.15	0.17	1.29	0.15	0.01	0.03	0.03	0.05	11.34	99.57	20.24	49.45	1.07
			24	CC	Pale-medium grey clay	74.37	0.93	16.16	1.45	0.00	0.26	0.14	0.18	1.48	0.09	0.01	0.03	0.05	0.05	4.87	100.07	2.38	48.33	0.12
West Holme	SY88NE/783	8851 8858	6.025	OC	Dark brown clay	68.45	1.18	18.03	1.58	0.01	0.39	0.08	0.12	1.59	0.04	0.02	0.01	0.04	0.04	7.85	99.43	2.76	69.26	1.35
			6.3	OC	Dark brown clay	60.12	1.25	22.99	2.53	0.02	0.78	0.22	0.16	2.27	0.06	0.02	0.01	0.03	0.05	9.45	99.96	3.78	99.14	1.54
			6.725	OC	Dark brown clay + lignite clasts	59.29	0.85	14.88	10.21	0.07	0.35	0.24	0.20	1.56	0.05	0.04	0.01	0.03	0.04	11.52	99.34	11.06	77.13	2.11
			7.35	OC	Pale grey clay	59.60	1.03	15.55	11.87	0.08	0.23	0.26	0.17	0.88	0.06	0.02	0.01	0.03	0.03	9.80	99.62	12.90	51.46	0.68
			8.1	OC	Pale grey clay	54.93	0.88	15.21	15.21	0.10	0.30	0.30	0.16	1.05	0.05	0.02	0.01	0.04	0.03	11.33	99.62	16.09	72.16	0.90
			8.65	OC	Pale grey clay	62.98	0.99	16.80	8.38	0.05	0.30	0.24	0.21	1.36	0.04	0.02	0.01	0.03	0.04	8.38	99.83	9.37	69.95	0.52
Five Tips	SY88SE/1540	8836 8472	15.225	CC	Pale grey clay	71.90	1.14	17.06	1.01	0.00	0.44	0.15	0.29	2.44	0.03	0.02	0.01	0.04	0.05	5.32	99.90	2.15	52.78	0.70
			15.475	CC	V dark brown clay	66.54	1.11	18.71	1.07	0.00	0.49	0.19	0.32	2.70	0.04	0.02	0.01	0.04	0.06	8.28	99.58	2.18	82.65	2.37
Earl’s Kitchen	SY88SE/1541	8743 8322			Not sampled																			
Wareham Forest 1	SY99SW/97	9287 9170	10.05	OC	Pale grey silty clay	77.73	1.06	13.77	0.82	0.00	0.39	0.05	0.22	1.89	0.07	0.01	0.01	0.05	0.06	3.67	99.80	1.88	32.53	
			10.7	OC	Pale grey silty clay	68.99	1.23	18.13	2.37	0.02	0.8	0.1	0.31	2.68	0.05	0.02	0.01	0.03	0.06	4.70	99.50	3.60	52.99	
			11.225	OC	Pale grey silty clay	64.15	1.23	21.19	2.88	0.02	0.93	0.12	0.36	3.15	0.05	0.02	0.01	0.03	0.07	5.41	99.62	4.11	64.97	
			11.65	OC	Pale grey silty clay	71.14	1.14	15.69	3.3	0.05	0.86	0.1	0.27	2.34	0.04	0.01	0.01	0.04	0.05	4.42	99.46	4.44	38.97	
Wareham Forest 2	SY99SW/98	9202 9032	5.425	OC	Greyish yellow clay	48.28	1.00	26.92	8.65	0.06	0.54	0.19	0.39	2.78	0.07	0.02	0.01	0.02	0.07	10.38	99.38	9.65	107.71	
			6.515	OC	Greyish yellow clay	52.88	1.13	27.92	5.00	0.01	0.57	0.17	0.42	3.04	0.10	0.02	0.02	0.02	0.07	7.89	99.26	6.13	108.31	
			7.225	OC	Greyish yellow clay	55.74	1.20	28.24	2.21	0.01	0.54	0.18	0.42	2.93	0.07	0.02	0.01	0.02	0.07	7.76	99.42	3.41	114.93	
			7.835	OC	Yellowish grey clay	63.31	1.27	22.36	2.40	0.01	0.54	0.12	0.37	2.97	0.06	0.01	0.01	0.03	0.07	5.93	99.46	3.67	63.93	
			9.625	OC	Laminated mid grey clay	65.12	1.23	21.30	1.29	0.01	0.58	0.06	0.35	3.08	0.04	0.02	0.01	0.03	0.07	5.85	99.04	2.52	51.08	
			9.85	OC	Orange stained mid grey clay	65.35	1.15	20.47	2.67	0.01	0.52	0.05	0.33	2.92	0.04	0.02	0.01	0.02	0.06	5.56	99.18	3.82	56.66	
			9.975	OC	Pale grey clay	68.2	1.21	19.69	1.59	0.01	0.49	0.04	0.35	2.84	0.04	0.02	0.01	0.03	0.06	5.10	99.68	2.80	53.09	
			22.675	CC	Pale grey sandy clay	64.38	1.39	21.84	1.89	0.00	0.34	0.09	0.28	2.08	0.04	0.02	0.01	0.03	0.06	6.68	99.13	3.28	69.91	
			23.175	CC	Pale grey clay	67.57	1.42	20.18	1.24	0.00	0.40	0.10	0.29	2.48	0.04	0.02	0.01	0.03	0.06	5.54	99.38	2.66	58.37	
			24.225	CC	Pale yellow grey clay	65.65	1.38	20.91	2.49	0.00	0.45	0.13	0.33	2.73	0.06	0.01	0.01	0.03	0.07	5.52	99.77	3.87	65.02	45

Name	BGS number	NGR	Mean depth (m)	Strat	Description	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	Mn_3O_4 %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	Cr_2O_3 %	SrO %	ZrO_2 %	BaO %	LOI %	Total %	Fe_2O_3 +TiO_2 %	Surface area m^2/g	TOC %
			25.175	CC	Pale yellow grey clay	71.02	1.33	17.05	2.43	0.00	0.36	0.11	0.27	2.12	0.05	0.01	0.01	0.04	0.05	4.72	99.57	3.76	62.85	65
			26.725	CC	Pale yellow grey clay	61.76	0.96	16.15	10.54	0.06	0.34	0.12	0.25	1.94	0.04	0.02	0.01	0.03	0.05	7.52	99.79	11.50	54.15	75
			27.7	CC	Pale yellow grey clay	67.19	1.00	15.35	6.80	0.04	0.35	0.10	0.23	1.89	0.03	0.01	0.01	0.04	0.04	6.56	99.64	7.80	44.89	75
			28.225	CC	Pale yellow grey clay	63.46	1.16	18.68	6.62	0.02	0.43	0.12	0.29	2.53	0.06	0.02	0.01	0.03	0.05	6.20	99.68	7.78	51.54	
			28.675	CC	Pale yellow grey clay	59.38	1.31	21.35	6.67	0.02	0.46	0.15	0.34	2.73	0.07	0.02	0.01	0.02	0.06	6.85	99.44	7.98	69.80	45
			30.15	CC	Pale grey clay	59.83	1.15	21.66	6.02	0.02	0.48	0.17	0.33	2.72	0.05	0.02	0.01	0.02	0.06	6.83	99.37	7.17	74.37	55
			31.05	CC	Pale grey clay	64.13	1.16	19.89	4.93	0.01	0.45	0.16	0.30	2.55	0.06	0.02	0.01	0.03	0.06	5.93	99.69	6.09	72.56	55
			32.1	CC	Pale grey clay	51.55	0.89	29.62	3.83	0.02	0.67	0.27	0.42	3.59	0.09	0.02	0.02	0.02	0.09	8.53	99.63	4.72	119.31	
			32.5	CC	V dark brown clay	49.36	0.70	29.82	4.87	0.02	0.63	0.36	0.38	3.01	0.06	0.02	0.01	0.02	0.06	10.23	99.55	5.57	158.94	
			33.05	CC	Mid grey clay, sl. Sandy	51.26	0.83	30.65	3.70	0.01	0.52	0.33	0.39	2.68	0.07	0.02	0.02	0.02	0.06	8.92	99.48	4.53	154.67	
			33.55	CC	Mid grey clay, sl. Sandy	72.00	1.30	17.16	1.56	0.00	0.26	0.14	0.20	1.39	0.03	0.02	0.01	0.04	0.04	5.21	99.36	2.86	66.92	
			34.55	CC	Pale grey clay	67.68	1.12	18.39	4.01	0.01	0.29	0.17	0.24	1.59	0.03	0.02	0.01	0.03	0.04	6.01	99.64	5.13	77.32	
			35.05	CC	Pale greyish-brown clay	66.29	1.11	20.00	3.13	0.01	0.36	0.19	0.28	1.87	0.03	0.02	0.01	0.03	0.04	6.18	99.55	4.24	85.03	
			35.55	CC	Pale greyish-brown clay	60.01	1.16	23.10	4.04	0.01	0.49	0.21	0.33	2.64	0.04	0.01	0.01	0.02	0.06	7.01	99.14	5.20	93.19	
			36.05	CC	Pale grey clay	57.58	1.15	21.77	7.78	0.03	0.47	0.21	0.32	2.65	0.04	0.02	0.01	0.02	0.06	7.55	99.66	8.93	85.70	
Wareham Forest 3	SY89SE/251	8960 9234	11.1	OC	Pale grey sandy clay	77.84	0.97	13.29	1.17	0.00	0.31	0.08	0.21	1.74	0.03	0.02	0.01	0.05	0.04	3.88	99.64	2.14	43.32	
			16.55	OC	Greyish brown clay	59.13	1.18	24.16	2.64	0.01	0.98	0.19	0.40	3.53	0.05	0.01	0.01	0.03	0.07	7.22	99.61	3.82	81.97	
			17.825	OC	Sandy grey brown clay	61.75	1.15	18.82	6.20	0.06	0.83	0.20	0.30	2.73	0.08	0.01	0.01	0.03	0.06	7.34	99.57	7.35	61.98	
			19.3	OC	Greyish brown clay	64.93	1.14	18.15	4.72	0.04	0.84	0.15	0.30	2.66	0.06	0.01	0.01	0.03	0.06	6.27	99.37	5.86	60.08	
			19.525	OC	Sandy yellow brown clay	67.62	1.12	15.90	4.95	0.04	0.80	0.13	0.26	2.42	0.06	0.01	0.01	0.04	0.05	5.74	99.15	6.07	44.38	
			19.925	OC	Clay with sand bands	68.36	1.12	16.01	4.50	0.04	0.77	0.12	0.26	2.37	0.06	0.02	0.01	0.05	0.05	5.63	99.37	5.62	49.03	
Wareham Forest 4	SY89SE/252	8700 9132			Not sampled																			
Wareham Forest 5	SY89SE/253	8688 9271			Not sampled																			
Snaggs Farm	SY98SE/500	9546 8430	1.725	PC	Grey silty clay	72.54	1.27	16.69	1.06	0.00	0.40	0.20	0.25	2.25	0.04	0.01	0.01	0.04	0.05	4.76	99.57	2.33	53.70	
			11.3	BC	Dark brown clay	54.36	1.01	15.80	6.91	0.01	0.31	0.27	0.17	1.49	0.03	0.02	0.01	0.03	0.04	19.14	99.60	7.92	145.23	
			11.45	BC	Pale grey clay, stained yellow	56.85	1.44	28.01	1.40	0.01	0.46	0.23	0.42	2.87	0.06	0.02	0.02	0.02	0.07	7.91	99.79	2.84	105.86	
			7.035	BC	Pale grey clay, stained yellow	55.87	1.45	28.34	1.64	0.01	0.47	0.23	0.40	2.91	0.07	0.02	0.02	0.03	0.07	7.97	99.50	3.09	102.29	
			13.025	BC	Pale grey clay, stained yellow	55.29	1.34	28.81	1.35	0.01	0.48	0.23	0.39	2.85	0.06	0.02	0.01	0.02	0.07	8.12	99.05	2.69	105.80	
			13.525	BC	Pale grey clay, stained yellow	54.47	1.24	29.83	1.37	0.01	0.51	0.25	0.39	2.89	0.06	0.02	0.01	0.02	0.07	8.40	99.54	2.61	111.90	
			14.525	BC	Pale grey clay, stained yellow	52.52	1.12	31.17	1.43	0.01	0.53	0.26	0.41	3.02	0.06	0.02	0.02	0.02	0.07	8.97	99.63	2.55	124.49	
			15.625	BC	Pale grey clay	49.71	1.02	33.13	1.50	0.01	0.58	0.32	0.42	2.94	0.06	0.02	0.02	0.02	0.07	9.78	99.60	2.52	134.14	
			16.125	BC	Pale grey clay	50.51	1.11	32.48	1.42	0.01	0.62	0.29	0.42	3.26	0.06	0.02	0.01	0.02	0.07	9.31	99.61	2.53	109.17	
			16.6	BC	Pale grey clay	48.76	1.07	33.24	1.38	0.01	0.64	0.36	0.45	3.25	0.06	0.02	0.02	0.02	0.07	10.19	99.54	2.45	132.47	
Studland 1	SZ08SW/37	0195 8371	8.725	BC	Brown-brownish grey sandy clay	67.94	1.13	18.18	1.41	0.00	0.30	0.01	0.15	1.44	0.04	0.02	0.01	0.04	0.03	8.52	99.22	2.54	67.9	1.78
			10.025	BC	Brown-brownish grey sandy clay	62.47	1.28	22.40	1.44	0.00	0.39	0.01	0.18	1.82	0.05	0.02	0.01	0.03	0.04	9.74	99.88	2.72	79.2	1.99
			12.225	BC	Brown-brownish grey sandy clay	65.24	1.22	19.89	1.69	0.01	0.38	0.02	0.18	1.68	0.04	0.02	0.01	0.04	0.04	9.14	99.60	2.91	84.3	1.99

Name	BGS number	NGR	Mean depth (m)	Strat	Description	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	Mn_3O_4 %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	Cr_2O_3 %	SrO %	ZrO_2 %	BaO %	LOI %	Total %	Fe_2O_3 +TiO_2 %	Surface area m^2/g	TOC %
			14.675	BC	Silty brown clay	61.27	1.28	22.06	2.41	0.01	0.42	0.03	0.20	1.85	0.04	0.02	0.01	0.03	0.04	10.02	99.69	3.69	95.5	1.95
			15.625	BC	Silty brown clay	58.96	1.43	24.05	2.14	0.01	0.45	0.05	0.22	1.96	0.05	0.02	0.01	0.03	0.05	10.38	99.81	3.57	97.5	1.86
Studland 2	SZ08SW/38	0256 8320	1.225	BC	Pale pinkish brown silty clay	51.64	1.37	31.72	1.58	0.00	0.43	0.00	0.24	2.17	0.05	0.02	0.01	0.03	0.05	10.22	99.53	2.95	87.9	0.45
			7.4	BC	Grey silty clay	56.49	1.20	27.98	1.62	0.01	0.66	0.04	0.43	3.58	0.06	0.02	0.01	0.02	0.08	7.57	99.77	2.82	74.9	0.37
			7.925	BC	Pale grey clay	57.64	1.23	27.57	1.64	0.01	0.61	0.05	0.42	3.25	0.07	0.02	0.01	0.02	0.08	7.17	99.79	2.87	69.2	0.11
			8.175	BC	Pale grey clay	58.22	1.18	27.26	1.63	0.01	0.60	0.05	0.42	3.15	0.07	0.02	0.02	0.02	0.08	7.15	99.88	2.81	78.5	0.11
			9.025	BC	Pale grey clay	62.43	1.13	24.29	1.52	0.01	0.54	0.04	0.36	2.74	0.06	0.02	0.02	0.03	0.07	6.44	99.70	2.65	73.0	0.10
			10.05	BC	Pale grey clay	77.80	1.11	14.11	0.99	0.01	0.23	0.03	0.21	1.23	0.04	0.01	0.01	0.04	0.03	4.06	99.91	2.10	61.1	0.07

BC Broadstone Clay
OC Oakdale Clay
CC Creekmoor Clay
TOC Total organic carbon

Appendix 8 Hydrogeology

Mean annual rainfall varies from more than 1000 mm on the high ground north-west of Lulworth [80 83] to less than 800 mm at South Haven Point [SZ 03 86] (Meteorological Office). The mean annual rainfall from MORECS for 1961 to 1990 was 887 mm in the west and 852 mm in the centre and east of the area. Mean actual evapotranspiration is 501 mm/a, leaving an effective precipitation of between 350 and 385 mm (MORECS), the relative proportions between infiltration and surface runoff varies depending on the distribution of the precipitation with time and the permeability of soils and underlying deposits. Monkhouse *in* Bristow et al. (1991) quoted an infiltration figure of at least 350 mm/a for the Palaeogene sands.

Table 10 Annual quantities of ground water (in Ml) licensed to be abstracted by aquifer and usage

Aquifer	**Public Supply**	**Private supply and bottling**	**Industry**	**Gravel washing**	**Agriculture**	**Spray irrigation**	**Cress beds**	**Fish Farming**	**Augmentation and Leisure**	**Total**
Drift	1387 (1)	7 (3)		5 (1)	19 (5)					1417 (10)
Branksome Sand		10 (1)			3 (1)					14 (2)
Poole Formation		16 (3)	20 (1)	1038 (2)	119 (26)					1193 (32)
London Clay					15 (4)					15 (4)
West Park Farm Member		2 (1)			27 (3)	25 (1)				54 (5)
Chalk	30144 (10)	38 (7)	14 (2)	397 (4)	270 (33)	207 (4)	20175 (8)	5958 (3)	4285 (2)	61488 (73)
Total Groundwater	31530 (10)	133 (17)	34 (3)	1440 (7)	495 (79)	232 (5)	20175 (8)	5958 (3)	4285 (2)	64282 (134)
Surface Water				623 (3)	26 (2)	853 (27)		46251 (4)	2675 (4)	50428 (40)
Total Abstraction	31530 (10)	133 (17)	34 (3)	2063 (10)	521 (81)	1084 (32)	20175 (8)	52209 (7)	6960 (6)	114710 (174)

The numbers in brackets refer to the number of licences. They do not always add up as some licences abstract from more than one aquifer.

Appendix 9 Sand Grading Diagrams for Palaeogene (Tertiary) Sands

In order to assess the particle-size distribution of the Palaeogene sands in the project area, 273 samples were collected from pits and boreholes. Each pit sample was channelled over a 1 m interval and in the boreholes over a more variable interval (between 0.5 and 1 m). The samples were sieved in the Exeter Office using sieves, which ranged from 2 mm at the coarsest end down to 64 µm at the finest. Although sieves coarser than 2 mm are involved in the BS 1200 and BS 882 specifications, the sands analysed were sufficiently fine that little was retained on the 2 mm sieve in most instances, and it was not considered worthwhile to add coarser sieves.

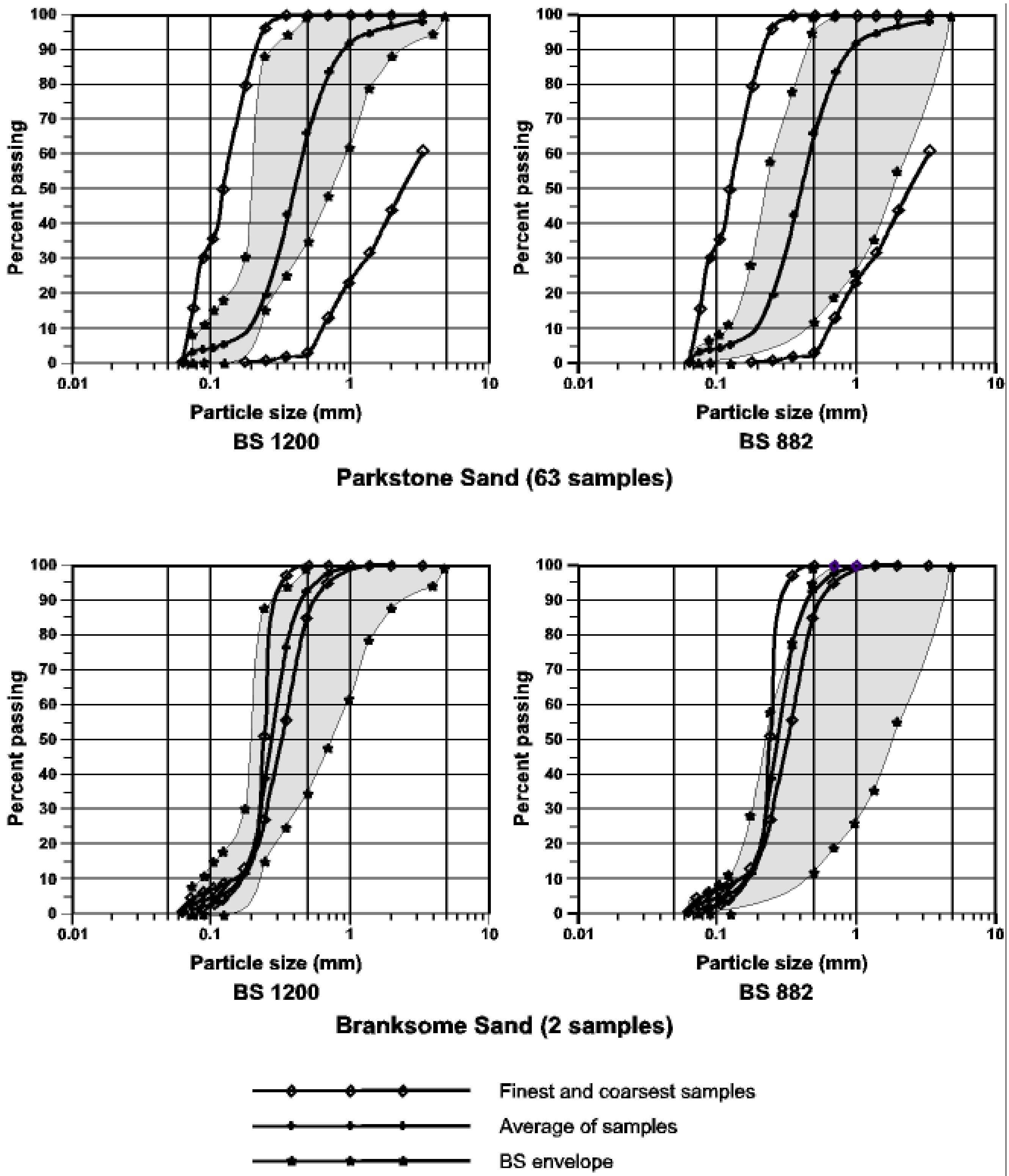
Data from a farther 132 samples from within the present project area were available from sieving undertaken in 1983-86 during a BGS Land Use Planning project carried out for the Department of the Environment. These earlier samples were collected from pits and natural sections, but the samples were collected from 0.1m intervals within the section and, therefore, less averaging of the properties occurred. The coarsest sieve used in the analysis of these samples was 1 mm. Nonetheless it was felt that these data were useful enough to add to the more recent information.

The grading data was analysed using *Sivpro*, a software package, which besides producing grading curves on demand for individual samples, also produces composite grading curves. These show the curves for coarsest sample, finest sample and an average for a given selection of samples, normally chosen on a stratigraphical basis. A chosen BS grading curve envelope is also plotted. The software can produce lists showing passes and fails for individual samples.

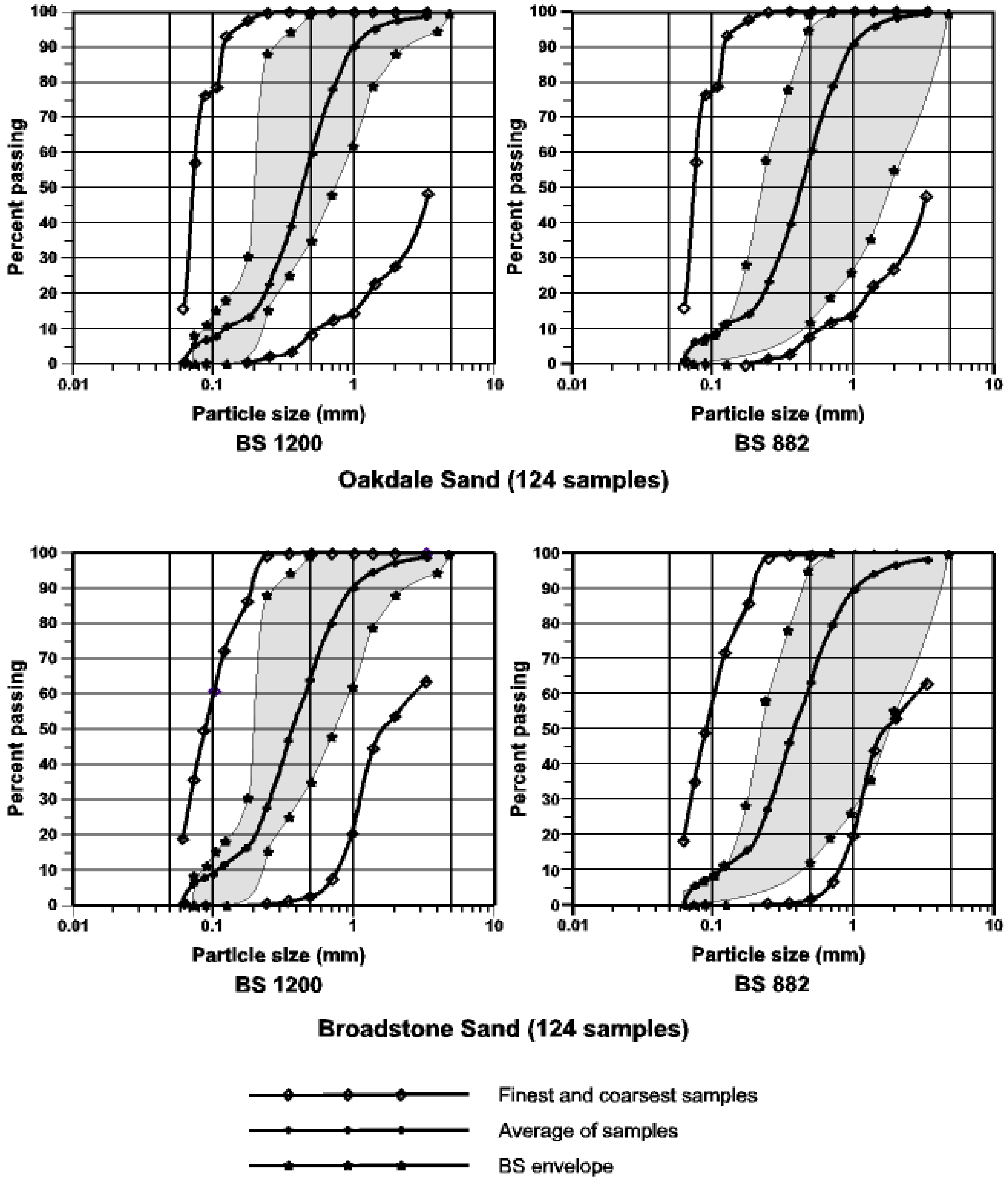
British Standards Institution BS 882:1992. Specifications for Aggregates from Natural Sources for Concrete.

British Standards Institution BS 1200: 1984. Specifications for Buildings sand from Natural Sources – Sands for Mortars for Bricklaying.

Sand grading diagrams for Parkstone Sand and Branksome Sand



Sand grading diagrams for Oakdale Sand and Broadstone Sand



Sand grading diagrams for London Clay sands and Creekmoor Sand