GREEN INFRASTRUCTURE AND OPEN ENVIRONMENTS:
LONDON'S FOUNDATIONS: PROTECTING THE GEODIVERSITY OF THE CAPITAL

SUPPLEMENTARY PLANNING GUIDANCE

MARCH 2012

LONDON PLAN, 2011
IMPLEMENTATION FRAMEWORK

MAYOR OF LONDON

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BGS prepared the draft report in 2008 on behalf of the London Geodiversity Partnership, led by the GLA. BGS is a component body of the Natural Environment Research Council.

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British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

NATURAL ENGLAND

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LONDON GEODIVERSITY PARTNERSHIP

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Mayor's foreword

Our city's development is intimately bound to its geodiversity – to the variety of natural materials and processes that have shaped it over the millenia and continue to do so.

When we piece together the geological jigsaw puzzle we gain insights into our past. But crucially this also helps us to understand our present and future. We need this knowledge to safeguard our environment, our heritage, and our wildlife, but also in order to most effectively harness our resources and develop our city's economy and infrastructure in a sustainable way.

When I published London's Foundations in 2009 it was one of the first comprehensive documents for a major urban area in this country. Now that I have published a new London Plan, it is time to update the guidance to reflect my revised policy. This document also reflects the significant work undertaken by the London Geodiversity Partnership to help us to protect and value geodiversity.

Boris Johnson

Mayor of London

Summary

This guidance is based upon a geodiversity audit of London commissioned in 2007 by a partnership led by the Greater London Authority (GLA), which include the British Geological Survey (BGS), Natural England, Government Office for London, London Biodiversity Partnership, London Borough of Lambeth, Harrow and Hillingdon Geological Society, South London RIGS Groups, Hanson UK and Queen Mary College, University of London. The project was funded by an Aggregates Levy Sustainability Fund grant from Natural England plus additional support from the GLA, BGS and Natural England London Region.

The audit began with a review of the available geodiversity documentation for London including: BGS field maps, databases and publications; Regionally Important Geological Sites (RIGS) Group information; Natural England Sites of Special Scientific Interest (SSSI) and Geological Conservation Review (GCR) documentation; and documentation and data from the GLA and London Boroughs. An initial list of around 470 sites with potential for geodiversity value was compiled from this information. This list was then narrowed down to 100 for further assessment by exporting site locations to a GIS and cross-checking against digital aerial photography backed up by BGS staff local geological expertise.

Using the procedure set out in this report field auditing was carried out by BGS staff and the South London RIGS Group between November 2007 and April 2008. From the list of 100 sites, 35 sites were found to be suitable for detailed auditing. Harrow and Hillingdon Geological Society audited a further site in November 2008, bringing the total to 36 sites.

Using the criteria set out in this report 14 of the 36 sites are recommended for designation as Regionally Important Geological/ geomorphological Sites (RIGS) in borough Local Development Documents. Of the 33 London boroughs, RIGS are recommended in eight, with five in Bromley, three in Croydon and one each in Lewisham, Ealing, Greenwich, Harrow, Hillingdon and Bexley.

Using the criteria set out in this report 15 of the 36 sites have the potential to be designated as Locally Important Geological Sites (LIGS). These sites are located in nine boroughs, three in Waltham Forest, two in Bromley, two in Islington and one each in Barnet, Lewisham, Redbridge, Wandsworth, Southwark and Sutton.

However, the audit was never intended to be a static document and since its publication in 2009 the London Geodiversity Parnership have continued to undertake a programme of site audits and has made, and will continue to make, recommendations for both additions and deletions to the list of sites. During 2010 and 2011 the London Geodiversity Partnership re-evaluated a number of sites and recommended the deletion of nine of the 15 potential LIGS in the 2009 edition of London's Foundations, and their replacement with nine new sites. They are also recommending changes to Regional Sites, increasing them from 14 to 28. The 14 potential RIGS and 15 LIGS are recommended for further consideration and consultation by Boroughs through the LDD process. The GIS audit information on the sites is held by Greenspace Information for Greater London.

Planning proposals should have regard to geodiversity in order to implement strategic and local policies. Sites should be protected, managed and enhanced and, where appropriate, new development should provide improvements to the geodiversity value of a site. This can include measures that promote public access,

study, interpretation and appreciation of geodiversity.

In addition to individual sites of geodiversity interest, Greater London has distinctive natural landscapes shaped by geological processes, such as undulating chalk downlands with dry valleys in south London, and river terraces forming long flat areas separated by steeper areas of terrace front slopes. This natural topographic geodiversity underlying London should be understood, respected and only altered with full knowledge of its origin and form. Planners are encouraged to use authentic contouring in restoration work and new landscaping schemes, maintain the contributions of natural topography, rock outcrops, landscape features, and to maintain soil quality, quantity and function.

The guidance in this document replaces London Foundations 2009. The document is divided into 9 sections;

1. The Introduction – sets out the purpose behind the document and its relationship to the London Plan, specifically Policy 7.20;
2. Explains what geodiversity is and why it matters;
3. Explains the three levels of geological conservation designation – national, regional and local;
4. Explains the evolution and development of London's geological landscape;
5. Looks at London's geological resources;
6. Takes the reader through the audit process;
7. Sets out the audit results and recommendations;
8. Sets out guidance to boroughs; and
9. Looks at Geodiversity Action Plans.
10. Appendices 1-6 provide more detailed information underpinning the text above.

CHAPTER ONE

INTRODUCTION

1.1 The London Plan published in July 2011, aims to protect and promote geodiversity in London (see Policy 7.20 and Map 7.4). These can be Regionally Important Geological Sites (RIGS) or Locally Important Geological Sites (LIGS); these sites, along with the designated national sites, are of strategic importance for geodiversity across London. This report identifies suitable RIGS and provides guidance to enable the boroughs to identify Locally Important Geological Sites (LIGS), which would represent additional sites of local value.

1.2 This supplementary guidance provides advice that shows how the London Plan policy can be delivered. It is intended for all those interested in the geodiversity of the Greater London area and seeks to address geodiversity in its very broadest sense. Although dealing with a varied, and sometimes complex, range of issues relating to geodiversity, it is not targeted solely at practitioners in earth science, but is intended as a source of information and guidance for a wide range of planning, management, conservation and interpretation interests.

1.3 The document and associated GIS information, which is available from Greenspace Information for Greater London (GiGL), will help to provide a strong environmental evidence base for adoption of good practice in the planning system. The Mayor looks to the boroughs to use this information to inform the protection of important sites and the promotion of geodiversity in their local development documents and in the exercise of their planning powers. Land managers and owners are also encouraged to consider ways of managing sites to improve access to and understanding of geodiversity.

1.4 It does not seek to offer a detailed geological description of the area, or provide detailed technical advice, but introduces those aspects of the geology that are essential to appreciating their importance in London. The use of technical language has been kept to a minimum, though the use of some geological terms is unavoidable. To assist readers unfamiliar with such terms a glossary is provided.

1.5 The 2009 report was produced by a partnership led by the Greater London Authority (GLA), which includes the British Geological Survey (BGS), Natural England, Government Office for London, London Biodiversity Partnership, London Borough of Lambeth, South London RIGS Group, Harrow and Hillingdon Geological Society, Hanson UK and Queen Mary, University of London. It was funded by an Aggregates Levy Sustainability Fund grant from Natural England and funding from the GLA, BGS and Natural England London Region. On behalf of the partnership, BGS undertook the survey work and provided technical expertise in the selection of sites and preparation of this report. This 2012 update reflects the new London Plan policy and the work of the London Geodiversity Partnership in producing and then implementing their Geodiversity Action Plan (2009-2013) by reviewing the Locally Important Geological Sites (LIGS).

Aims

1.6 The principal aim of this SPG is to achieve more effective geoconservation by helping to ensure that the requirements of London Plan policy on Geological Conservation are met. It also seeks to identify and record features of geological and geomorphological value, including identification and assessment of potential RIGS. As one of the first comprehensive plans for such a densely populated area it is intended to serve as an example of good practice for cities and other urban areas in the UK. The project was one of the first to address regional scale geoconservation in a largely urban area.

To achieve these aims, the SPG:

- reviews existing guidance and criteria for geodiversity assessment
- undertakes a geodiversity audit of London, including: a regional geodiversity overview; a description of methods and criteria used for the audit; a map and description of each recommended RIGS; good practice guidance on geoconservation for the London Boroughs
- outlines further actions needed to facilitate the implementation and future development of the Geodiversity Action Plan (GAP) for London.

1.7 Geological conservation can be viewed as a four-part process:

- audit and selection
- site designation using a hierarchical approach that reflects the importance of the sites, from statutory Sites of Special Scientific Interest to non-statutory Regional and Locally Important Geological Sites
- site protection, proactive management and promotion
- valuing geological interests in the wider landscape.

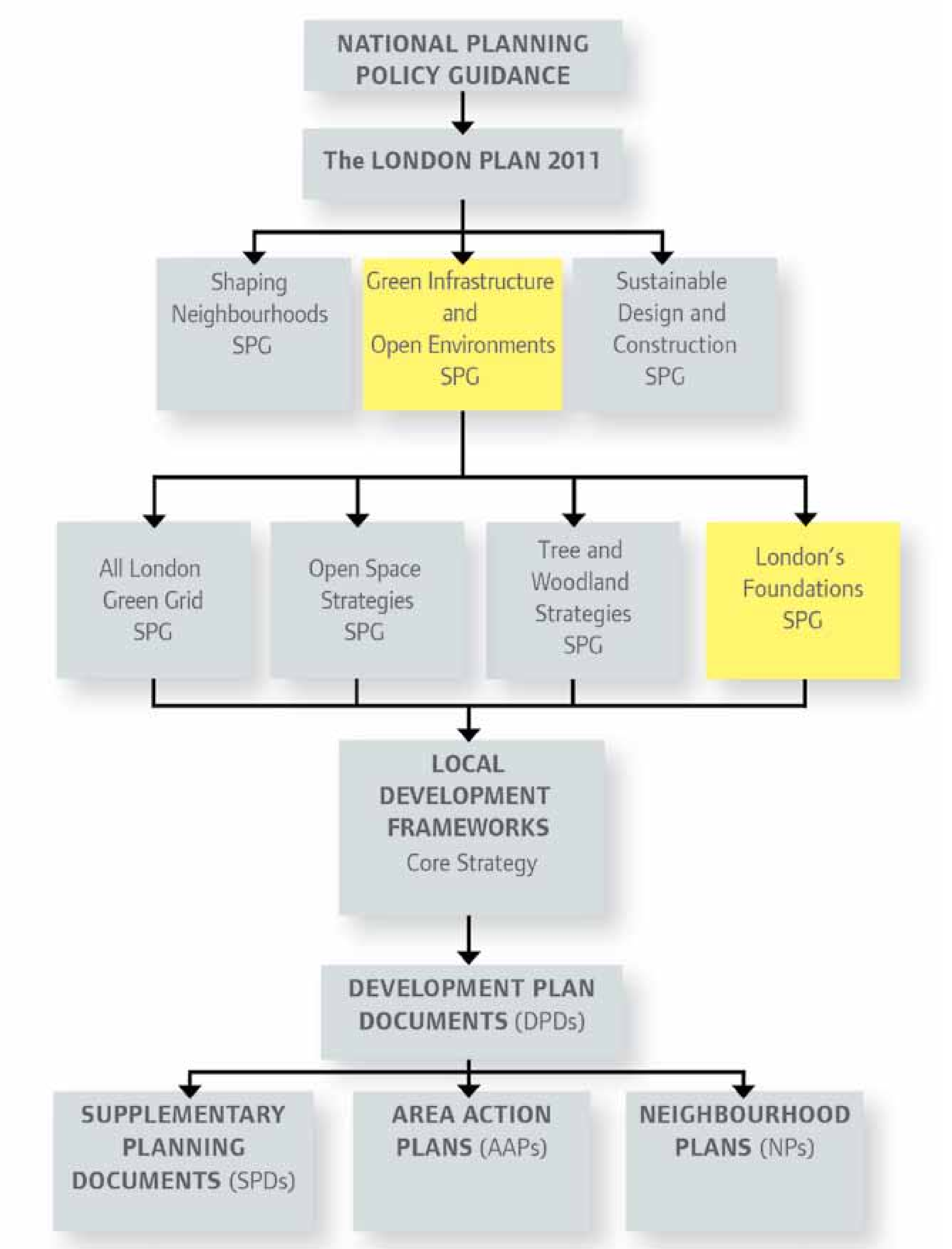
1.8 This process is not a linear progression, but cyclical as there is an ongoing need to ensure that the site coverage remains up-to-date both from a scientific perspective and because some sites may lose their original value through damage or loss of interest of certain features. This document continues this process by recommending changes to sites (see Section 7).

1.9 This SPG provides non-statutory guidance that can be taken into account as a material planning consideration. It is consistent with the advice of Circular 1/2008 and has been prepared as paragraph 2.22 of the Circular requires. This SPG is supplementary to London Plan Policy 7.20 Geological Conservation. It is consistent with the advice in the current relevant PPS, PPS 9 (Biodiversity and Geological Conservation). In July 2011 the Government issued for consultation a National Planning Policy Framework (NPPF) to replace all of the existing advice set out in PPGs and PPSs. In the draft NPPF the planning system is advised to 'aim to conserve and enhance the natural and local environment by protecting valued landscapes' (para 164) and to 'prevent harm to geological conservation interest' (para 168).

1.10 This SPG is one part of a suite of guidance on green infrastruture and the open environment. The All London Green Grid SPG sets out an overall framework on the provision of green infrastructure. This SPG and the Preparing Tree & Woodland

Strategies SPG provide more detailed guidance on particular aspects of the open environment. A further publication on open space strategies, will follow later in the year.

Planning Policy Framework



CHAPTER TWO

UNDERSTANDING GEODIVERSITY

What is geodiversity and why is it important?

2.1 The European Landscape Convention defines landscape as 'an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors' (ELC, Article 1). Geodiversity is concerned with both the natural and human aspects of landscape, but is primarily focused on the rocks, sediments, soils, the landscape topography and the processes that act on the landscape. Geodiversity can be defined as:

'the variety of rocks, fossils, minerals, landforms, soils and natural processes, such as weathering, erosion and sedimentation, that underlie and determine the character of our natural landscape and environment' (London Plan)

2.2 Geodiversity is a fundamental natural resource – all raw materials that cannot be grown and all energy that cannot be generated by renewables have to be won from the Earth's crust using geological science. It is the source of much of our prosperity, a key factor in our cultural identity, and will play a fundamental role in our nation's future development. Understanding of geology is also vital to the design and location of buildings and infrastructure as well as to the safe disposal of waste, and the identification and management of a wide range of natural and man-made hazards. All are aspects of geodiversity.

2.3 An awareness of geodiversity helps us to understand our environment and predict environmental change in the future. Geoscience research demonstrates that surface environments are continually evolving through natural self-regulating systems involving the Earth's crust and mantle, oceans, atmospheric processes and life forms. Human activity imposes further pressures and changes to these natural cycles, which pose great challenges to modern society. Global climate change from rising levels of greenhouse gases and exhaustion of finite resources such as fossil fuel are two of the most pressing. Studying the geological record can play a vital role predicting the Earth's response to these changing conditions. Recognition of geodiversity can help maintain this record for future study.

2.4 Geology is fundamentally a field-based discipline and the existence of well-exposed geological features is critical for scientific study, educational use and recreational enjoyment. If advances in geoscience and the educational and the recreational study and enjoyment of geology are to continue, important sites need to be identified and managed. Geoscientists need sites on which to undertake their research. Teachers and students need sites on which to demonstrate the principles of geology and landscape evolution processes. In order to locate and utilise the Earth's resources and to give advice on the management of natural hazards, trained earth scientists are needed. Such training requires access to high-quality geodiversity sites to provide field-based experience. Consequently, it is necessary to audit, conserve and manage our geological heritage so that it remains available for future scientific, educational and recreational use (Prosser et al., 2006).

2.5 The recognition of natural and cultural heritage features and their sustainable management are today accepted as important functions within a modern society. The geodiversity of any area is an equally important part of its natural heritage as its biodiversity. Conservation, sustainable management, educational use and interpretation of geodiversity are thus as important as biodiversity or archaeology.

2.6 However, geodiversity is not, or should not be regarded merely as concerned with conservation of Earth heritage sites or features (sites of geological and geomorphological interest) – it has a vital place in all aspects of natural heritage and impacts in fields as varied as economic development (for example, supporting the development of geotourism in the European Geopark Network), building stone resource development, education and lifelong learning, archaeology, art and wildlife.

2.7 The intrinsic, cultural, aesthetic, economic, functional and research value of geodiversity has been evaluated by Murray Gray in his book 'Geodiversity: valuing and conserving abiotic nature' (Gray, 2004). Webber et al. (2006) reviewed the social and economic value of geodiversity and summarized the four main geodiversity value in geodiversity value classes (Figure 1).

2.8 An essential starting point in understanding an area's geodiversity is an appreciation of the most up-to-date available knowledge of its geological features, together with the processes that have formed them and continue to influence them.

2.9 An area's geodiversity includes:

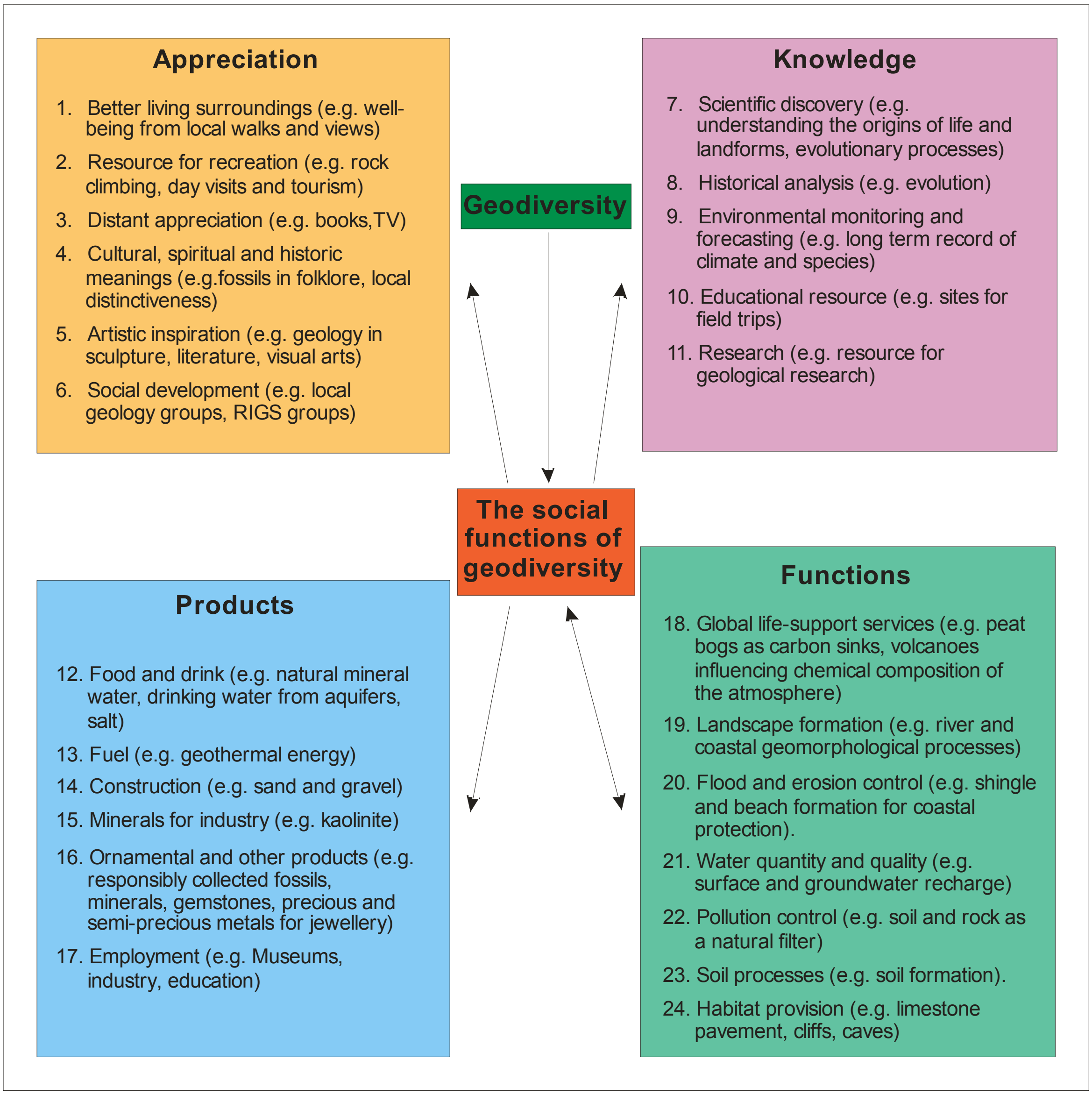
- the broad geological and geomorphological character of the area
- key natural systems and processes within the area, such as pedological, fluvial or coastal processes
- main topographic features, including those which, due to their linear or continuous nature, are important habitats and conduits for the migration, dispersal and genetic exchanges of plants and animals
- sites or features where representative examples of the area's geological strata and features may be seen
- sites or features which are deemed worthy of some form of designation or protection for the quality of the Earth heritage features displayed
- the location and nature of past and present working of minerals
- sites and features currently employed in interpreting geodiversity
- the influence of geology in shaping the man-made environment, urban landscapes and architectural heritage
- the inter-relationship between Earth heritage and other interests, for example biodiversity, archaeology, history.

2.10 Documentation of an area's geodiversity may include:

- materials collections and site and other records such as borehole logs
- published literature and maps

- the historical legacy of research within the area.

Figure 1 The social functions of geodiversity (from Webber et al., 2006)



Relationship with biodiversity

2.11 Geodiversity is of fundamental importance in controlling the topography, altitude, aspect and the physical substrates which provide the habitats that underpin biodiversity. At the physical level, geological processes such as glacial erosion and properties such as the relative resistance to erosion of different rock types produce varying landforms and relief features within a landscape. These landscape features in turn provide diversity in physical conditions that support plant and animal communities, at all scales from small outcrops through to mountain ranges.

2.12 At the larger scale, tectonic processes (e.g. continental break-up and collision) create pronounced relief which has a direct influence on regional and local climate, and in turn, on the ecosystems that develop. This also works at smaller scales, for example, microclimate differences between the top and base of a cliff. Landscape variety is continually modified by geomorphological processes acting at a variety of scales. Glacial, periglacial, fluvial and other processes such as slope failure produce new habitats that promote ecological succession and cyclicity and increase overall biodiversity.

2.13 In locations where climate, relief and human management are constant, the variation in rock type can strongly influence vegetation distribution. The way in which a rock weathers and acts as parent material for soil development is the most obvious mechanism for influencing floral characteristics. The main factors that rock type influences are soil chemistry, grain size, texture, porosity and permeability. Differences in pH have a major impact on the uptake of various minerals by plants – this is probably the key factor in differentiating the floras from calcareous and non-calcareous rocks. Specific plant-rock associations do occur with rocks of a very distinct chemistry such as serpentinite (for example Calaminarian grasslands of the Violetalia calaminariae). Rock type also influences chemistry of both ground and surface waters which give rise to differing aquatic communities.

2.14 In summary, the very diversity of rock types and geomorphological processes creates and leads to further diversity in their interaction with other processes. Ultimately biodiversity is a direct function of geological form and process. In recognition of these close links the London Geodiversity Partnership is now working closely with the London Wildlife Sites Board.

Geodiversity and spatial planning

Sustainable development policies

2.15 At the Rio Earth Summit in 1992, governments around the world committed to the principles of sustainable development contained within the Rio Declaration on Environment and Development.

2.16 Since the transposition of the Strategic Environmental Assessment (SEA) Directive (EC Directive 2001/42 EC) into UK law in 2004, the Mayor of London and Local Planning Authorities (LPAs) must prepare an SEA as an integral part of the preparation of the Spatial Development Strategy (London Plan) and Local Development Documents respectively. Included in the preparation of these documents is the need to collect and present baseline environmental information, which includes geological, soil and landscape information. As well as the current state of this baseline, the likely significant effects on the environment of implementing the plan need to be identified, described and evaluated.

2.17 Also at the Rio Earth Summit, international acceptance of the need to conserve biodiversity led to the UN Convention

Biological Diversity and the subsequent signing by over 200 countries. Since the UK Government published 'Meeting the Rio Challenge' in 1995, most local authorities or regions in the UK have prepared and implemented Biodiversity Action Plans (BAPs) for their areas, and biodiversity is now accepted as an essential element in sustainable development planning and management strategies. The GLA published its Biodiversity Strategy in 2002 (GLA, 2002). Until relatively recently the parallel concept of geodiversity had attracted little interest from planners, despite its fundamental importance in underpinning biodiversity.

Planning policy

2.18 The 1949 National Parks and Access to the Countryside Act established the legal framework for nature conservation, including geological conservation. Since then geodiversity, alongside wildlife interests, has been an important part of the planning process.

2.19 PPS9, that will be replaced by the draft NPPF once it is finally adopted, is explicit about the significance of geological conservation in relation to the planning process and associated policy development (paragraph 168).

2.20 PPS9 has informed the development of Policy 7.20 and Map 7.4 in the London Plan, the Mayor's Spatial Development Strategy (Figure 2). The policy underlines the need to protect and promote London's geodiversity and sets the strategic context for local planning decisions and policies in the Development Plan Documents (DPDs) prepared by the London boroughs. Chapter 8 of this report sets out advice on incorporating geodiversity into local level planning. The Government has consulted on a draft National Planning Policy Framework (NPPF). The draft NPPF requires the planning system to prevent harm to geological conservation interest. This guidance provides the evidence base for boroughs to demonstrate how to achieve this through the local planning process.

Figure 2 London Plan Extract

London Plan Policy 7.20 Geological Conservation

Planning Decisions

A Development proposals should:

a wherever possible, make a positive contribution to the protection and enhancement of geodiversity

b be resisted where they have significant adverse impact on sites with existing or proposed European or national designations in accordance with Government guidance

c protect regionally important geological sites (RIGS)

d give locally important geological sites (LIGS) the level of protection commensurate with their importance

B LDF preparation

In their LDFs borough should:

a establish clear goals for the management of identified sites to promote public access, appreciation and interpretation of geodiversity

b ensure sites of European, national or regional conservation importance are clearly identified

c use the guidance set out in London's Foundations (2009) and work with appropriate organisations to investigate additional sites that maybe of value in the local area and afford them the appropriate level of protection in LDFs.

7.63 New development should have regard to the conservation of geological features and should take opportunities to achieve gains for conservation through the form and design of development. Where development is proposed which would affect and identified geological site the approach should be to avoid adverse impact to the geological interest. If this not possible, the design should seek to retain some of the geological interest and enhance this where possible, for example by incorporating permanent sections within the design. The negative impacts of development should be minimised and any residual impacts mitigated. On behalf of the London Geodiversity Partnership, and working with Natural England, the Mayor has published 'London's Foundations' as implementation guidance to advise boroughs on fulfilling their statutory duty set out in PPS9 to protect geodiversity. The Mayor will continue to work with all relevant partners to identify regionally important geological sites.

CHAPTER THREE

GEOLOGICAL CONSERVATION

Statutory designations

Sites of Special Scientific Interest (SSSIs)

3.1 A representative sample of the best of the UK's wildlife and geological sites enjoy legal protection through their designation as SSSIs. The designation was introduced as one of the provisions of the 1949 National Parks & Access to the Countryside Act and has been maintained through subsequent legislation. The term SSSI is used today to denote an area of land notified as being of special nature conservation interest under the Wildlife and Countryside Act 1981. The Countryside and Rights of Way (CRoW) Act 2000 greatly strengthened the legislation relating to the conservation of geology and wildlife in England and Wales by placing emphasis on management rather than just conservation of SSSIs. It requires that all public bodies should conserve and enhance SSSIs. The CRoW Act also makes it an offence for anyone to knowingly or recklessly damage an SSSI, including by irresponsible mineral or fossil collecting. The network of SSSIs in England is the responsibility of Natural England. Designation as an SSSI does not imply any right of access for third parties. Neither does it follow that the site is necessarily appropriate for public interpretation. There are seven SSSIs designated for their geological interest in Greater London area (Figures 3 and 4).

Figure 3 Geological Sites of Special Scientific Interest in Greater London

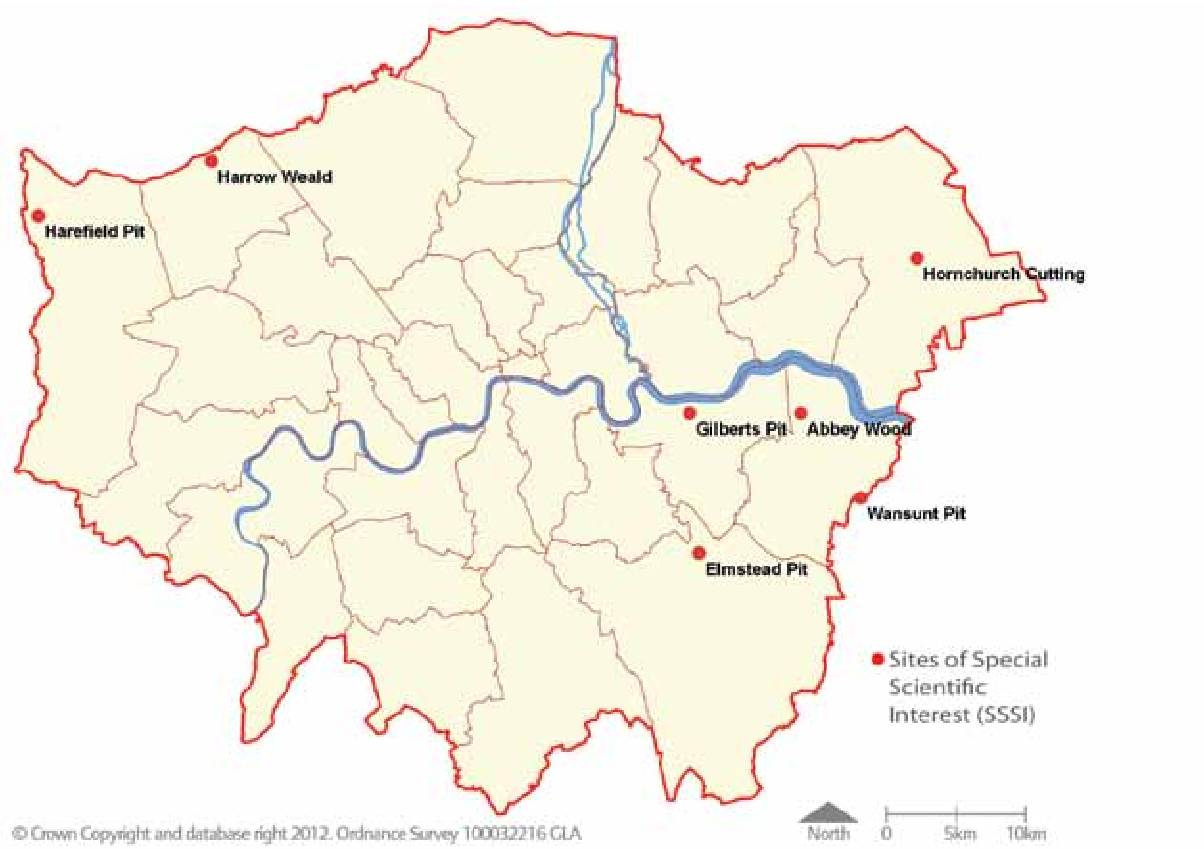


Figure 4 Geological SSSIs in Greater London

Site Name Site No.	Location Grid ref Area (ha)	Condition Ownership	Comments and stratigraphy
Abbey Wood GLA 1	Bexley TQ 480 786 6.89	Favourable London Borough of Bexley	Abbey Wood contains some of the most fossiliferous deposits in the Greater London area providing remains of a diverse mammal assemblage of earlyEocene age. The deposits are also important for studies in the evolution of bird faunas. The deposits occur in the Harwich Formation in the 'Lessness Shell Bed'.
Wansunt Pit GLA 35	Bexley TQ 515 738 1.94	Unfavourable Private landowner, but site managed by London Wildlife Trust	The site currently provides no exposures in the Dartford Heath Gravel, a deposit that has been the subject of considerable controversy since the turn of the century. Current geological maps indicate the deposit is part of the Boyn Hill Gravel, of equivalent age to the terrace deposit at Swanscombe, but it has also been attributed to the Black Park Gravel, an older terrace deposit (Ellison et al., 2004).
Elmstead Pit GLA 33	Bromley TQ 4232 7066 0.05	Favourable Private landowner	Elmstead Pit provides a nationally important exposure of the Harwich Formation (Blackheath Beds) through a section containing an unusually rich fossil fauna (Daley, 1999a)
Gilbert's Pit GLA 14	Greenwich TQ 418 786 5.35	Unfavourable London Borough of Greenwich	Gilbert's Pit provides one of the most complete sections through the Early Palaeogene beds in the Greater London area. It forms a key Palaeogene site for stratigraphic studies and is particularly important for a palaeogeographic reconstruction of the Lambeth Group. It exposes the Woolwich Formation and the Harwich Formation (Blackheath Beds) but former exposures of the Thanet Sand and Chalk are now buried by war-time rubble and scree (Daley, 1999a)
Harefield Pit GLA 34	Hillingdon TQ 049 898 1.61	Unfavourable Private landowner	Harefield Pit provides a key section in the London Basin for a sequence through the Upper Chalk, Lambeth Group and London Clay. It is also the only known site for calcareous floral remains in the Reading Formation. As discussed by Daley (1999b), the stratigraphy of the Harefield Pit has been described in various ways. It includes representatives of the Upnor Formation (resting on a burrowed Chalk surface), the Reading Formation, Harwich Formation and the sandy basal part of the London Clay.

Site Name Site No.	Location Grid ref Area (ha)	Condition Ownership	Comments and stratigraphy
Harrow Weald GLA 18	Harrow TQ 147 929 3.52	Favourable London Borough of Harrow	Harrow Weald is a small but important geological site which exhibits the most compelte exposure of the Stanmore Gravel, overlying the Claygate Member at the top of the London Clay Formation.
Hornchurch Cutting GLA 19	Havering TQ 547 874 1.57	Favourable Network Rail	Hornchurch Cutting provides unique sections through a series of deposits which are of great stratigraphical importance for studies of the Pleistocene. In particular the site is of considerable significance for correlating the formation of the Thames terrace sequence with the glacial stratigraphy of southern Britain. The sections expose a channel within London Clay bedrock infilled by Anglian till (the 'Hornchurch till'). This till is overlain by river terrace deposits currently assigned to the Black Park Gravel (although a correlation with the Boyn Hill Gravel has also been suggested).

Geological Conservation Review (GCR) Sites

3.2 The Geological Conservation Review (GCR) was initiated by the Nature Conservancy Council in 1977 to identify, assess, document and eventually publish accounts of the most important parts of Great Britain's rich and varied geological heritage. In general, only one site was selected as the best example of each aspect of geology under consideration. GCR sites were selected on the basis of their scientific value rather than their educational or historical importance. Three criteria were applied in selecting the GCR sites:

- sites of international geological importance
- sites that are scientifically important because they contain exceptional features
- sites that are nationally important because they are representative of a geological feature, event or process which is fundamental to understanding Britain's geological history.

3.3 Once selected, a GCR site was then proposed as a potential SSSI. All the GCR sites in Greater London area are designated as SSSIs (See Figure 5 below, see para 3.1 above for more on SSSIs). For further detail of the Geological Conservation Review, see http://www.jncc.gov.uk/page-2947

Figure 5 GCR Sites and Blocks

Site Name and Grid ref	Site Code	GCR Block
Abbey Wood(s) - TQ 480 786	2903	Mesozoic-Tertiary Fish/ Amphibia
	1248	Tertiary Mammalia
	582	Aves
Harefield - TQ 049 898	762	Tertiary Palaeobotany
	519	Palaeogene
Charlton Sand Pit (Gilberts Pit) - TQ 419 786	520	Palaeogene
Elmstead Rock Pit - TQ 423 706	521	Palaeogene
Hornchurch - TQ 547 873	893	Quaternary of the Thames
Wansunt Pit - TQ 514 737	846	Quaternary of the Thames
Harrow Weald Common - TQ 147 929	1170	Quaternary of the Thames

Regionally Important Geological/ geomorphological Sites (RIGS)

3.4 RIGS were established in 1990 by the Nature Conservancy Council (NCC) (predecessor of English Nature and Natural England). They have support from Natural England and other national agencies, and are increasingly recognised by local planning authorities. RIGS complement the SSSI coverage. To date RIG Sites have been selected by voluntary groups (known as RIGS groups), which are generally formed by county or by unitary authority area in England. There are more than 50 local groups in the UK, though not all are active. There are two active RIGS groups in London, South London RIGS and North West London RIGS.

3.5 RIGS are currently the most important designated places for geology and geomorphology outside statutorily protected land such as SSSIs. The designation of RIGS is one way of recognising and protecting important geodiversity and landscape features for future generations to enjoy.

3.6 Guidance on RIGS is available from GeoConservation UK (www.geoconservationuk.org.uk). They are important as an educational, historical and recreational resource. Sites are selected according to:

- the value for educational purposes in life-long learning
- the value for study both by professional

and amateur earth scientists

- the historical value in terms of important advances in Earth science knowledge, events or human exploitation

- the aesthetic value in the landscape, particularly in relation to promoting public awareness and appreciation of geodiversity.

3.7 In London RIGS are sites that are considered worthy of protection for their geodiversity importance at the London-wide level. They can be viewed as equivalent to Sites of Metropolitan Importance for Nature Conservation (SMIs), which include land of strategic importance for nature conservation and biodiversity across London. Chapter 7 of this report identifies sites that meet the criteria for London RIGS and are recommended that they be designated in the DPDs prepared by the London boroughs. These sites should be protected as set out in Policy 7.20 of the London Plan. An additional 14 sites have been identified as potential RIGS. Boroughs should carry out further consultation on these potential sites to consider their designation as RIGS in DPDs

Locally Important Geological Sites (LIGS)

3.8 The London boroughs may designate certain areas as being of local conservation (including geological) interest. The criteria for inclusion, and the level of protection provided, should reflect the local level of importance in the hierarchy of sites.

3.9 LIGS are equivalent to Sites of Borough or Local Importance for nature conservation, which are accorded a level of protection commensurate with their borough or local significance. Local site networks provide a comprehensive rather than a representative suite of sites. Defra have published detailed guidance on identification, selection and management of local sites (DEFRA, 2006).

3.10 These sites are designated in the DPDs prepared under the Town and Country Planning system by the London boroughs and are a material consideration when planning applications are being determined. Chapter 7 of this report identifies potential LIGS that may be designated in DPDs by the London boroughs.

Potential conflict of interest

3.11 Sites or features selected for any form of protection can rarely, if ever, be satisfactorily regarded as ‘single interest’ sites. Statutory designation of sites, as SSSIs or scheduled monuments, offers a powerful means of protecting the most important sites and features, though even here failure to take account of other interests can lead to misunderstandings and potential conflict. In some instances scheduling without adequate multi-disciplinary consultation may result in these related interests being put at risk. Non-statutory designations, whilst offering no legal protection, may nevertheless be extremely useful in highlighting a site’s importance.

3.12 In some instances the legal restrictions associated with scheduled monuments may be detrimental to the conservation and use of the site’s geodiversity interest.

For example, a mine or quarry site selected for conservation and restoration of its archaeological interest may also include extremely important geological features. Failure to take these into account may result in them being compromised or even destroyed. Similarly, an abandoned quarry which displays extremely important geological sections may also support interesting or important plant communities, may be a bat roost, or may be associated with historically interesting buildings. Thus, there is a need to resolve the potential for conflict of conservation interests and it is hoped that this report will help to identify such conflicts and opportunities to combine interests.

3.13 A multi-disciplinary approach to conservation of all features is not only highly desirable, but offers enormous potential to enhance the value and interest of many individual sites. Whereas this may seem obvious, often the underlying principle seems to have been overlooked, or even ignored, in many previous conservation initiatives. More recently, integrated approaches are increasingly being encouraged and adopted, for example through the development of integrated management plans and conservation objectives.

CHAPTER FOUR

LONDON'S GEOLOGICAL HERITAGE

Evolution

4.1 This chapter sets the geological scene for a discussion of the geodiversity of Greater London, summarising the geological evolution and development of the landscape.

Geological time

4.2 Geological time is divided into Eons, Eras, Periods and Epochs (Figure 6). Although the Earth is almost 4600 million years old, events from only the last 100 million years or so are represented in the surface geology of London. The coloured bands in Figure 6 indicate those periods of geological time represented in the district's rocks, from the mid-Cretaceous to the present, with their age in millions of years. Also indicated are events that occurred during the long periods of time for which no record remains; their presence has been inferred from evidence in adjoining areas.

4.3 The extent of geological time may be appreciated by considering the whole of Earth history as a single day. On this scale, the oldest rocks in the London area formed around 11.30 pm, and the London Clay that underlies most of the metropolis about 11.45 pm. The Quaternary ice ages began less than one minute before midnight and human-like creatures first strolled by the River Thames at less than one second to midnight.

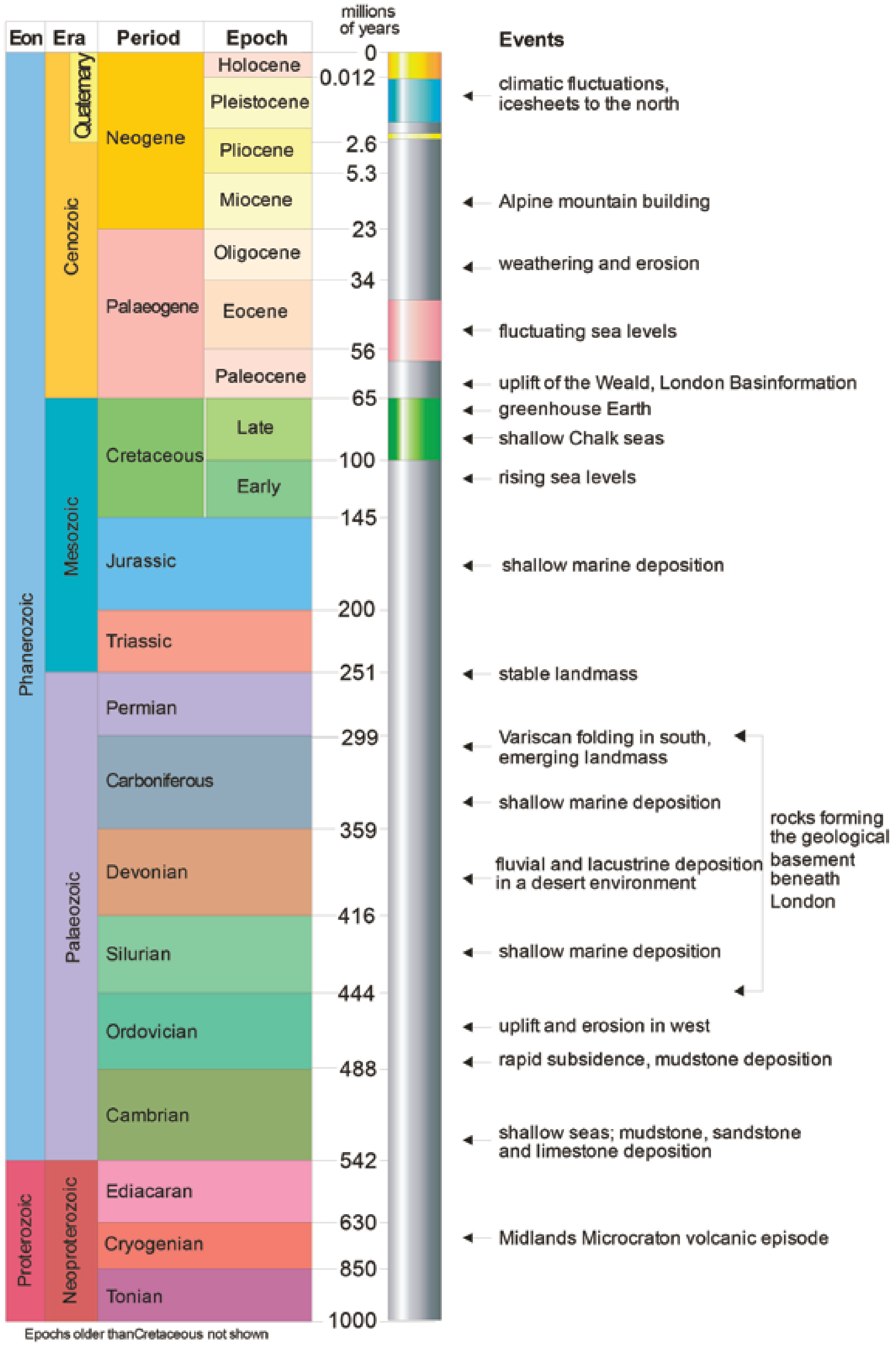
4.4 To understand the surface geology, however, it is also necessary to consider the older rocks that form the local geological basement. In much of the district these lie between only 250 and 400 metres below the surface, but in the south they are much deeper, at more than a kilometre (Figures 7 and 8). The London district lies at the junction of two deep-seated geological terranes within the pre-Mesozoic basement. A third terrane lies just to the east (Pharaoh et al, 1993). These can be seen on the Bouguer gravity anomaly map of the region Figure 9).

4.5 The north and west of the district is underlain by the Midlands Microcraton, an area where Proterozoic and Palaeozoic rocks occur at relatively shallow depths. Structural trends are complex. The Midlands Microcraton extends west as far as Worcestershire and north beneath Leicestershire. It formed part of the Early Palaeozoic continent of Avalonia. In mid-Silurian times, when it lay at a latitude of about 30° south, the northern edge of Avalonia was driven at a shallow angle beneath Laurentia, during the Caledonian Orogeny. Since then, the Midlands Microcraton has been relatively tectonically stable. The terrane to the east of London is part of a Caledonide fold belt that underlies eastern England.

4.6 Evidence from the English Midlands suggests that the Proterozoic strata beneath London include volcanic rocks between about 600 and 700 million years old. Deep boreholes in the region show that the Early Palaeozoic strata are dominated by mudstones and sandstones, with some limestones, laid down in shallow seas. Most of the Ordovician, however, was a period of non-deposition in this region.

4.7 During the Devonian, following the Caledonian Orogeny, the London region formed part of a broad low-lying area with mountains of the Anglo-Brabant Massif to the north and an ocean to the south. Devonian strata occur at depth throughout

Figure 6 A timescale and summary of geological history for the Greater London area



most of the region, although varying in thickness considerably. They are dominated by sandstones, with siltstones and mudstones, deposited in desert, lacustrine and fluvial environments.

4.8 The southern part of the area includes the northern margin of a Variscan fold belt, formed towards the end of the Carboniferous and in early Permian times during the Hercynian Orogeny, a mountain-building event that can be traced across southern Europe. This terrane is represented by arcuate structural trends, oriented approximately east-west, as seen in the Bouguer anomaly map. In the usual interpretation, the Variscan Front (the northern limit of the main fold belt) is locally marked by the Addington Thrust, a major fault detected by seismic reflection at more than a kilometre deep beneath the North Downs. To the south of this thrust, a borehole at Warlingham, Surrey, found early Carboniferous limestones and shales. Rocks of Carboniferous age have not so far been proved in the London district to the north of the Addington Thrust.

4.9 The presence of a thick wedge of folded Late Palaeozoic sedimentary rocks (probably Devonian in age), deep beneath south London, is shown by a large negative

Figure 7 Palaeozoic basement of Greater London (from Ellison, 2004)

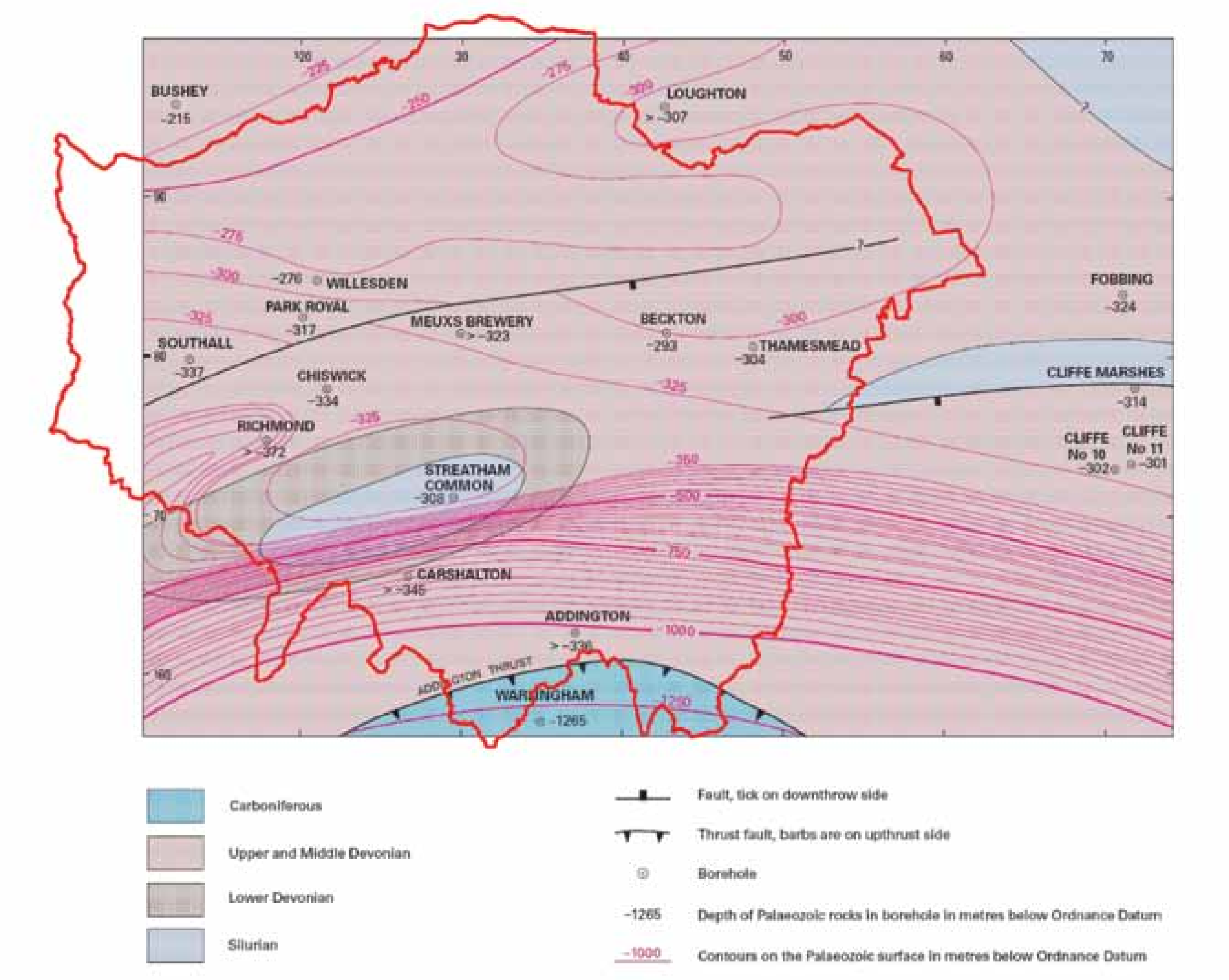
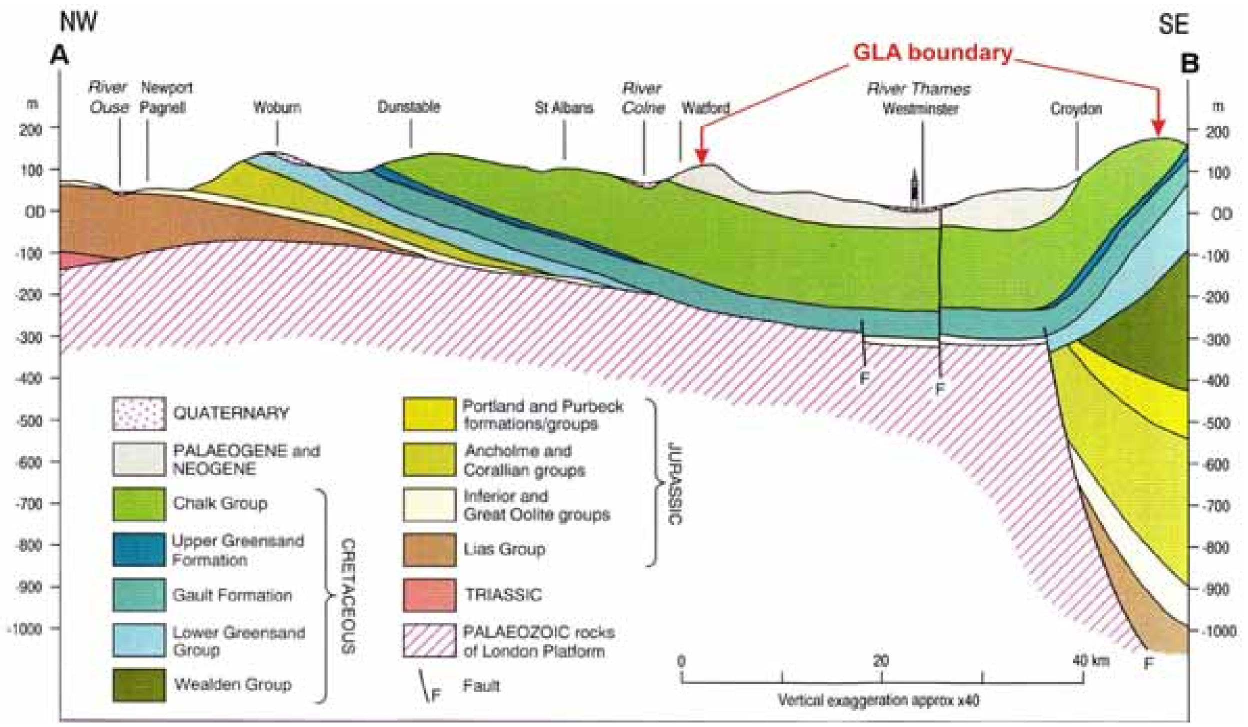


Figure 8 Geological section showing the London Basin syncline (from Sumbler, 1996)



Bouguer gravity anomaly. This wedge may also be part of the Variscan fold belt. It is faulted against the older, denser rocks of the Midlands Microcraton, as shown by the curvilinear traces in the gravity map, extending from the south-west in a north-eastwards and then eastwards direction. These curvilinear fault traces represent a northwards splay from the main Variscan fold belt. This fault zone is likely to be quite complex at depth, becoming simpler upwards. Faults and folds seen in the bedrock under south-west and south London (the Wimbledon to Greenwich tectonic zone) formed by later movement in this structural zone.

Mesozoic and Cenozoic

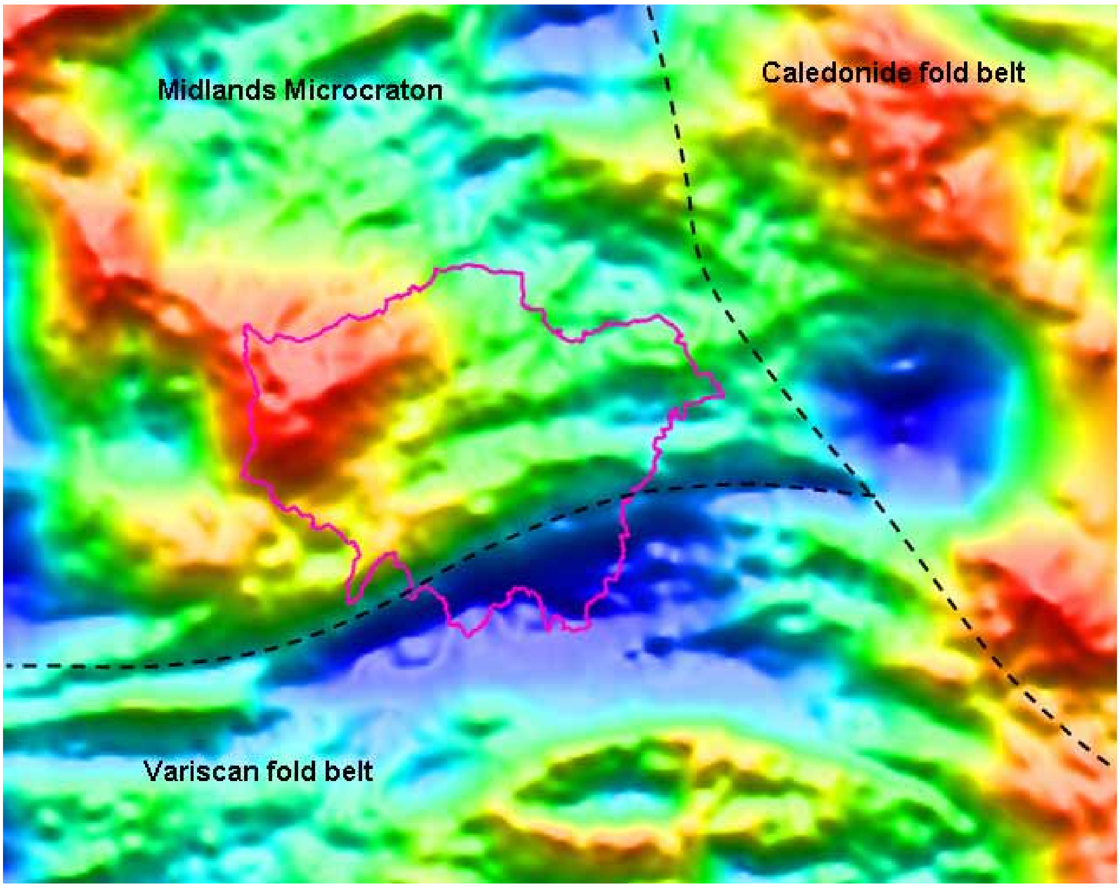
4.10 The Variscan fold belt was the site of basin subsidence during the Mesozoic and basin inversion during the Cenozoic. During that time, the Midlands Microcraton and the Caledonide fold belt of eastern England remained relatively stable, together forming the London Platform (Figure 10). No beds of Permian or Triassic age are known in the London area.

4.11 The northern edge of the Weald Basin occurs in the south of the London district. Movement on major faults bounding this basin controlled the distribution and thickness of Jurassic strata. For example, about 1050 m of Jurassic mudstones with interbedded limestone and sandstone occur at Warlingham, but only 12 m occur in a borehole at Streatham Common, just 15 km to the north. In general, younger Jurassic formations overlap further onto the London Platform. Some may have extended right across it but were removed by erosion during periods of low sea level, and uplift in the late Jurassic or early Cretaceous associated with the opening of the North Atlantic Ocean. The London area appears to have been dry land during this time, with no deposition.

4.12 In mid-Cretaceous times, however, about 120 million years ago, rising sea levels began to flood the London Platform and by about 105 million years ago, deep water marine mudstone of the Upper Gault were being deposited throughout the area. Beneath London, the Gault is typically between about 50 and 70 m in thickness. In most of the London area, the Gault passes upwards into the Upper Greensand, composed of glauconitic fine-grained sandstone and siltstone and less than about 15 m thick. It is absent in the north-west of the district, passing laterally into the Gault or having been removed by erosion.

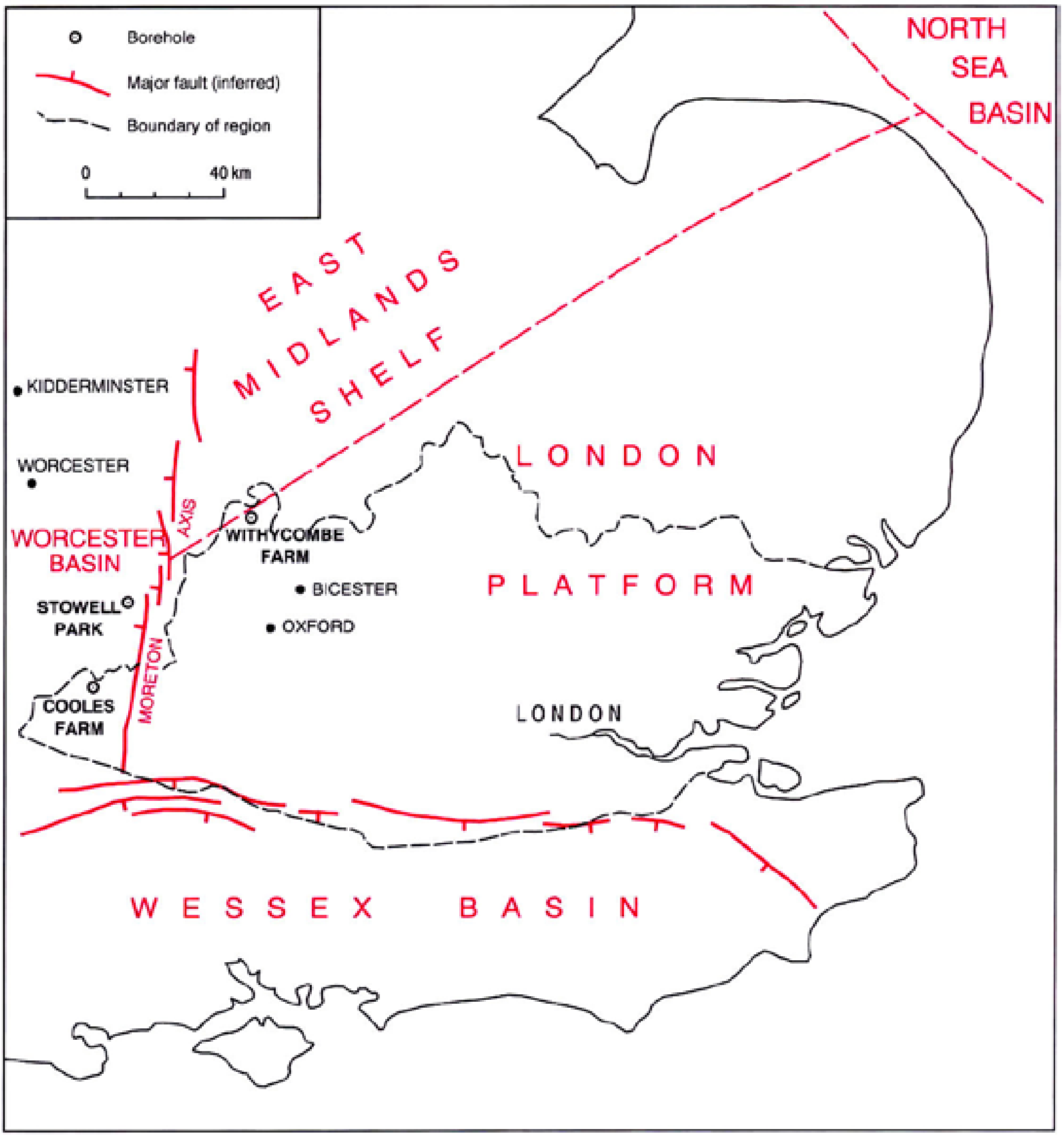
4.13 The Late Cretaceous, from about 100 million to 65 million years ago, was a period of 'greenhouse Earth', with a much warmer global climate than at the present, and globally very high sea levels, possibly the highest of the past 500 million years. A warm epicontinental sea extended across Europe, and at least

Figure 9 Gravity map of London and surrounding area



Colour shaded relief image of variable density Bouguer gravity residual of upward continued field to 10 km. Dotted lines indicate the approximate boundaries of the regional basement terranes: the 'deep geological structure'. Red: gravity 'high' (mass of underlying rock is greater than average); Blue: gravity 'low' (mass of underlying rock is less than average). Outline of the GLA in magenta.

Figure 10 Mesozoic structural setting (from Sumbler, 1996)



as far east as Kazakhstan. The gradual accumulation of the calcareous, siliceous and phosphatic remains of marine organisms of many kinds led to the formation of the Chalk. With nearby areas of dry land diminishing and ultimately confined to the highlands of Wales and Scotland (and possibly even further afield), and the onset of a predominantly arid climate, input of terrigenous sediment was minimal, although occasional clouds of volcanic ash were blown across the region, probably from volcanoes to the west of Britain. Although this was a period of tectonic stability in the region, limited earth movements led to some localised compositional variations in the Chalk.

4.14 Greater, more widespread earth movements in the latest Cretaceous and early Palaeogene, associated with the early phases of the Alpine Orogeny of southern Europe, caused the onset of basin inversion and uplift of the Weald. There was gentle folding and some erosion of the Chalk, and the formation of a broad basin of Palaeogene deposition that extended from Berkshire eastwards into the North Sea and across Europe. The portion now preserved in England is known as the London Basin.

4.15 The Palaeogene sediments of the London area, which lie across the centre of the London Basin, were deposited in shallow marine, coastal and fluvial environments between about 58 million and roughly 50 million years ago. At this time, Britain lay at about 40° N, and 'greenhouse' global climate conditions continued. Generally high, but fluctuating sea levels, driven by global sea level changes coupled with local tectonic movements, brought a series of cyclical marine transgressions and retreats. To begin with, this generated a varied and in places rather complex sedimentary sequence with evidence of erosion between some of the formations. The prevailing climate was generally warmer than at present, with evidence of mangrove swamps and tropical-style weathering and soil formation on emergent coastal plains. However, the greater part of the Palaeogene deposits in the London area belongs to the London Clay, which was laid down in fully marine conditions.

4.16 The youngest Palaeogene sedimentation in the London area is represented by the Bagshot Formation, sands deposited in a shallower sea than the London Clay, or possibly a coastal environment.

4.17 The main period of Alpine earth movements occurred in the mid-Miocene, when further basin inversion caused uplift of the Weald, and concomitant down-warping of the London Syncline, in which the London Basin is preserved. The London Syncline extends from east-north-east to west-south-west between the Chiltern Hills in the north-west and the North Downs in the south: its axis passes through central London. Smaller folds, notably the Greenwich and the Millwall anticlines, were caused by more localised 'up-to-the-south' movements on deep-seated faults amongst those bounding the Midlands Microcraton. Some of these folds have faulted axial zones, within a zone of faulting extending from Wimbledon north-eastwards across the Thames near Greenwich, and beyond towards Essex.

4.18 For most of the period since the late Eocene, the London district has been land, and the existing deposits have been gradually weathered and eroded. Sparse remnants of coastal gravel deposits on the highest ground suggest that the sea covered the area relatively briefly in the Pliocene.

Quaternary

4.19 In the early Quaternary, rivers flowed across the London area from the south and south-west towards the 'proto-Thames', a river larger than the modern Thames that flowed out of Wales, through the Midlands and southern East Anglia, into the North Sea (Figure 11). The Quaternary saw the onset of a series of extreme climatic fluctuations, with glacial periods much colder than at present alternating with interglacial periods that were in general somewhat warmer. During the Anglian glaciation, about 450 000 years ago, the ice sheets that covered northern Britain reached their most southerly extent, in the north of the London district (Figure 12). This caused a diversion of the River Thames to its present-day valley. In the

Figure 11 Reconstruction of the pre-Anglian drainage system (from Sumbler 1996)

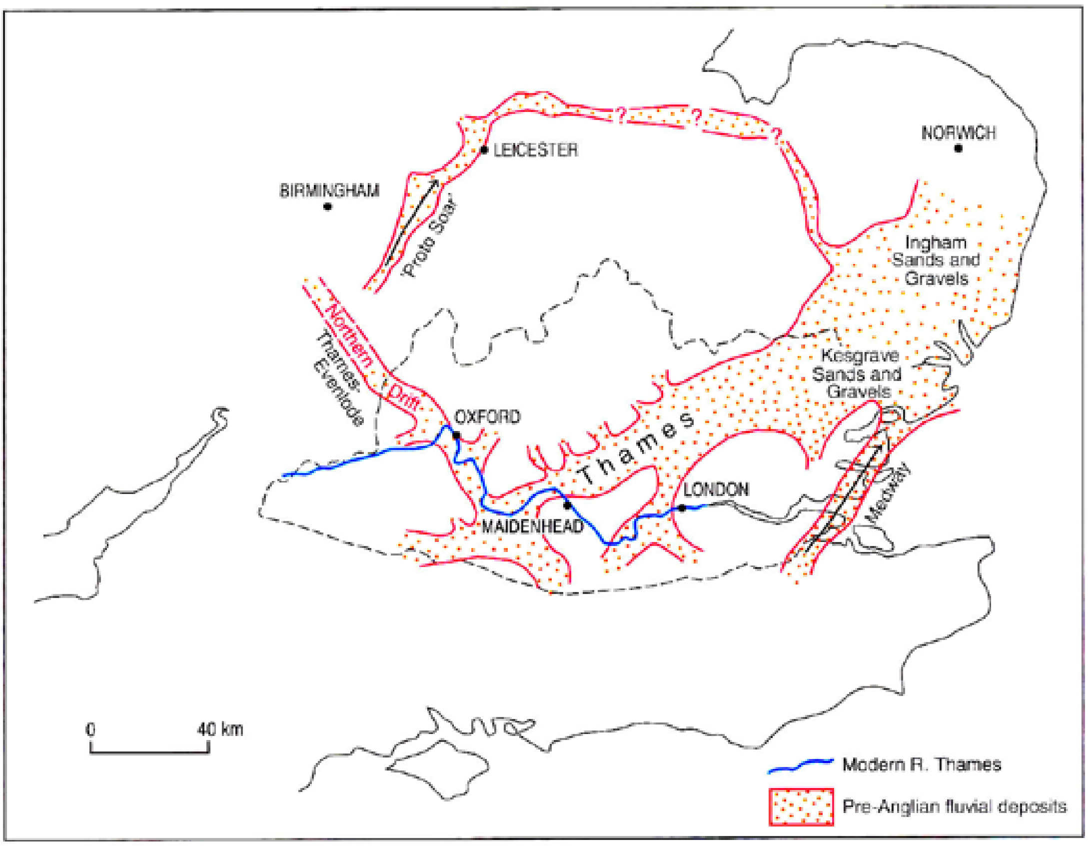
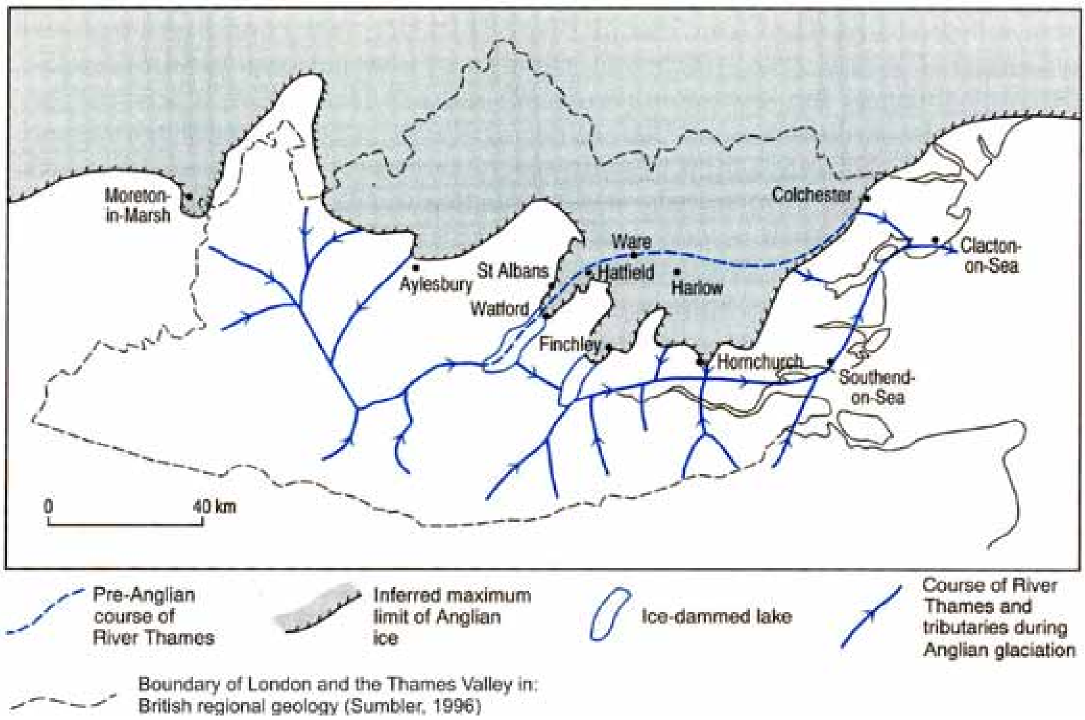


Figure 12 The extent of the Anglian glaciation in the Thames Valley (from Sumbler 1996)



north of the district, where tributaries of the Thames had once flowed north, they now flowed south.

4.20 Cyclical deposition and downcutting by the Thames, chiefly following changes in sea level caused by climatic change and crustal adjustments to glaciation, has left a complex series of river terrace deposits. These form a discontinuous and rather irregular 'staircase' down the valley sides. They are dominated by gravels and sands laid down under cold climate conditions by large braided river systems, overlain in many places around London by fine-grained 'brickearths', whose major component is wind-blown silt, or loess. Pockets of interglacial deposits also exist, typically at the 'back edge' of a river terrace. These deposits mark periods of warm climate, when the Thames would have followed a single meandering channel with a broad flood plain much as at present, although at times with much more lush vegetation and a fauna with some exotic elements reminiscent of modern Africa. Interglacial deposits dating from about 400 000 years ago, overlying the Boyn Hill Terrace at Swanscombe (just east of the London district), include the remains of one of the oldest hominids found in Britain.

4.21 During the coldest part of the last glacial stage, the Devensian, between about 25 000 and 13 000 years ago, ice-sheets covered northern Britain, reaching as far south as north Norfolk. The London area was subject to frigid, periglacial conditions. Peat with plant remains indicating the severity of the climate has been found close to the River Lea at Ponders End, in the north-east of the district. With enormous volumes of water captured within ice, global sea level was considerably lower than at present. Down-cutting in the Lower Thames, which then extended far into what is now the offshore area, created a deep channel. As the climate ameliorated and sea level rose once more, this channel was then infilled with gravels and sands. These deposits now form a 'buried channel' beneath the river alluvium, peat, salt-marsh and estuarine sediments, which have been lain down within the past 10 000 years or so, since the end of the last glacial period.

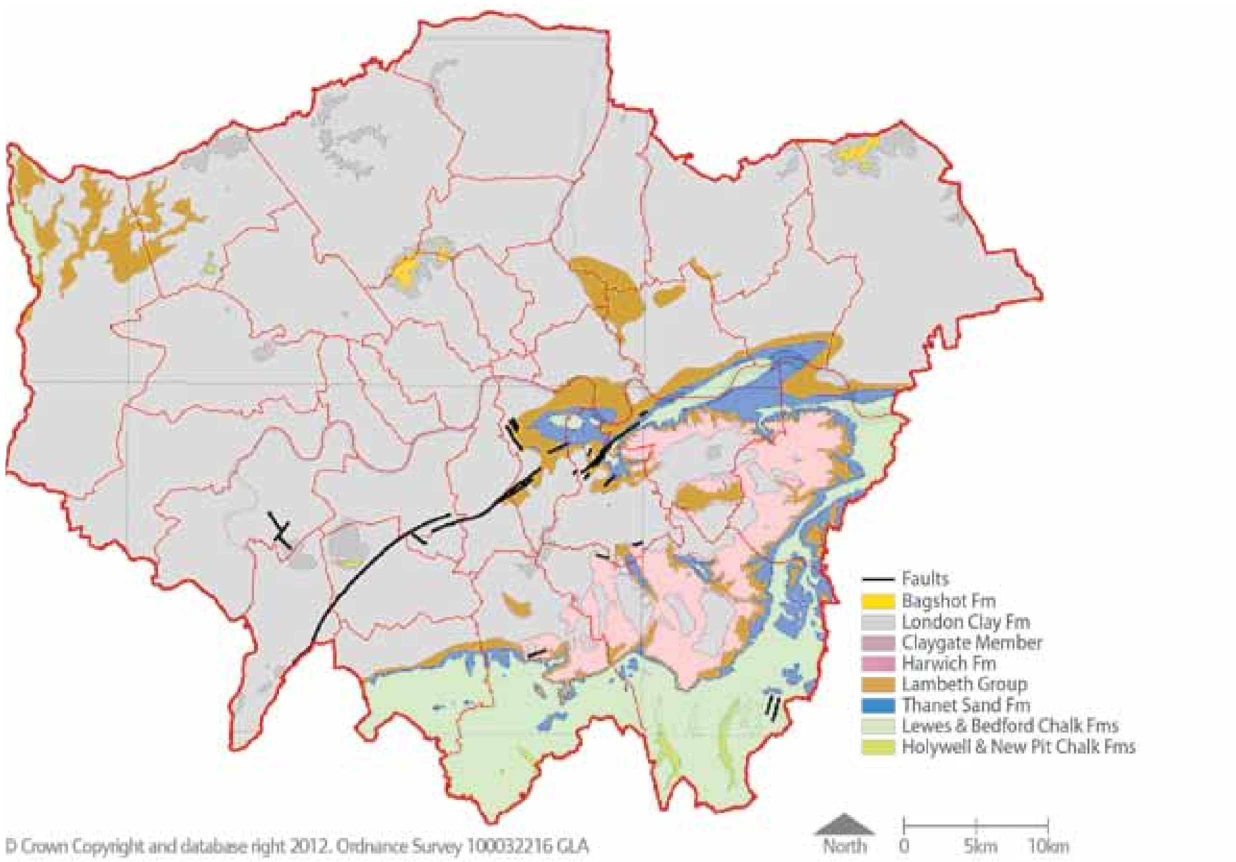
4.22 Upstream of its confluence with the River Lea, the width of the Thames flood plain decreases abruptly, so creating the most natural place to found a crossing point and settlement. The rest, as they say, is history (!).

Bedrock geology

4.23 Bedrock formations predate the Quaternary Sub-Era: they define the local geological structure (Figure 13). The bedrock may be overlain by natural superficial deposits, by artificial deposits, or by both; or it may crop out at the surface, perhaps covered only by soil. Parts of the bedrock close to the surface have generally suffered the effects of weathering; they are then typically weaker and more oxidised compared with fresh, unweathered material from the same formation, and are commonly of a different colour.

4.24 The exposed geological succession is described in order of formation age, from the oldest to youngest. The Chalk represents the youngest part of the Mesozoic. The rest of the bedrock sequence dates from the Palaeogene

Figure 13 Bedrock geology of Greater London



Period. The Palaeogene and the succeeding Neogene together used to be known as the 'Tertiary' period. The Tertiary and Quaternary periods are now referred to as the Cenozoic Era (Figure 6). Quaternary and possible Neogene deposits are described in later in this chapter. A summary of the geological strata of London is given in Figure 14.

Chalk Group

4.25 The Chalk, of Late Cretaceous age (100 to 65 million years ago), is the oldest bedrock unit seen at outcrop in the district, and underlies the whole area at depth. The Chalk is a very widely occurring geological unit, extending across southern England, East Anglia and northwards into Lincolnshire and Yorkshire. It also occurs widely outside the UK, reflecting the remarkable continuity of depositional conditions produced by the exceptionally high sea levels in the Late Cretaceous. The UK Chalk succession was deposited in a few hundred metres of water, and probably blanketed much of the British Isles. Chalk deposition largely ceased at the end of the Cretaceous when there was a major fall in sea level that transformed much of the UK into land and exposed the newly-formed Chalk to erosion.

4.26 In the London area the Chalk crops out in the Chiltern Hills and in the North Downs, and also in the core of the Greenwich

Figure 14 Summary of the geological strata of London (adapted from Ellison, 2004)

Period		Group	Formation	Thickness (m)
Palaeogene			**Bagshot Formation:** sand, fine-grained with thin clay beds	10 – 25
Palaeogene		Thames	**London Clay Formation:** clay, silty; fine-grained sand and clay at base. **Claygate Member:** interbedded sand and clay at top	90 – 130
Palaeogene			**Harwich Formation:** sand, clayey fine-grained sand and pebble beds	0 – 10
Palaeogene		Lambeth	**Reading, Woolwich, & Upnor Formations:** clay mottled with fine-grained sand, laminated clay, flint pebble beds and shelly clay	10 – 20
Palaeogene			**Thanet Sand Formation:** sand, fine-grained	0 – 30
Cretaceous		Chalk	Undivided mainly **Seaford Chalk Formation:** chalk, soft, white with flint courses	Up to 70
Cretaceous		Chalk	**Lewes Chalk Formation:** chalk, white with hard, nodular beds	25 – 35
Cretaceous		Chalk	**New Pit Chalk Formation:** chalk, white to grey with few flints	30 – 40
Cretaceous		Chalk	**Holywell Chalk Formation:** chalk, white to grey, shelly, hard and nodular	13 – 18
Cretaceous	Concealed strata		**Undivided Zig Zag Chalk Formation** and **West Melbury Marly Chalk Formation** (formerly Lower Chalk): chalk, pale grey with thin marls; glauconitic at the base	65 – 70
Cretaceous	Concealed strata		**Upper Greensand Formation:** sand, fine-grained, glauconitic	Up to 17
Cretaceous	Concealed strata		**Gault Formation:** mudstone	50 – 70
Cretaceous	Concealed strata	Lower Greensand	**Folkestone Formation:** sandstone, fine- to medium-grained	60
Cretaceous	Concealed strata	Lower Greensand	**Sandgate, Hythe & Atherfield Clay Formations:** sandstone and mudstone	34
Cretaceous	Concealed strata	Wealden	**Weald Clay Formation**: mudstone **Hastings Beds**: sandstone and mudstone	Up to 150
Jurassic	Concealed strata		Limestone and mudstone	0 – c.750
Silurian & Devonian	Concealed strata		Sandstone and siltstone	

Anticline and related fold structures. Its maximum preserved thickness is about 200 m, which is quite small compared to the c. 400 m present in the Hampshire – Sussex area. This contrast partly reflects deeper erosion of the Chalk in the London area prior to deposition of Cenozoic sediments, and partly differences in tectonic environment. The relatively shallow occurrence of ancient basement rocks in the London area may have influenced the extent of this erosion as well as limiting the space available for Chalk accumulation.

Lithology

4.27 In southern England, the Chalk is typically a very fine-grained, relatively soft, white limestone, predominantly composed of the disaggregated skeletal remains of tiny planktonic algae called coccolithophores. These flourished in the seas of the Late Cretaceous, and today remain an important source of biologically produced marine limestones. The Chalk is compositionally similar in northern England, but much harder due to greater cementation.

4.28 The lower part of the Chalk Group contains up to 30 per cent clay, and comprises a decimetre-scale alternating succession of hard limestones and soft mudstones. Individual limestones and mudstones are widely traceable across the UK and far beyond, and individual beds have been identified using an alphanumeric code. The rhythmic cycle of limestone and mudstone has been interpreted as reflecting regular climatic oscillations, with the limestones accumulating in warmer phases and the mudstones in colder periods. Estimates of the frequency of these changes, every 20 000 years or so, suggests that they correspond to Milankovitch Cycles, produced by regular changes in the Earth's attitude and orbit that in turn altered the amount and distribution of solar radiation.

4.29 The higher part of the Chalk Group is almost pure calcium carbonate in the form of low magnesian calcite, and is the typical white chalk with which most people are familiar. Flints are a conspicuous feature of this part of the succession, occurring as bands at regular intervals and giving an indication of the natural bedding. Flint is composed of silica, in the form of ultramicroscopic quartz crystals, derived from the dissolved skeletons of siliceous sponges and microfossils (radiolarians and diatoms) that inhabited the Chalk sea. The complex chemical process of flint formation occurred at some distance below the sea bed whilst the Chalk was still being deposited, often as replacements of burrow systems formed by organisms living in the seabed sediment (Clayton, 1986). Such flints typically have irregular nodular or elongate forms. Laterally continuous tabular flints are typical of homogeneous, well-bedded sediments in which burrows are either absent or poorly defined; lack of these preferred sites for silica replacement promoted the formation of more evenly developed flint horizons (Clayton, 1986). Some flint bands have a distinctive appearance and are geographically extensive, making them valuable for correlation. Locally, thin sheet-like flints, with a distinctive hollow centre, are found cross-cutting parts of the Chalk succession. These flints are inferred to have grown along fractures or shear-planes in semi-consolidated chalk.

4.30 The thin marls that are first seen in the lower part of the Chalk Group continue to occur at intervals through the higher part of the succession. These clay-rich horizons have higher water retention than the adjacent chalk, and are often preferentially vegetated in outcrops. Where visible in weathered exposures, marls may appear as shaly horizons and can be preferentially eroded, but in fresh exposures their darker colour is usually their key distinguishing feature.

4.31 Some aspects of the formation of the marl seams in the higher part of the Chalk remain unknown, but some have been interpreted as decomposed volcanic ashes and others as the result of an enhanced influx of land-derived sediment (Wray and Wood, 1995; Wray, 1999). Many marl seams are geographically extensive marker beds and are important for correlation.

4.32 Decimetre-scale beds of characteristic hard, nodular chalk occur at some levels in the Chalk. These have a distinctive knobbly appearance produced by preferential removal by weathering of the softer chalk that surrounds the harder nodules. Thinner horizons of very hard chalk, known as hardgrounds, also sometimes occur. These beds, generally less than a metre thick, have typically been bored and encrusted by marine organisms and stained orange, green or brown with iron and phosphate minerals. Both nodular chalk and hardgrounds reflect primary hardening of chalk caused by enhanced sea floor cementation associated with periods of non-deposition (Hancock, 1989). Cementation occurred just below the sea floor, initially producing nodules of harder chalk in softer sediment (Gale, 2000). Local exposure by sea floor erosion facilitated further cementation, and allowed the hard chalk pavement to become bored into and encrusted by marine fauna. The formation of nodular chalks and hardgrounds has been related to reductions in sedimentation rate by current-winnowing across submerged massifs, in proximity to basin margins, or associated with eustatic fall in sea level (Hancock, 1989).

Stratigraphy

4.33 Traditionally, a three-fold classification was applied to the Chalk Group everywhere in the UK. This simple subdivision into Lower, Middle and Upper Chalk was based on the development of beds of hard chalk which, through their topographic expression, could be traced across chalk downlands. In the last 20 years, research has shown that there is much greater variation within the Chalk than is suggested by the traditional classification. Separate modern classifications are given to the Chalk of north-eastern England and southern England, based on differences in the character of the chalk and distribution of flint and marl. Between these two areas is a region, extending from the London area across most of East Anglia, where classification of the chalk becomes less straightforward because of subtle changes in its character (Mortimore et al., 2001). Investigations of the outcropping succession around Dartford and buried successions seen in boreholes suggest that in general, the southern England classification can be applied to the Chalk of the London area. The southern England scheme follows Rawson et al. (2001); it recognises two subgroups and up to nine formations within the Chalk Group.

4.34 The two major subdivisions are the Grey Chalk Subgroup and White Chalk Subgroup. The boundary between them is an erosion surface at the base of a clay-rich unit named the Plenus Marls Member. The top of the Plenus Marls marks the top of the traditional Lower Chalk, but in the new scheme this unit marks the base of the White Chalk Subgroup.

4.35 In the London area, where Cenozoic erosion has removed part of the succession, a maximum of even formations can be recognised.

Grey Chalk Subgroup

4.36 The Grey Chalk Subgroup is typically 60 – 70 m thick in the London area, and generally comprises less pure, more clay-rich chalk than the White Chalk Subgroup. Unlike the latter, it does not contain flint. The two formations that make up the Grey Chalk Subgroup, the West Melbury Marly Chalk Formation and overlying Zig Zag Chalk Formation, are not seen at outcrop in the London district, although they are penetrated by boreholes. These boreholes, and outcrops in quarries south of London, show that the base of the West Melbury Marly Chalk, as elsewhere in southern England, comprises a sandy clay, rich in the green-coloured iron mineral glauconite, named the Glauconitic Marl Member. Above this are regularly alternating hard limestones and mudstones, each typically a few tens of centimetres thick. This interval was traditionally referred to as the Chalk Marl. Alternating limestones and mudstones continue up into the lower part of the Zig Zag Chalk, but eventually these give way to thick beds of creamy grey chalk with thin interbeds of marl, traditionally known as the Grey Chalk. The base of the Zig Zag Chalk is marked by a silty chalk horizon, named the Cast Bed, within the upper part of the Chalk Marl of the traditional scheme. The West Melbury Marly Chalk is unusually thin in the Fetcham Mill Borehole [TQ 1581 5650] at Leatherhead, where it is less than 20 m thick, but it shows evidence of thickening to perhaps 30 m or more elsewhere within the region. The Zig Zag Chalk is more uniform, at about 40 m thickness.

White Chalk Subgroup

4.37 The change to the much purer chalks that characterise the White Chalk is thought to be related to a major sea level rise, following the short-lived sea level fall that led to the erosion surface at the base of the Plenus Marls. This sea level rise curtailed the supply of detrital material from land areas and probably fundamentally changed the circulation pattern on the drowned continental margins, allowing the low-nutrient oceanic water favoured by coccolithophores to flood across these areas.

4.38 Five formations are recognisable in the London area, namely (from oldest to youngest) the Holywell Nodular Chalk, the New Pit Chalk, the Lewes Nodular Chalk, the Seaford Chalk and the Newhaven Chalk. The lowest three of these are seldom seen at outcrop in the London area, except where exposed in deep quarry or mine workings. The Seaford Chalk has the greatest surface exposure and underlies most of the Cenozoic sediments. The Newhaven Chalk has a restricted occurrence along parts of the southern margin of the London area.

4.39 The Holywell Nodular Chalk Formation is hard, nodular, and distinctively shell-rich in the upper part. It is typically 14 to 18 m thick in the London area, and contains regularly developed thin beds of marl throughout and an interval with several beds of greenish-grey marl at the base, up to several metres thick, named the Plenus Marls Member. Much research has focussed on the Plenus Marls and immediately overlying strata in recent years, since evidence from their carbon and oxygen isotope geochemistry points to a series of major environmental perturbations at this level, including oxygen-starvation of the Late Cretaceous oceans and a major change from global climatic warming to global cooling. The base of the traditional Middle Chalk Formation was mapped using a hard bed of chalk that immediately overlies the Plenus Marls, named the Melbourn Rock.

4.40 The New Pit Chalk Formation is firm, smooth-textured chalk, 40 to 46 m thick where recognised in boreholes in central London. It lacks the nodularity and abundant shell remains of the Holywell Nodular Chalk, and in its upper part, bands of nodular flint appear. Marls continue to occur in the succession, and are generally slightly more noticeable than in the Holywell Chalk. Several thick marl beds, more than 0.1 m thick, occur in the upper part of the New Pit Chalk.

4.41 The Lewes Nodular Chalk Formation, up to 40 m thick, marks a return to hard, nodular chalk, but unlike the underlying Holywell Chalk, flint occurs fairly regularly throughout the formation. Some of the flints are very distinctive, such as the Lewes Tubular Flints, which can be traced across southern England and northern France. Hardgrounds are relatively common, with at least four major intervals containing closely spaced hardground surfaces. In some parts of the London area the top of the Lewes Chalk is marked by the Rochester Hardground, but elsewhere this is replaced by a pair of marl seams separated by sponge-rich chalk. Marls occur at intervals through most of the succession. They include important marker horizons such as the distinctively thick (about 0.1 m) and plastic-textured Southerham Marl, which chemical analysis has shown to be a decomposed volcanic ash. The base of the traditional Upper Chalk falls within the lower part of the Lewes Chalk, but in the London area the beds that define this boundary are not well developed.

4.42 The Seaford Chalk Formation is typically soft, smooth-textured chalk, with shell-rich beds and common horizons of nodular and tabular flints. Some flints are widespread marker beds in the Chalk of southern England, such as the Seven Sisters Flint in the lower part of the succession, and Bedwell's Columnar Flint and Whittaker's 3-inch Flint in the higher part of the Seaford Chalk. Marls are restricted to the lower part of the formation, and in the higher part of the succession is an interval of iron-stained chalk with common sponge remains (Barrois Sponge Bed) or a hardground (Clandon Hardground). Over most of the area the preserved thickness is affected by the depth of Early Palaeogene erosion (where overlain by Palaeogene rocks) and Quaternary erosion (where exposed). The complete thickness of Seaford Chalk is proved in the Fetcham Mill Borehole at Leatherhead, but the c.33 m there assigned to the formation is probably atypical because part of that succession shows unusual local thinning.

4.43 The Newhaven Chalk Formation is very soft, smooth-textured chalk with marl seams, and less abundant flint than the underlying Seaford Chalk. Only the lower and middle parts of the formation are preserved locally, mainly on the southern and south-western fringes of the London district. The thickest development is probably in the Fetcham Mill Borehole at Leatherhead, just south-east of the London district, where nearly 20 m of Newhaven Chalk were proved. Sparsely flinty chalk belonging to this formation also occurs around Croydon, Purley, Ewell and Beddington.

Landscape

4.44 Where it crops out, Chalk produces attractive undulating downlands, seen in the North Downs to the south of London, and the Chiltern Hills to the north-west. The undulating character is controlled by geological structure and by the different character of each of the formational subdivisions of the Chalk. Where not overlain by younger strata, the gentle dip of the Chalk produces a broad tract of outcrop, successively revealing each of the different formations to the effects of surface weathering.

4.45 Both ancient and modern weathering has shaped the Chalk landscape. In the Quaternary, the development of permafrost during glacial epochs and/or the presence of an elevated water table, allowed streams to flow across the normally permeable Chalk and develop valley systems. These are now visible as networks of dry valleys. Weathering of the Chalk has also been affected, and continues to be influenced, by the unique combination of physical features that characterise each of the formational subdivisions. These features include the presence or absence and relative abundance of flint, marl, nodular chalk and hardgrounds, as well as variable chalk composition, cementation and style of fracturing. Differences in these characters between formations subtly alter the way each weathers, which in turn produces changes in slope profiles. It is this feature that has allowed the new Chalk Group stratigraphy to be mapped out across often poorly exposed terrains.

Economic Importance

4.46 Water supply and cement manufacture are the two most important economic uses of the Chalk. In the past chalk was also exploited in small workings as a source of agricultural lime, and has been mined extensively in several places in south-east London as a raw material for brick manufacture, or for flint.

4.47 The Chalk is crucially important for water supply, being one of the UK's major aquifers. Boreholes drilled into the Chalk are a source of water for large parts of south-east England, including the London area. The dense urban development that covers much of the exposed Chalk in south-east England also means that this aquifer is vulnerable to contamination from surface pollutants. Often a considerable interval of Chalk occurs above the water table (the 'unsaturated zone'), where pollutants may build up over many years, and then be rapidly distributed into the aquifer by a rise in the water table. In recent years there has also been concern about maintaining supplies of ground water during prolonged droughts; mitigating the negative effects of excessive groundwater abstraction on chalk streams and wetlands, and assessing the risks of flooding due to sudden rises in the water table. Consequently much recent work has focussed on understanding pathways of ground water movement in the Chalk, and how this is influenced by stratigraphical variation and geological structure.

4.48 Chalk is an important source of raw material in the manufacture of cement, and has been extensively worked in quarries close to the London area, especially along the Chalk outcrop flanking the Thames estuary. Some of these quarries have a long history of development and have furnished important geological data that has greatly contributed to our understanding of the Chalk of the London area. Some of the older quarries, especially those adjacent to built-up areas, were extended underground by driving adits from the faces.

4.49 Chalk mines are found in places in the south-east of the London district, and at Pinner in the north-west. The oldest and smallest types of mine are the 'dene hole' and related forms of hand-dug mine used to win agricultural lime in areas of acidic or clay-rich soils. Some may be of pre-Roman age but most seem to date from the 13th to the 19th centuries. They typically consist of a shaft of about 1 m in diameter sunk through a cover deposit of Thanet Sand or of clay-with-flints, plus enough Chalk to make a safe roof. Chalk was excavated by expanding the shaft, commonly along adits of various patterns and lengths, over a radius up to about 12 m. Dene holes can occur singly or in groups of up to 70, or more. They are common in parts of the Cray valley in south-east London (see also paragraphs 5.9-5.10)

4.50 Pillar and stall chalk mines mostly date from the 19th century, with some earlier or later. Their passages are typically 2 to 5 m wide and can be up to 9 m high, generally narrowing upwards for stability. They can extend more than 100 m from the access point. Some of the largest were dug within brick works, as a source of chalk to be added to the brick clay prior to firing. The Pinner chalk mine, dug through the Lambeth Group in north-west London, is one of the deepest, at about 35 m. Most other examples are in south-east London, around Woolwich and Erith, or in south London, most notably at Chislehurst.

Wider Geological Importance

4.51 The Late Cretaceous is thought to have had a 'super greenhouse' climate, produced by large amounts of submarine and continental volcanic activity that pumped huge volumes of carbon dioxide into the atmosphere. Consequently there has been considerable interest in studying the Chalk in order to gain insights into how biological systems responded to this environment, and what the implications might be for modern global warming. There has been particular focus on the strata at the base of the White Chalk Subgroup, represented by the Plenus Marls and immediately overlying succession of the lower Holywell Nodular Chalk. This interval appears to show evidence of a period of global oceanic oxygen starvation that is broadly coincident with a sudden climatic reversal, from global warming to global cooling.

4.52 Milankovitch cycles are regular climatic fluctuations produced by cyclical changes in the Earth's orbital parameters. Evidence of the presence and impact of these changes has been gained by studying the sediments of the Grey Chalk Subgroup, and it has been suggested that some aspects of the flint distribution in the White Chalk Subgroup might be a response to environmental changes produced by these cycles.

4.53 The details of the Chalk succession in the London area, particularly the nature of any local variations, are likely to be pertinent to an understanding of the relationship between sedimentation and structure during the Late Cretaceous, particularly the timing of tectonic movement at the southern margin of the London Platform and along the Wimbledon – Greenwich tectonic zone.

4.54 Exposures of the local Chalk will aid understanding of its behaviour in engineering and hydrogeological contexts, including (for example) the likely pathways taken by pollutants in the groundwater system.

Palaeogene strata

4.55 Most of the London district is underlain by an intricate succession of Palaeogene strata within the London Basin. This was laid down during a series of cyclical fluctuations in sea level between about 58 and 50 million years ago, and represents deposition in environments ranging from terrestrial to fully marine.

4.56 Four major divisions are present. The oldest, the Thanet Sand Formation, is overlain in turn by the Lambeth Group (with 3 formations), the Thames Group (with 2 formations) and the Bracklesham Group, of which the Bagshot Formation is the only representative in the London district. The Lambeth Group comprises the Upnor Formation, overlain by the Reading Formation in the west, the Woolwich Formation in the east, and by a complex interdigitation of both in the centre of the district. The Thames Group consists mostly of the London Clay Formation, which is by far the most widespread single bedrock formation in the London district, with the Harwich Formation, previously known as the 'London Clay basement bed'.

Thanet Sand Formation

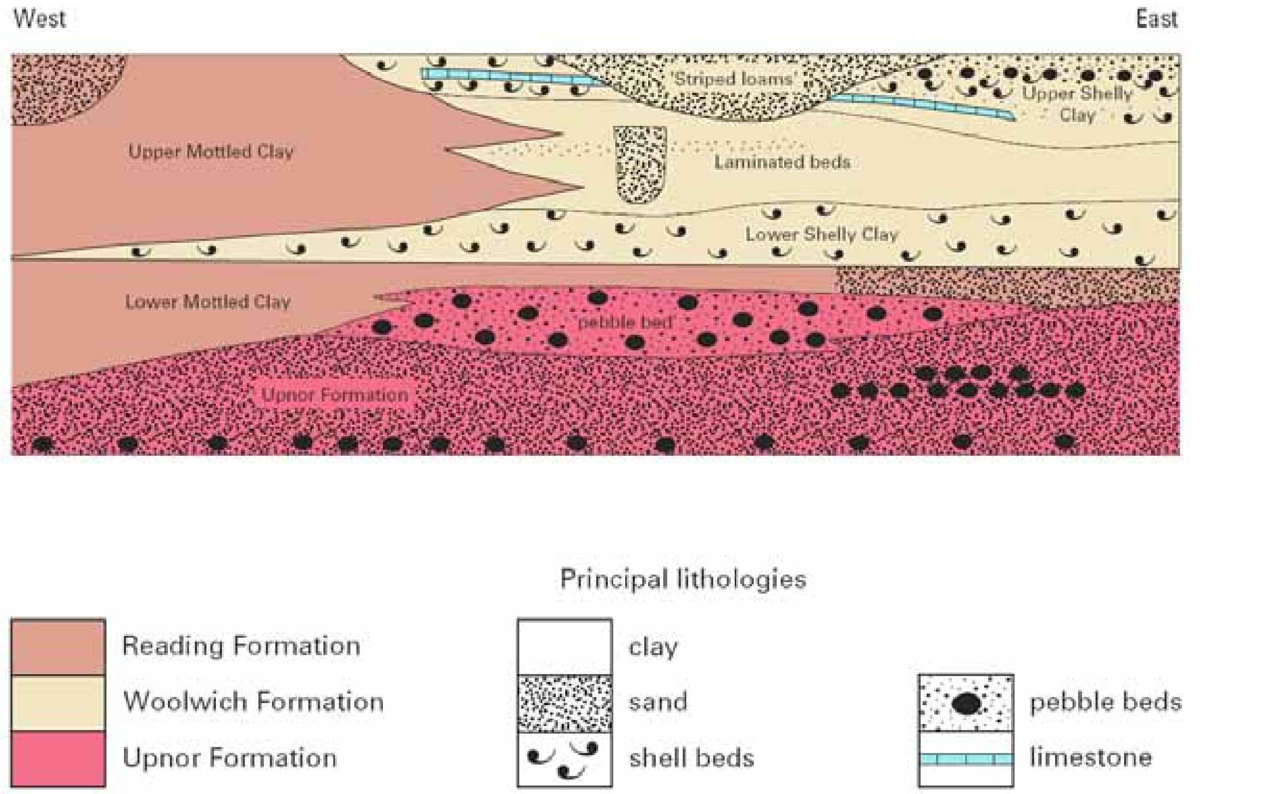
4.57 The Thanet Sand is the oldest Palaeogene formation in Essex and Kent, with London marking its north-western extent. It forms a fairly narrow outcrop along the west side of the Cray valley and westwards at the foot of the North Downs, with a few broad outliers just to the east of the Cray at the south-eastern boundary of the district and some narrow inliers in south-east London. It also crops out around the Greenwich and Millwall anticlines but is there almost entirely covered by superficial deposits. The Thanet Sand and the Lambeth Group were together previously known as the 'Lower London Tertiaries'.

4.58 The Thanet Sand was deposited in a shallow marine environment, following a global rise in sea level after about 58 million years ago in the late Paleocene (the earliest series of the Palaeogene). It rests unconformably on the Chalk, on what was originally an approximately planar erosion surface, although that surface is now folded, and typically highly convoluted on a small scale following dissolution of the Chalk. The unconformity surface is attributed to erosion and reworking during two or more depositional cycles. Where it is more fully developed to the east, up to nine onlapping sequences have been recognised in the Thanet Sand but the bulk of the deposits (and perhaps all) in the London area represent only one. Deposition of the Thanet Sand was followed by further cycles of falling and rising sea level prior to the deposition of the succeeding Lambeth Group, which overlaps the Thanet Sand towards the west. Consequently, the Thanet Sand has been truncated, diminishing in thickness from about 22 m in east and south-east London to where it is cut out almost completely along a line between Hillingdon and Borehamwood. To the west of this line, sparse remnants that occur in some solution cavities in the Chalk demonstrate the greater original extent.

4.59 In the London district, the Thanet Sand Formation consists predominantly of a coarsening-upwards sequence of fine-grained sands which is clayey and silty, particularly in the lower part. The proportion of fine-grained sand varies from about 10 per cent at the base, to about 60 per cent at the top. The unweathered strata are pale grey to brownish-grey, and weather to a yellowish-grey. They are often intensely bioturbated, shown by wisps of relatively dark silt and clay, but few primary sedimentary structures remain. The sands may locally contain irregular masses of much harder siliceous sandstone known as 'doggers'.

4.60 At the base of the Thanet Sand Formation there is typically a distinctive unit up to 0.5 m thick called the Bullhead Bed. This is usually a conglomerate with flints ranging in size from small well-rounded pebbles to large unworn flint nodules (the 'bull heads'). The flints typically have a distinctive green coating of glauconite and are set in a matrix of dark greenish-grey clayey, fine- to coarse-grained sand containing glauconite pellets. Some fossils

Figure 15 Relationship of Lambeth Group informal lithological units in central London



derived from the underlying Chalk are present.

Lambeth Group

4.61 The Lambeth Group (formerly known as the 'Woolwich and Reading Beds') succeeds the Thanet Sand, overlapping it to rest on the Chalk in the north-west of the district. Like the Thanet Sand, it forms a narrow outcrop on the south-east side of the London Basin, but with only a few small outliers. It likewise delineates the Greenwich and Millwall anticlines and forms scattered inliers, where it is mostly covered by superficial deposits. Some of the inliers have arisen through incision in the Ravensbourne River and its tributaries, but others (such as those in the Lower Lea Valley and nearby) are probably controlled by a local geological structure. Unlike the Thanet Sand, the Lambeth Group also crops out at the north-western edge of the London Basin, in north-west London.

4.62 The Lambeth Group is of rather more uniform thickness than the Thanet Sand. It is generally thickest in south-west London and reaches as much as 30 m at Southwell, but in most of the district it is between 10 and 20 m thick. It is least in south-east London, in large part due to erosion prior to the deposition of the Harwich Formation, and in places east of the Cray valley, near Swanley, it has been removed entirely.

4.63 The Lambeth Group typically comprises interbedded colour-mottled clays and fine silty sands, with occasional shell beds, thin limestones and some beds of sandy gravel containing black, very well-rounded flint pebbles. The colour-mottling is a consequence of weathering under conditions of a warm climate with a distinct dry season. It is associated with duricrust formation and soil formation.

4.64 Three formations are present in the Lambeth Group, each of which varies significantly in composition both laterally and vertically. They together make up four depositional sequences separated by unconformities (Knox, 1996). The basal Upnor Formation occurs throughout the area. In the west of the London Basin it is overlain by the Reading Formation, and in the east by the Woolwich Formation. In the centre of the London area, both the Reading and Woolwich formations are present in a complex interbedded relationship, in which a number of informal subdivisions have been recognised (Figure 15). These divisions are described in more detail in the London Memoir (Ellison et al., 2004).

4.65 The Lambeth Group was deposited during the youngest part of the Paleocene and the oldest part of the Eocene (Collinson et al., 2003; King, 2006). The Upnor Formation is of marine origin, and rests unconformably on a erosion surface. Deposition of the upper part of the Upnor Formation followed a lowering of sea level that may have led to the removal or reworking of earlier deposits. The Upnor Formation as a whole was followed by a further fall in sea level. Emergence of the Upnor Formation is indicated by the local presence of silcretised sediments (some as clasts in the pebble beds at the top of the formation) typical of 'Hertfordshire puddingstone' and 'sarsen stone'.

4.66 The succeeding Reading Formation represents deposition in an area of marshy coastal plains crossed by rivers, and the Woolwich Formation in estuarine, lagoonal or nearshore marine conditions. These two formations are divided by a sequence boundary, marking a period of sea level fall, emergence of the lower part of the Lambeth Group and their consequent weathering and local erosion. This boundary marks onset of the 'Paleocene-Eocene Thermal Maximum', a relatively short-lived period of global warming (King, 2006). The corresponding stratigraphic surface (which seems to disappear westwards within the Reading Formation) has been named the 'mid-Lambeth Group hiatus' (Hight et al., 2004). This is commonly characterised by pedogenic effects such as calcrete formation in the underlying strata, which may be part of the Reading Formation or the Upnor Formation, and by lignite deposits.

Upnor formation

4.67 This formation comprises fine- to medium-grained sand with variable glauconite, beds and stringers of flint pebbles and minor thin clay interbeds or intraclasts. It may be bioturbated, or well-bedded or laminated. Oyster shells occur. Rare fragments of carbonaceous material occur also. It is mainly dark grey to greenish-grey in colour, but the highest part (and locally the whole thickness) has been oxidised to brown, orange, red, and purple-brown. It tends to be made up of slightly coarser sand than the Thanet Sand, and the lower beds may be gritty. A basal bed of rounded flint pebbles up to 1 m thick is usually present, but is not persistent. Where the Thanet Sand is absent, the Upnor Formation rests directly on the Chalk and can contain unworn flint nodules, as found in the Bullhead Bed. At the base, burrows extend as much as 2 m below the contact.

4.68 The pebbles that occur throughout the formation are generally less than 30 mm in diameter but may exceptionally reach 200 mm. They are typically well-rounded and elongate, spheroidal to flattened spheroidal. Many have small surface crescentic percussion marks. Pebble-dominated beds occur principally at the base and top of the unit: in central and south-east London, there is a persistent pebble bed up to 3 m thick at the top of the formation.

4.69 The Upnor Formation was previously treated as the 'basal bed' of either the Woolwich Formation or the Reading Formation, respectively. It underlies the mid-Lambeth Group hiatus and so is of Paleocene age.

4.70 Harefield Pit SSSI, Hillingdon, exposes the Upnor Formation overlying the Chalk (Figure 4).

Lower Mottled Clay (Reading Formation)

4.71 The Lower Mottled Clay generally consists of purple, red, green, blue-grey and brown mottled clays, with some silty or sandy, and fine- to medium-grained sands. The clays are generally unbedded. The sands tend to be brown. Lenticular bodies of cross-bedded, medium-grained sand (commonly containing layers of mud flakes) are interpreted as the deposits in river channels.

4.72 The Lower Mottled Clay is present throughout the Lambeth Group in the London district, but is thin or absent in the north-east. In the west of the district, it has not been differentiated from the Upper Mottled Clay (if that is present). The Reading Formation as a whole is as much as 20 m thick in the south-east of London, decreasing eastwards where it interfingers with the Woolwich Formation.

4.73 Harefield Pit SSSI, Hillingdon, exposes the whole of the Reading Formation (Figure 4).

Lower Shelly Clay (Woolwich Formation)

4.74 This is a very uniform unit composed of dark grey to black organic clay with shells. Some brownish grey clay, partly cemented with siderite, can be present, especially in the upper part. Sand or shell beds can be present, especially in the north-east of the district. Lignite is commonly seen at the base of the unit, especially in the south-east, where it marks the mid-Lambeth Group hiatus. The thickest such lignite bed (up to 2 m) occurs at Shorne, in Kent.

4.75 In general this unit thickens from central London towards the south-east, reaching as much as 6 m. It is absent in the west of the district.

4.76 The Lower Shelly Clay overlies the mid-Lambeth Group Hiatus and so is of Eocene age.

4.77 The Lower Shelly Clay is exposed in Gilberts Pit SSSI, Greenwich (Figure 4).

Laminated Beds (Woolwich Formation)

4.78 The Laminated Beds are mostly composed of fine- to medium-grained, laminated sands, silts and clays, which can contain shells. These sediments are typically pale greenish grey to brown in colour.

4.79 The Laminated Beds generally rest conformably on the Lower Shelly Clay and have a similar distribution. The unit reaches as much as 5 m thickness in east London.

4.80 A second unit of similar composition occurs higher in the sequence (above the Upper Shelly Clay) in places, notably in south-east London. This has been called the 'Striped Loams'.

4.81 The Laminated Beds (these also known as the 'Leaf-Bed of Lewisham') are exposed in Gilberts Pit SSSI, Greenwich (Figure 4).

Upper Mottled Clay (Reading Formation)

4.82 This unit comprises clay and sands, very occasionally with gravel. It is typically grey-brown in colour. It is generally less variable than the Lower Mottled Clay, and can be difficult to differentiate from the Harwich Formation. In places it is known to interdigitate with the Laminated Beds.

4.83 The Upper Mottled Clay occurs only between Walthamstow and Merton. To the east its distribution is limited by non-deposition or erosion before the deposition of the Harwich Formation, whereas to the west (where the Woolwich Formation is absent) it is not differentiated from the Lower Mottled Clay.

Upper Shelly Clay (Woolwich Formation)

4.84 This comprises grey shelly clay, with thinly interbedded grey-brown silt and very fine-grained sand with glauconite grains. Lignite is locally present. The unit is lithologically the same as the Lower Shelly Clay, but the shelly fauna can be more diverse. It can include 'Paludina' freshwater biogenic limestone, especially in south London.

4.85 The base of the unit is generally sharp and rests on the Upper Mottled Clay, the Laminated Beds or, probably, the Lower Shelly Clay.

4.86 It is up to about 3 m thick, but tends to have a patchy development, and is inferred to be preserved in depressions below the erosion surface at the base of the Thames Group.

Thames Group

4.87 The Thames Group underlies the large majority of the London district. The basal unit, the Harwich Formation, is present throughout, but is mostly too thin to show separately on geological maps. Only in south-east London, where it attains as much as 12 m in thickness, has its outcrop been delineated from the London Clay. The London Clay is up to 130 m thick.

4.88 The Thames Group is entirely of marine origin, and was deposited during the Early Eocene, between about 55 and 51.5 million years ago. It everywhere overlies the Lambeth Group on an erosion surface. In places considerable portions of the Lambeth Group have been removed prior to the deposition of the Harwich Formation.

4.89 Several subdivisions of the London Clay can be recognised in borehole core but only the topmost, the Claygate Member, can be mapped on the ground.

Harwich Formation

4.90 In the London area, this is typically composed of glauconitic fine-grained sand with beds of rounded black flint pebbles. The proportion of pebbles varies considerably. Fossil shells occur in places. The formation is locally cemented. This type of deposit, known as the Blackheath Beds, where at it's thickest in south-east London. Elsewhere, the Harwich Formation was previously known as the 'basement bed' of the London Clay.

4.91 A sandy shelly bed at Abbey Wood SSSI, Bexley, is part of the Harwich Formation (Figure 4). The Harwich Formation is exposed in Elmstead Pit SSSI, Bromley, Gilberts Pit SSSI, Greenwich and Harefield Pit SSSI, Hillingdon (Figure 4).

London Clay Formation

4.92 The London Clay typically comprises bioturbated or poorly laminated, slightly calcareous, silty to very silty clay. It commonly contains thin courses of carbonate concretions ('cementstone nodules') and disseminated pyrite. At depth, where fresh, it is grey, blue-grey or grey-brown in colour. Near the surface the uppermost metre or few metres typically weathers to clay with a distinctive brown colour produced by the oxidation of pyrite. The London Clay may contain thin beds of shells, and fine sand partings or pockets of sand, which commonly increase towards the base and towards the top of the formation. Glauconite can be present in the sands and in some clay beds. White mica grains may be present. At the base, and at some other levels, there may be a thin bed of black well-rounded flint pebbles.

4.93 Five sedimentary cycles have been recognised in the London Clay, each recording an initial sea level rise and marine transgression, followed by gradual shallowing of the sea (King, 1981). The base of each cycle of deposition is typically marked by a sparse pebble bed. This is covered by thick clays, which become progressively more silty and sandy upwards. An alternative scheme of subdivision has been recognised in the London area, from the study of borehole core (Ellison et al., 2004).

4.94 The Claygate Member is the uppermost part of the London Clay Formation, and corresponds to the upper part of the last of the five sedimentary cycles. It typically comprises interbedded fine-grained sands, and silty clays and silts. The proportion of sand tends to increase upwards. The clays are generally blue-grey where fresh, and brown where weathered.

4.95 The Claygate Member deposits are of tidal marine origin, and represent a transition to the overlying Bagshot Formation. They occur only as scattered outliers, throughout the Thames Group outcrop.

4.96 The sandy basal beds of the London Clay, there known with the Harwich Formation as the Harefield Member, are exposed at Harefield Pit SSSI, Hillingdon (Figure 4) (Daley, 1999b).

Bracklesham Group

4.97 Only the oldest part of the Bracklesham Group, the Bagshot Formation, is represented in the London district. It occurs only as a few scattered outliers, forming high ground (most notably Hampstead Heath). It is much more extensive to the north-east in Essex and to the south-west in Surrey. The maximum thickness in the outliers in London ranges up to about 18 m. Local erosion at the base has removed the top part of the Claygate Member.

Bagshot Formation

4.98 The Bagshot Formation is the lowest part of the Bracklesham Group in the London Basin, and the only part to occur within the London area. It is typically composed of brown to white-coloured quartzose sands, with occasional thin beds of clay, and some pebbly layers. A coarse iron-cemented flint gravel is commonly found at the base.

4.99 The Bagshot Formation was deposited in a shallow marine and estuarine environment.

Landscape

4.100 In southern and south-west London, the older Palaeogene strata form a gentle escarpment rising up to about 20 m from the Chalk dip slope of the North Downs, or (from Erith westwards) up to about 35 m from the river terraces adjacent to the River Thames. The Palaeogene outliers to the south and east tend to form low, well-drained hills with convex slopes. The inliers tend to occur in the floors of shallow valleys.

4.101 The main outcrop of the Thanet Sand lies at the foot of gently rising ground formed by the Lambeth Group, or is covered by superficial deposits. No distinctive landforms are associated with the Lambeth Group, which crops out in concavo-convex slopes or locally on hill-tops in some outliers. Minor springs occur at the top of clay-rich units, particularly the Lower Shelly Clay.

4.102 The London Clay gives rise to a broad swathe of low-lying, subdued topography in the Thames Valley. Even where dissection has been most pronounced (as between Stanmore and Hampstead) only gently rolling ground with convex slopes of generally less than 4° is found.

4.103 The Bagshot Formation underlies the prominent hills of Hampstead Heath and Highgate in north London, Harrow On The Hill in the north-west, and Havering-atte-Bower in the north-east. It gives rise to relatively steep convex slopes up to 12°. It is characteristically free-draining and in a natural or semi-natural state supports typical heathland vegetation. The base of the formation is commonly marked by a spring line.

4.104 There are few natural exposures of the Palaeogene formations in the London district, where it is usually studied in borehole samples or in temporary excavations, especially those associated with construction projects. Some exposures occur in nearby parts of Essex and Kent (Ellison et al., 2004, pp.24, 26). Publications of the Geologists' Association and of local societies such as the Croydon Natural History Society contain a wealth of description of pits and cuttings that are no longer available for study.

Economic significance

4.105 Regionally, the clays of the Reading Formation and of the London Clay have been important historical sources for the local production of bricks and tiles. Local examples include those on the Woolwich side of Plumstead Common. Sand and gravel for construction purposes has also been taken from the Palaeogene formations in places.

4.106 Fragments of silcrete and ferricrete from the Lambeth Group have been used locally as building stone.

4.107 The variability of the Palaeogene deposits, and in particular the presence of poorly cemented sand bodies (some of irregular and unpredictable shape and distribution), have important implications for the ground conditions experienced by the construction industry. Exposures of the Lambeth Group are of great potential value to its understanding by the engineering geology community, through which the information provided by ground investigation boreholes can be better appreciated. On the other hand, the London Clay is an excellent medium in which to drive tunnels: this has greatly facilitated the development of the metropolis.

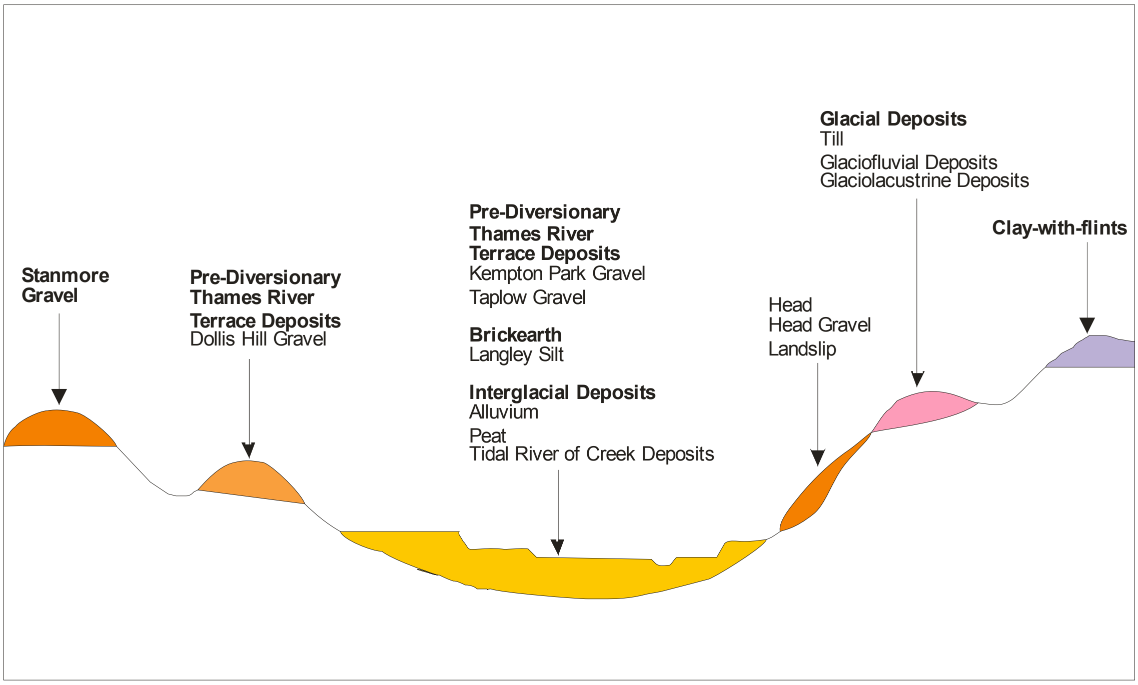
4.108 However, the Palaeogene clay deposits, especially the London Clay, are known for a relatively high content of the clay mineral smectite. This is especially prone to change volume with moisture content. The resulting ground movement is a common cause of structural damage in the London district. Steep slopes in the London Clay are prone to landslide. This has occurred particularly in places in north and north-east London that were once adjacent to the Anglian ice sheet.

Wider geological significance

4.109 Parts of equivalent Palaeogene successions offshore beneath the North Sea are up to 2 km thick and include sands that are important hydrocarbons reservoirs. Study of their onshore correlatives in the London Basin has helped understand these strata.

4.110 The Palaeogene is particularly relevant to studies of global climate. It contains a variety of fossil indicators of environment

Figure 16 Summary of the Quaternary strata of London



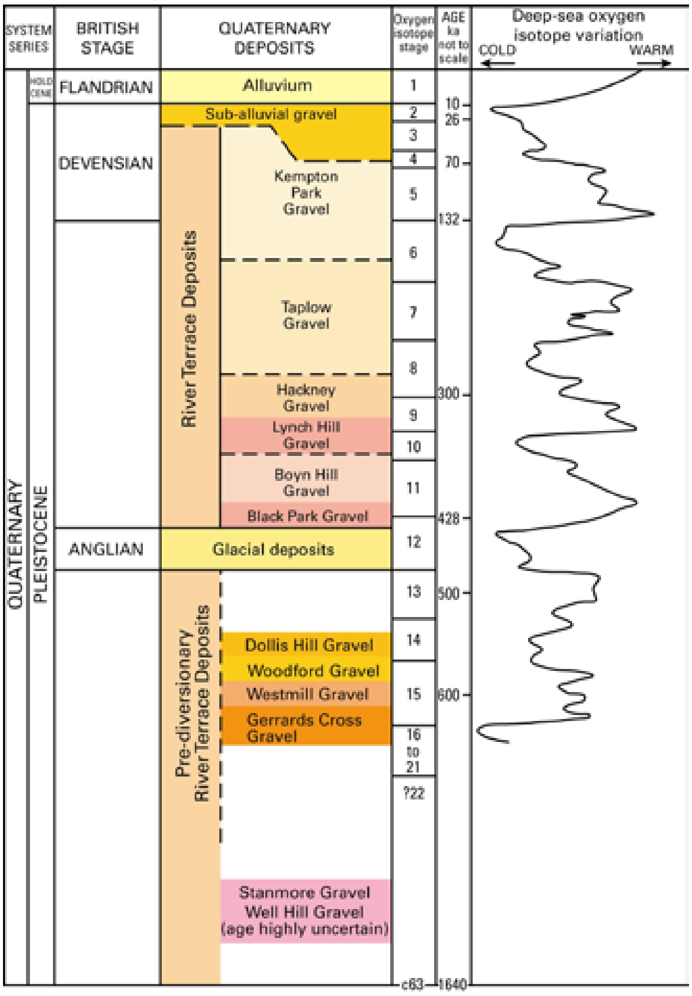
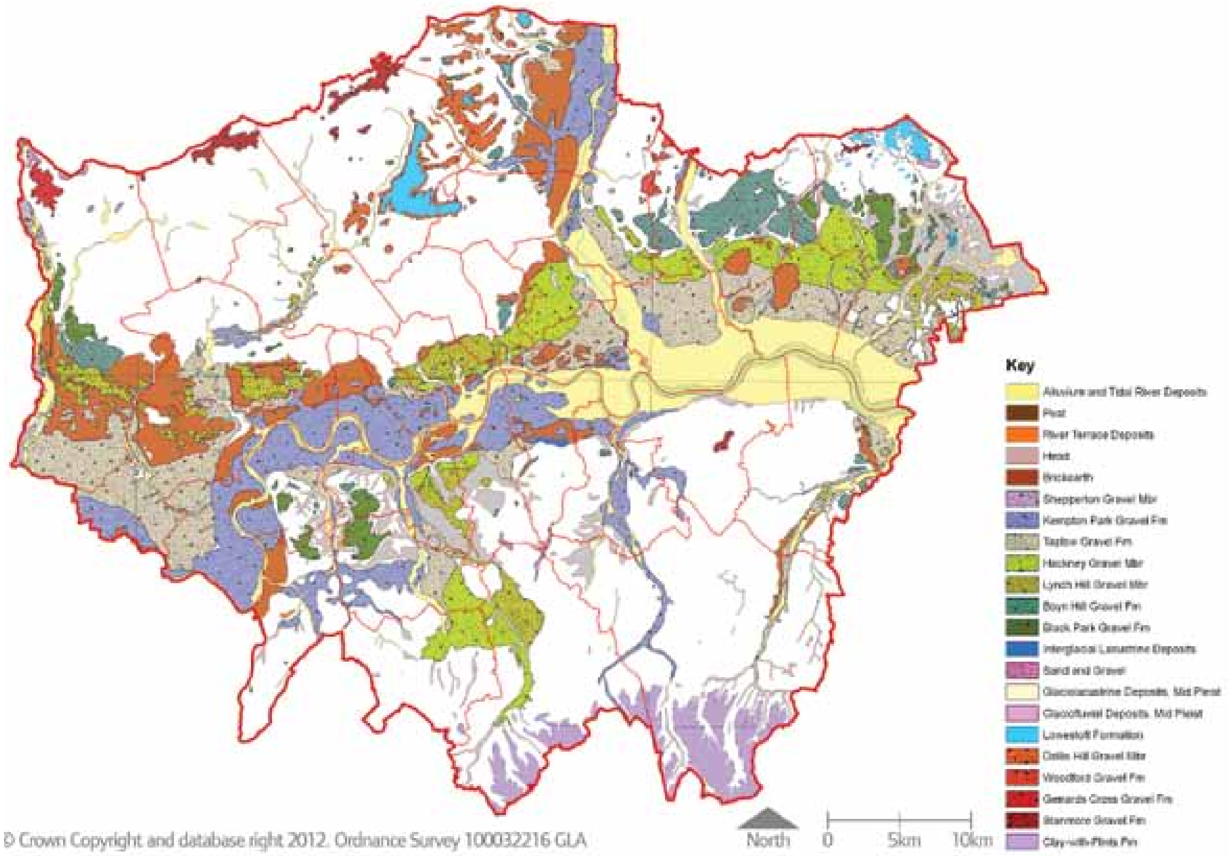


Figure 17 Chronology of the main Quaternary deposits of London (from Ellison, 2004)

Figure 18 Superficial deposits of Greater London



and climate, and encompasses a variety of climatic conditions, including a short thermal maximum at the Paleocene-Eocene boundary, and a longer period of climatic warming in the early Eocene (King, 2006).

Geological Structures

4.111 The axis of the London syncline runs in an east-north-east to west-south-west direction across the middle of the London area, from the vicinity of Romford in the north-east to Surbiton in the south-west.

4.112 North-west of that axis, the bedrock dips gently south or south-east at less than about 2°, decreasing to near horizontal in the middle of the basin. To the south-east of the axis, the bedrock generally dips north-west at 2° or less (and in general somewhat more steeply than to the north-west), but this regional pattern is distorted by a series of elongated periclinal folds. The largest of these is the Greenwich Anticline. Some of these subsidiary folds are asymmetrical, with steeper north-facing limbs, in which dips are generally up to about 7°.

4.113 A belt of faults, extending from Wimbledon to Greenwich, lies parallel to the axes of these periclinal folds, some cases breaching the fold noses. Close to these faults, the dip of the strata may increase and in some places is vertical. The largest faults have displacements of as much as about 30 m.

4.114 Structure contours on the Palaeogene basal unconformity (Ellison et al., 2004) show that the patterns of folding and of faulting are significantly more complex than shown by the geological map. Although not all structures present at the base of the Palaeogene necessarily extend to the surface, some probably do so within the outcrop of the London Clay, where a lack of lithological contrast renders such structures unmappable.

Future Earth science research potential

4.115 The Chalk of the London area probably has a much more complex structure (folds and faults) than has previously been assumed. The more refined modern stratigraphy of the Chalk offers the potential to resolve previously unrecognised structures. Future understanding of the structure and related fracturing in the Chalk offers great benefits for major engineering works that impact on the Chalk and understanding the hydrogeology of the Chalk.

4.116 There are changes in the thickness of formational subdivisions in the Chalk across the London area. Future studies need to focus on the extent to which these relate to the effects of long-lived geological structures and the architecture of the sedimentary basin in which the Chalk was deposited.

4.117 The very large chalk quarries in the London area provide almost unparalleled opportunities for examination and sampling of inland chalk successions. This is important for wider Chalk studies, particularly those concerned with understanding the nature of the Late Cretaceous greenhouse climate and Chalk depositional environment. Many of these studies rely on examination of coastal successions, but these are not always ideal in terms of stratigraphical development and accessibility. The absence of saline water intrusion in inland Chalk successions is an advantage for geochemical studies.

4.118 Each of the Palaeogene formations, especially those of the Lambeth Group, will continue to be the subject of studies for regional stratigraphic correlation and palaeoenvironment analysis. These topics are relevant both to scientific research, for example in sequence stratigraphy and climatic variation, and to applied studies, for example in geotechnical engineering.

Quaternary deposits

4.119 The Quaternary deposits of London provide a fascinating insight into the capital's Ice Age past. They overlie the bedrock of the area and were deposited during the Quaternary Period, between 2.6 million years ago and present day (Figures 16 and 17). They are collectively known as 'superficial deposits' or, in older literature, as 'drift' or 'drift deposits' (Figure 18).

4.120 The superficial deposits are thickest and most extensive within a few kilometres of the River Thames, especially on its north bank, and along its main northern tributary, the River Lea. Less extensive Quaternary deposits occur in the valley floors of the other tributaries. By contrast, the older deposits are confined to interfluve areas and tend to have relatively restricted distribution on the higher ground. Large areas of ground, of intermediate elevation, are shown by the geological map to have no cover of superficial deposits, especially in the north-west and the south, but even here there is likely to be a thin discontinuous cover of head deposits (paragraphs 4.157-158).

4.121 The oldest superficial deposits in the London district probably date from the Neogene (Figure 6). In the south they are the clay-with-flints, a residual deposit derived mainly from a past cover of the Palaeogene, and in the extreme north-west the Stanmore Gravel of unknown but probable marine origin. At lower levels, the interfluve deposits also include a series of river terrace deposits laid down by southern tributaries of an ancestral River Thames. During the Anglian Glaciation, approximately half a million years ago, an ice-sheet extended southwards, diverting the river system and laying down glacial deposits in the north of the district. When the climate warmed and the glacier retreated, the River Thames and its tributaries had been established in approximately their modern positions. Subsequently, the superficial deposits were largely confined to valley floor areas: they include extensive representatives of cold climate deposition (river terrace deposits and 'brickearths') and restricted occurrences of warm climate interglacial deposits. The latter, however, arguably include the alluvium (the extensive deposits of the modern floodplain) and estuarine deposits. The mass movement deposits of the intermediate slopes (head deposits and landslides) formed mainly during periods of cold climate, albeit with some development at other times. This stratigraphy provides a remarkable record of climate change in the region, recording the oscillations between glacial and interglacial periods.

4.122 There are very few natural exposures of any of the superficial deposits.

Clay-with-flints

4.123 The clay-with-flints is a rather variable deposit that occurs on the highest interfluves of the chalk downlands in the extreme south of the district. Typically, it comprises an orange or reddish brown clay or sandy clay, with abundant matrix-supported flint nodules and pebbles. In places, however, it can comprise clean sand or gravel. The lower surface of the deposit is generally irregular, often infilling deep, steep-sided solution pipes and fissures in the underlying Chalk. The thickness of the deposit is thus very variable. In general it forms a blanket up to about 5 m thick, locally greater, but can abruptly increase to several tens of metres in a solution pipe.

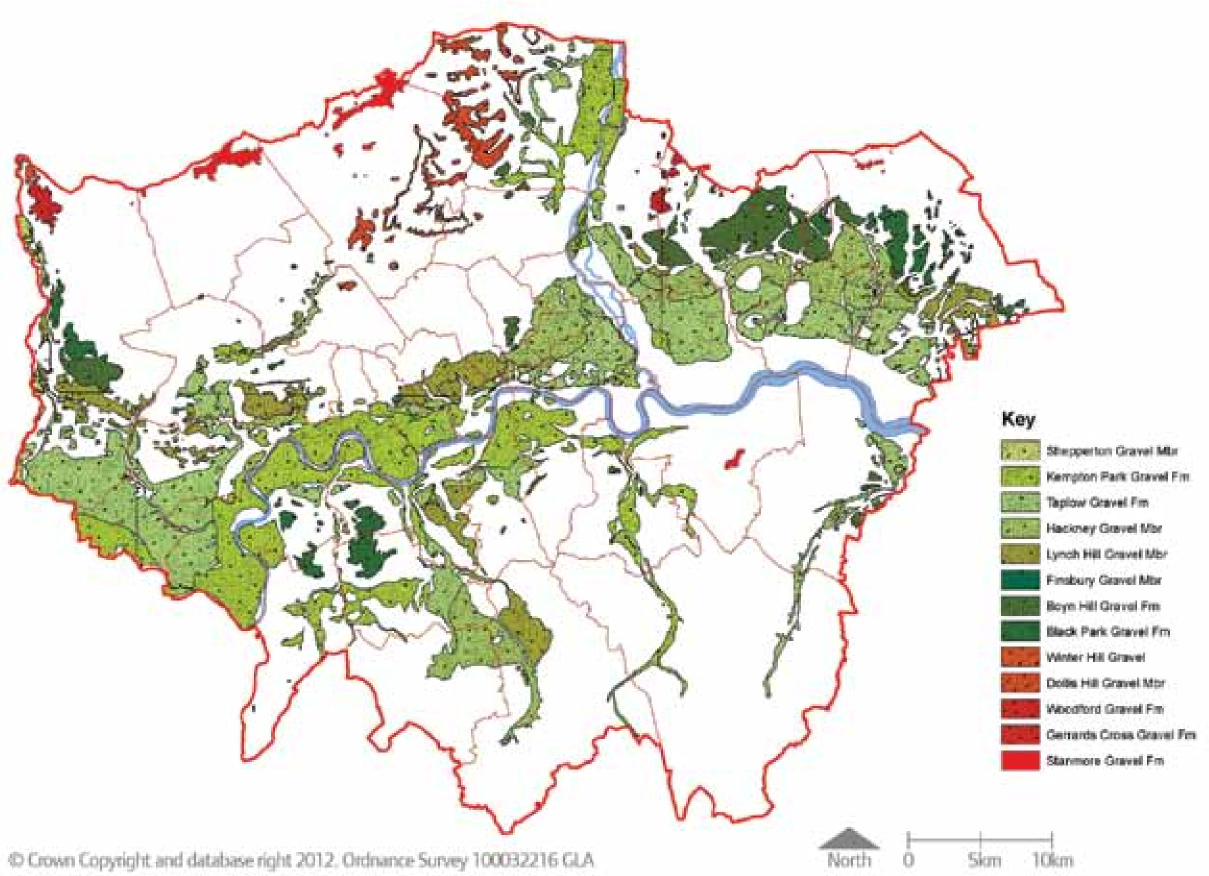
4.124 The clay-with-flints is a residual deposit formed by weathering, cryoturbation and solifluction of the original cover of Palaeogene, Neogene and early Quaternary deposits, together with the insoluble components left after dissolution of the Chalk. This process of weathering probably started during Neogene times, continuing into the Quaternary.

4.125 The clay-with-flints is very widespread on the Chalk of southern England. The occurrences in the London district appear to have no special significance, other than as local representatives of this deposit.

Stanmore Gravel

4.126 Hilltop occurrences of gravel at between 130 and 150 m OD in the extreme north-west of the London district have been named the Stanmore Gravel. This typically

Figure 19 River Terraces of Greater London (pre-diversionary terraces in red colours)



contains well-rounded pebbles of flint, with lesser proportions of quartz pebbles, subangular to nodular flint, quartzitic sandstone, and some other types. These are set in a clayey, sandy matrix, with some pockets of coarse sand. The deposit is up to about 5 m in thickness.

4.127 The Stanmore Gravel is of uncertain age and origin. It has been proposed as river deposits from south bank tributaries of the proto-Thames, rather like the older of the Thames terraces. However, its distribution suggests that it is a westwards correlative of the Red Crag of East Anglia, and that it therefore comprises marine deposits of latest Pliocene to earliest Pleistocene age (Ellison et al., 2004, p. 52).

4.128 As such, it could yield significant information about the early Quaternary palaeogeography and climate, and about the long term rates and patterns of vertical crustal movement in the London region.

4.129 The Stanmore Gravel, overlying the Claygate Member, is exposed at Harrow Weald SSSI, Harrow (Figure 4).

Glacial deposits and landforms

Till

4.130 In the north of the district, particularly around Finchley, and in the north-east at Upminster, glacial till overlies the proto-Thames river terrace deposits. The till (part of the Lowestoft Formation) was deposited during the Anglian Glaciation, about half a million years ago, when an ice-sheet extended into the region from the north. The deposits in north-east London mark the most southern ice margin in eastern England (Figure 12).

4.131 The Anglian till of eastern England was traditionally known as 'chalky boulder clay', reflecting its most obvious lithological characteristics. It is a heterogeneous deposit typically consisting of variably sandy, silty clay with pebbles, cobbles and boulders. The clayey matrix is derived mainly from Jurassic mudstones. The clasts are mostly of flint or chalk but commonly include Jurassic and Carboniferous sandstones and mudstones (and fossils derived from them, such as the Jurassic oyster Gryphaea), Triassic quartzite, as well as other rarer erratic material such as dolerite or granite. The till is composed essentially of the material eroded, transported and subsequently deposited by the ice-sheet.

4.132 The Lowestoft Till (locally known as the 'Hornchurch Till') is exposed below river terrace deposits in Hornchurch Cutting SSSI (Figure 4).

Glaciofluvial sands and gravels

4.133 Glaciofluvial sands and gravels form lenses and sheets in close association with the till, locally underlying it. They were deposited by meltwater streams flowing from the ice-sheet. Their composition is thus similar to that of the coarser components of the till, chiefly flint and chalk pebbles with variably clayey sand.

Glaciolacustrine deposits

4.134 Small outcrops of glaciolacustrine deposits also occur near Upminster, in the north-east of the district. They consist of thinly bedded sand, clayey sand and silty clay laid down in proglacial lakes at, or close to the front of the ice-sheet. As with glaciofluvial deposits, in the GLA area, these occur only in very small areas in the north and extreme north-east.

Wider geological significance

4.135 The glacial deposits mostly occur on what is now high ground, on the interfluves. Although they were therefore once more extensive, their distribution provides important information on the maximum extent of the Anglian ice-sheet.

4.136 There are also sporadic occurrences of till found in boreholes at relatively low levels in the Lea Valley, near Edmonton and Waltham Cross (Cheshire, 1981). These provide evidence about the contemporary topography, and the pre-glacial river systems.

4.137 Their relationship to some of the older river terrace deposits is an important constraint on the age and stratigraphy of those deposits.

Fluvial deposits

Thames river terrace deposits

4.138 The Thames has left a record of its former courses in the form of a series of fluvial deposits, which together make up the most widespread suite of superficial deposits in the London area (Figure 19).

4.139 The river terrace deposits consist primarily of sand and gravel in varying proportions, most usually comprising flint gravel in a matrix of medium- to coarse-grained sand or clayey sand. Beds or lenses of sand, some clayey or silty, occur locally and there are rare lenses of clayey silt, silty clay or peat.

4.140 Each of the terraces was originally deposited on the contemporary valley floor, typically overlying bedrock. They mostly represent deposition under cold climate conditions, when vegetation was sparse, freeze-thaw weathering was active, and seasonal run-off was great. Consequently, large braided rivers carried voluminous sediment, which accumulated relatively rapidly. Subsequent uplift and erosion left portions of each deposit some distance above the modern river, with the older terraces at greater altitude. Together the Thames river terraces thus take the form of a disjointed 'staircase' which range from some ridge-tops down to beneath the floor of the main valleys, where they are overlain by alluvium and peat. Some terraces are preferentially preserved on one side of the valley; and the older terraces have been more extensively dissected by subsequent erosion.

4.141 Each terrace deposit is typically a few metres thick, lying on a step-like surface eroded into the underlying bedrock. Greater thicknesses of the terrace deposits occur locally associated with either channels or closed hollows in the underlying bedrock. In their undisturbed state, each river terrace forms areas of almost level ground which slope gently downstream at a similar gradient to that of the modern river. The importance of this is that it gives the London landscape part of its topographic character of long flat areas, e.g. underlying Heathrow airport or Hyde Park, separated by steeper areas of terrace front slopes, e.g. leading from the Strand to Temple tube.

4.142 The river terrace deposits in the London district can be separated into two systems (Figures 18 and 19). The older terraces pre-date the Anglian glaciation. They mark north-eastwards-flowing tributaries of an ancestral River Thames, which at that time flowed through what is now Hertfordshire and Essex on its way to the North Sea. The advance of the Anglian ice-sheet diverted the Thames southwards to approximately its present course. The younger system of river terraces follows the course of the post-diversionary Thames and its tributaries. For example, in the London Borough of Enfield, the Dollis Hill Gravel was deposited by a pre-diversionary tributary of the Thames, flowing towards the north-north-east, whereas the nearby portions of the post-diversionary Taplow Gravel and Kempton Park Gravel were deposited by the southwards-flowing River Lea.

Wider geological significance

4.143 One of the main reasons the Thames river terrace deposits are so important to scientists studying the Quaternary is their content of the remains of plants and animals. These can give an insight into the types of vegetation and habitats in the area at the time, potentially providing information of the climate and temperature during the time of deposition. For example, organic deposits associated with the Kempton Park Gravel beside the River Lea in the Enfield area contain plant and insect remains indicative of a sub-arctic, tundra environment. Some terraces contain evidence of early human activity in the area, such as bones and flint tools.

4.144 Another of the values of the Thames river terrace deposits is the continuity in their source, and the river basin geometry, over a considerable duration of time. The continuity provided by this stratigraphy is vital for building an understanding of long term Quaternary climate change. The Thames river terrace deposits are arguably one of the most complete sequences of Quaternary deposits in the UK, particularly rich in information on the cold stages represented by the gravels, evidence of which is scarce in other parts of the UK.

4.145 The Wansunt Pit SSSI, Bexley, formerly exposed the Dartford Heath Gravel, part of the complex of Thames river terrace deposits (Figure 4).

Brickearth

4.146 The river terrace deposits (and some of the nearby bedrock outcrops) are widely overlain by 'brickearth', now assigned to the Langley Silt or other named formations on a geographical basis. The London brickearth is typically composed of very fine-grained sand, silt and clayey silt, ranging to silty clay, with some flint gravel. It is generally yellowish-brown in colour and poorly stratified.

4.147 The silt is thought to have originated as a wind-blown deposit, a loess, but the admixture of much sand and gravel in the local development of these deposits suggests they have been largely reworked by fluvial processes or solifluction (down-slope mass movement under cold climate conditions), or both.

4.148 In the past, the brickearths were extensively worked for brick manufacture. Large areas of London close to the Thames and its tributaries occupy former brickfields.

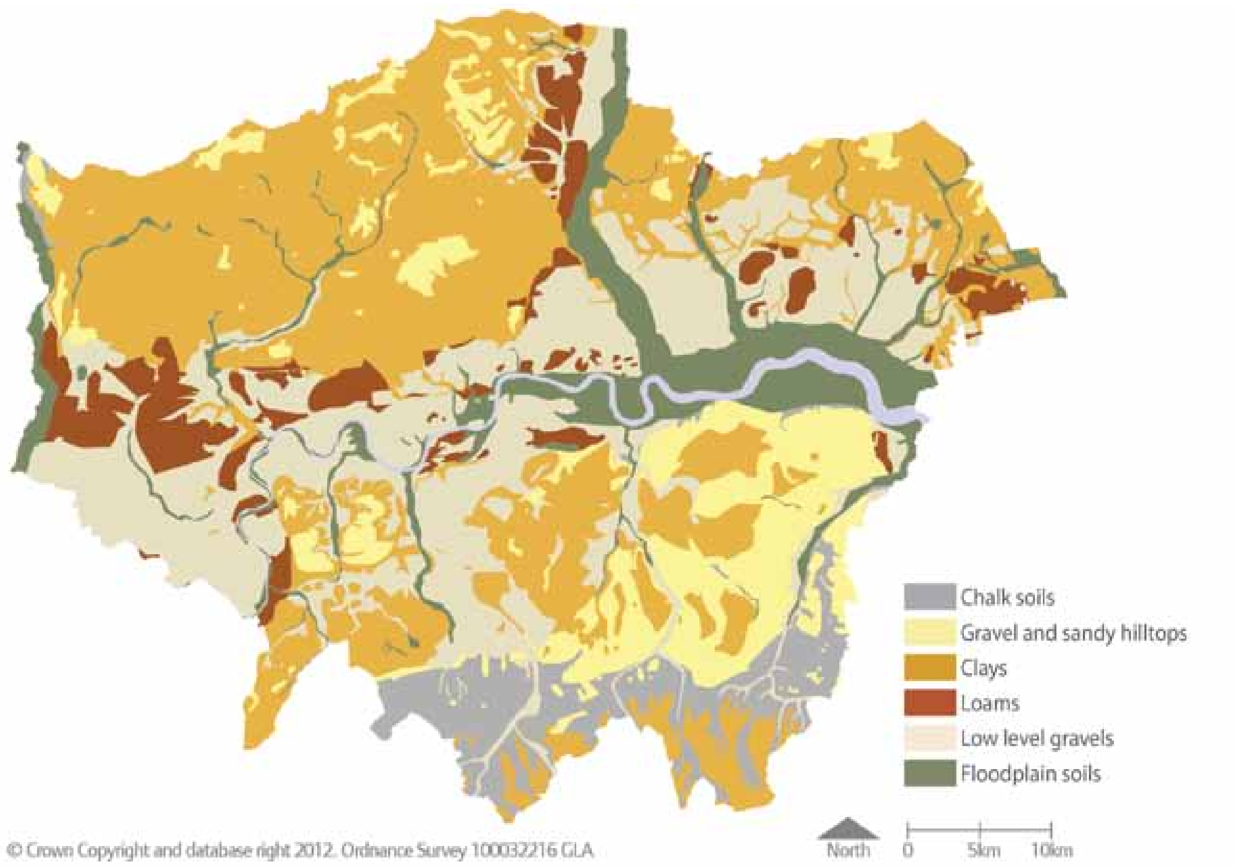
Interglacial deposits

4.149 There are a relatively few, small, but widely distributed examples of deposits from past interglacial periods, representing deposition in temperate climates, typically warmer than at present. These are associated with the river terrace deposits and the brickearths, typically towards the 'back' of the terraces, although the nature of the relationship is not everywhere clear.

4.150 They are mostly sandy to clayey in nature, representing fluvial or lacustrine deposition. Many have yielded significant fossil material, including in some cases the remains of large mammals now found in Africa, and so have a greater significance than their relative rarity might suggest.

4.151 The most well known of the Thames river terrace deposits are probably those evacuated from around Trafalgar Square. These were identified in the early 1700s, when remains of large vertebrates were first discovered. This river terrace deposit is from the Ipswichian (Last) interglacial, providing a detailed insight into the animals and habitats which would have been found living close to the Thames 125 000 years ago. Mammals found include present day hippo (Hippopotamus amphibious), cave lion (Panthera leo) and straight-tusked elephant (Palaeoloxodon antiguus). Molluscs found in the deposit suggest full interglacial conditions, with a large slow flowing river containing plenty of aquatic vegetation (Preece, 1999).

Figure 20 Soils of Greater London



4.152 The scientific importance of the interglacial deposits is quite disproportionate to their extent. The richness and variety of the contained flora and faunal assemblages provide detailed information about the prevailing climate and physical environment and in some cases can provide the basis for stratigraphic correlation from one site to another across northern Europe. For example, certain of the Pleistocene Mammal Assemblage Zones have been named after localities in the east of the London district and nearby Essex (Schreve, 2001). This stratigraphic value is enhanced by the close relationship with individual river terrace deposits, which can be traced over very wide areas.

Alluvium

4.153 Alluvium, composed of mainly silt and clay with rare seams of sand and gravel, forms the floodplains of the Thames and the other rivers in the region. Also found within the alluvium are peat beds, indicating periods of favourable conditions allowing vegetation growth. Mesolithic artefacts have been found in early Holocene alluvium, providing information on the activities of humans in the area. Also abundant in alluvium are fossil molluscs, insects, ostracods and mammals, providing yet more information on the habitats and climate during the Holocene. The Thames foreshore is a source of sites with Holocene alluvium, such as the submerged forest at Erith in east London.

4.154 In most parts of the London district, the floodplains are defended against inundation, and so alluvial deposition has there effectively ceased. Deposits below the level of high water, within the modern river channel, are generally referred to as tidal river or estuarine deposits.

Mass-movement deposits

Head

4.155 Head deposits are commonly present on slopes or on the floor of valleys. They formed mainly by gradual down-slope mass-movement (solifluction) under past conditions of cold climate, but can include the products of more recent soil creep or hill wash. Their composition reflects that of the local materials from which they were derived, either the bedrock or other types of superficial deposit, or both in combination. Head deposits typically are poorly stratified and poorly sorted, and can be variable in composition. Head deposits may be more extensive than shown on the geological map.

4.156 In some places head deposits may pass laterally into river terrace deposits or landslide deposits.

Landslide

4.157 In the London area, landslides are associated mainly with steep slopes on the London Clay. These occur in the Shooter's Hill area of Greenwich, in Richmond Park, and around Romford.

Superficial periglacial structures

4.158 Aside from the types of superficial deposit, the past occurrence of permafrost conditions can be demonstrated by the presence of certain superficial structures. The most common are cryoturbation structures, such as involutions. These occur in the glaciofluvial deposits and some river terrace deposits.

4.159 Pingo scars are thought to be present in a few places, notably at Blackwall. Aside from their scientific interest, these structures are an important element of the local groundwater systems, and place a major constraint on civil engineering works.

Holocene deposits and processes

4.160 After the end of the last glacial period, around 11,800 years ago, river alluvium, peat, salt-marsh and estuarine sediments were laid down and soils developed.

Soils

4.161 Soils link the underlying geology with surface habitats, biodiversity and land use. At any given location, soils reflect the interaction between soil parent material, climate, topography, vegetation and fauna. Soil biodiversity is known to be greater than above-ground biodiversity, but is poorly understood. London's soils, like all English soils, are young, but still represent more than 11,000 years of ecological processes and are thus irreplaceable (Figure 20). London's soils have also been extensively modified by urban development.

4.162 Chalk soils occur in a broad band across the south of London and include downland habitats of Down Bank, High Elms, Saltbox Hill, Riddlesdown, Farthing Down and

Happy Valley biological SSSIs. In the east of London chalk soils are confined to small areas in Lewisham, Woolwich, Crayford and Abbey Wood. A small area occurs in the north-west of London.

4.163 Sand and gravel soils (on river terrace deposits and parts of the Lambeth Group) occur extensively on the hill slopes south of the Thames, in small areas to the north-east of London, on top of the clay in south London at Richmond Park and Wimbledon Common and in a band north of the chalk, which widens to the east. Sandy hilltops occur on top of the clay across the north and west of London. Acid grasslands and heathlands include:

- Richmond Park, Wimbledon Common, Croham Hurst, Keston and Hayes Commons SSSIs in south London
- Hadley Green, the western end of Monken Hadley Common and some of the northern and western outliers of Hampstead Heath in north London
- Stanmore and Little Commons, Stanmore Country Park and part of Bentley Priory in west London
- Epping Forest SSSI, Hainault Country Park, Bedfords Park and Lesnes Abbey Wood in east London.

4.164 Low clay hills (London Clay Formation) occupy most of the north and west London and the north-eastern and south-eastern boundaries, now very largely occupied by built development, except in the Green Belt of the far north and west. In south London low clay hills occupy a band to the north of the chalk overlapping with the sands and gravels in the west. Many of London's surviving ancient woods are on the clay, including:

- Queen's Wood, much of Epping Forest biological SSSI and most of Highgate, Whitewebbs and Scratch woods in north London
- Ruislip woodlands National Nature Reserve and those on Stanmore Golf Course in west London
- Hainault Forest and all of the Oxleas Woodlands
- Sydenham Hill in south London.

4.165 Most grasslands tend to be damp, and this includes some of London's best 'mesotrophic' grasslands, which include:

- Totteridge Fields, Edgeware Way, Arrandene and Mill Hill in north London
- Richmond Park biological SSSI and Morden Cemetery in south London
- Bentley Priory biological SSSI, Fryent Country Park, Horsenden Hill, Yeading Brook Fields and Kensal Green Cemetery in west London.

4.166 In the north-east there is extensive agricultural land as at Fairlop Plain.

4.167 Loams occur south of the clay in west London in a wide band, in a few small areas near the Thames and to the west of the Lea Valley. A scattering of loam soils is also found over the low level gravels largely north of the Thames. These soils are fertile, and in history were the focus of productive agriculture and horticulture for London's breadbasket.

4.168 Extensive low level gravels (river terrace deposits) occur near the Thames and also beside tributary rivers, particularly the Wandle, and are found either side of the Lea Valley. Acid grassland and heathland habitats are evident here, such as:

- Bushy Park, Home Park, Ham Lands, and Barnes and Mitcham Commons in south London
- the centre of Whitewebbs Wood in north London
- Wanstead Flats in east London
- Wandsworth Common in south London.

4.169 Narrow belts of floodplain (alluvium) soils occur around the Thames and also in valleys of the tributaries (including the lost rivers of central London). These would once have been managed as grazing marsh, but most have been displaced by development. The best surviving grasslands and remnant saline grazing marsh are at:

- the northern edge of Ham Lands, Wilderness Parkfield at the eastern edge of Hampton Court and beside the upper Wandle in south London
- Frays Farm Meadows and Syon Park biological SSSIs and in wet gravel pits in west London
- Rainham biological SSSI, Dartford and Bexley Marshes, and the best fresh water example at the Ingrebourne Marshes biological SSSI.

4.170 Woodland is naturally scarce but there are some valuable wet woodlands in the Ruxley Gravel Pits SSSI, in the Ingrebourne valley and areas associated with wet gravel workings in the Colne and Crane valleys. In places, previous use has left rubble, sand, etc, on top of the natural floodplain surface.

Artificially modified ground

4.171 Artificial deposits are those created by human activity. They comprise Made Ground (material deposited on an existing land surface) and Infilled Ground (material deposited in an excavation, typically a quarry or the like). For example, rubble from cleared World War II bombsites was used to fill gravel excavations on Blackheath and large quantities were used to raise Hackney Marshes above flood level to create playing fields. In some instances this distinction cannot be made clearly and so Made Ground and Infilled Ground can together be referred to as Artificial Ground. Geological maps typically also include Worked Ground (excavated areas) in the category of Artificial Deposits or Artificially Modified Ground. Artificial Deposits may overlie either superficial deposits or bedrock formations.

4.172 Underground chalk workings are present in some parts of London, notably at Pinner, Chislehurst, Sidcup, Blackheath and Woolwich. These are of a variety of ages and types. Some are very extensive (see paragraphs 4.46-4.50 and 5.9-5.10).

Natural processes

4.173 London's natural river system has largely been lost due to urban development. Most smaller streams have been built over and channelized, or altered by the quarrying of aggregate, for example, in the Lea Valley. However, over the last few years, efforts have been directed at reversing this loss. The Blue Ribbon Network policies in the London Plan (7.24-7.30) aim to protect and improve London's semi-natural and man-made water systems. The policies take into account that this network is a dynamic system and is subject to natural forces such as tides, erosion and floods. Restoration of rivers to a more natural form is encouraged and proposals to impound or partially impound rivers and development on functional flood plains are resisted. Proposals that include the removal of impounding structures in rivers are also welcomed.

4.174 Guidance on river restoration in London is available from: River Restoration – A stepping stone to urban regeneration, highlighting the opportunities in South London (Environment Agency, 2002) and Bringing your rivers back to life - A strategy for restoring rivers in North London (Environment Agency, 2006).

Future Earth science research potential

4.175 Many of the Quaternary (and in the case of the Stanmore Gravel, possible late Neogene) deposits, particularly the system of river terrace deposits and the associated interglacial deposits, preserve an important record of changes in sea level and palaeoenvironment, and so also of climate variation. Some of these deposits also yield significant archaeological information.

4.176 The details of the relationships between the river terrace deposits, interglacial deposits, and glacial deposits provide important controls on Quaternary stratigraphic correlation in southern England.

Fossils and palaeontology

Late Cretaceous

4.177 On an ultra-microscopic scale, the Chalk is made entirely fossils. The nanometre-sized (a billionth of a metre) fragmented skeletons of coccolithophores, visible only under a scanning electron microscope, are the major constituent of the Chalk, but microfossils visible using conventional optical microscopes, such as foraminifera, radiolaria and ostracods, also occur. Macrofossils, those visible with the naked eye, have been the traditional focus of Chalk palaeontological studies, and include a wide variety of forms, the most important being sponges, brachiopods, bivalves, ammonites, belemnites, crinoids and echinoids. At some levels macrofossil remains are so abundant that they are important rock-forming elements, such as the bivalve Mytiloides forming the shell-rich higher part of the Holywell Chalk, or the fragmented occurrence of the bivalve Platyceramus in the Seaford Chalk. Trace fossils, representing burrows made by animals in the sea bed sediment whilst the Chalk was being deposited, are also locally abundant and extensively developed at some levels.

4.178 The technique of biostratigraphy classifies the Chalk into intervals (biozones) on the basis of its fossil content. Historically this methodology offered a much more sophisticated way of subdividing up the Chalk than was possible using the traditional scheme based on rock composition. The standard zones of the Chalk are based on macrofossils, but there are also microfossil schemes. In Mesozoic rocks, ammonites are usually the best macrofossils for biostratigraphy, as they show rapid evolution, are widely distributed and are normally well preserved. The Chalk is unusual, however, in that ammonite remains are only common in the lower part of the Grey Chalk Subgroup, requiring reliance on a variety of other macrofossil groups for the biozonation of the higher part of the Group.

4.179 Biostratigraphy remains important for understanding the age distribution and correlation of the Chalk, but increasingly attention is being focussed on the microscopic fossils, as these may offer insights into fundamental environmental processes in the Late Cretaceous, such as ocean circulation and global climate change.

Palaeogene

4.180 Parts of the Palaeogene sequence in the London area, particularly but not exclusively the marine deposits, have a rich and varied fossil fauna and flora.

4.181 Bivalves and microfossils such as foraminifera and ostracods have long been used for stratigraphic correlation. More recently, nanoplankton and dinoflagellates have also been found to be of value. Fossil remains of many other groups of marine organisms can be commonly found, including sharks' teeth which in places have been concentrated by winnowing of the sea floor sediment.

4.182 The Palaeogene fossil mammal fauna is less important for correlation than the marine assemblages, but provides valuable insights into evolution following the large-scale extinctions (most notably of the dinosaurs) at the end of the Cretaceous.

4.183 The Thanet Sand is not conspicuously fossiliferous, containing sporadic, poorly preserved bivalves and gastropods, but microfossils are important. Calcareous nanoplankton and palynomorphs have been used for regional correlation. The foraminifera and other fauna indicate that the greater part of the formation was deposited in a shallow sea, less than 50 m deep, and that the prevailing climate was generally cool, turning warmer during deposition of the younger sediments. Irregular nodules of pyrite, less than 5 mm across, are presumed to have replaced fragments of wood. The Bullhead Bed includes a variety of fossils, including echinoid spines, bryozoa, pelecyod shells and fish vertebrae, derived from the Chalk.

4.184 The marine deposits in the Lambeth Group contain molluscs and sharks' teeth. The Woolwich Formation, especially the Shelly beds, commonly contains a limited mollusc fauna indicating brackish water conditions. However, the 'Paludina Limestone' of the Upper Shelly Clay contains the remains of freshwater molluscs, while the rest of the Upper Shelly Clay contains a generally more diverse fauna than the Lower Shelly Clay, including more marine-tolerant species. The Harwich Formation is locally shelly, as at Elmstead Pit (Section 4.3), and also yields sharks' teeth and fish scales.

4.185 As a non-marine deposit, the Reading Formation is relatively poor in fossils, but thin beds rich in leaf impressions and other plant remains occur in places. Clay beds with leaf impressions have been noted in the 'Striped Loams' of the Woolwich Formation. The lignite deposits at the Paleocene-Eocene boundary arose from vegetation dominated by angiospermous trees and herbs, with many ferns, which was subject to repeated fires. These fires may have been a response to climatic events associated with the Paleocene-Eocene thermal maximum (Collinson et al., 2003; King, 2006).

4.187 The marine fossil fauna of the London Clay includes numerous types of bivalve, gastropods and some brachiopods, corals, echinoderms such as starfish and sea lilies, arthropods including crabs, lobsters and barnacles, cephalopods and a variety of sharks' teeth. Bones of fish and reptiles can also be found. A variety of plant seeds and fruits, some quite large, also occur in the London Clay.

Crystal Palace geological illustrations

4.188 The Crystal Palace was originally built in Hyde Park as part of the Great Exhibition of 1851; it was relocated to its current position once the exhibition was over. As part of the relocation and development of the grounds, Benjamin Waterhouse Hawkins was commissioned to build life-size models of extinct animals. With the help of Sir Richard Owen (a biologist and palaeontologist), he was able to design dinosaurs to be included in the collection. Concurrently, a model of geological strata and a lead mine were built to illustrate the natural state of geological resources including coal, iron and lead. These were constructed by James Campbell, an engineer and mineralogist.

4.189 The animal models were originally set out so they followed a rudimentary timeline; Palaeozoic, Mesozoic and Cenozoic eras were each represented by a separate island within an artificial lake. The Cenozoic models were later moved to different areas within the park and subsequently became damaged. Funding for the models was cut in 1855 before all those planned had been completed.

4.190 By the end of the 19th Century, further research into the species on display had revealed that the models were highly inaccurate and they drew many critics. The popularity of the models declined and they fell into disrepair – this was compounded by the fire in 1936 which destroyed the Crystal Palace. The models and much of the park became overgrown.

4.191 In the 1950s Victor H C Martin carried out a full restoration of the models during which time they were moved to fresh sites. After this restoration, the models were once again left to decay with the exception of occasional touch ups. This was the case for the whole park until 2002 when the Institute of Historic Building Conservation completed renovation of the models. The models were mended and repainted; missing models were reconstructed using fibreglass. The vegetation around the models was also restored to reflect the plant life that would have existed when the exhibited animals were alive.

4.192 There are now 29 models in the park representing the following genera:

Anaplotherium; Dicynodon; Hylaeosaurus; Ichthyosaurus; Iguanodon; Labyrinthodon; Irish Elk; Megalosaurus; Megatherium; Mosasaurus; Palaeotherium; Plesiosaurus; Pterodactyl; and Teleosaurus.

4.193 The models are now part of a 'Prehistoric Monster Trail' which leads visitors through time with information boards explaining each model and how they would differ if constructed today. This trail is now available as an I-Phone Application.

Quaternary

4.194 A number of flint artefacts have been found in London of Early and Late Palaeolithic age (corresponding to Pre-Anglian to Late Devensian in geological time). These include hand axes, blades, and other small tools.

4.195 Pleistocene bone, plant and insect remains have been found at a number of localities in London. The main sites are Isleworth, Ilford, Brentford, Kew, Trafalgar Square, Ponders End, Erith, East Ham and Crayford. The Corbetts Tey – Mucking/ Lynch Hill – Taplow terraces have yielded cave lion, wolf, mammoth, rhinoceros, giant ox and red deer, with Ilford being one of the best sites. The East Tilbury Marshes/Kempton Park terrace has yielded hippopotamus, beaver, hyaena, cave lion, brown bear, elephant, boar, bison, giant ox and red deer, with Brentford and Trafalagar Square being the best examples. More recent deposits associated with the Devensian ice age have yielded lemmings, hyaena, cave lion, polar bears, woolley mammoth, rhinoceros, reindeer, bison, ox and antelope. Erith, Twickenam and the Lea Valley are the best examples. The alluvium has yielded beaver, wolf and giant ox with East Ham being the best known site.

Evidence of early Man

4.196 Palaeolithic artefacts have been found in the river terrace deposits of the Thames and its tributaries, and in associated interglacial deposits, reflecting the presence of human occupation along the water's edge.

4.197 The oldest such remains were found in interglacial deposits dating from the Hoxnian (which immediately followed the Anglian glaciation) about 400 000 years ago, in association with the post-diversionary Boyn Hill Gravel. Such deposits at Barnfield Pit, Swanscombe (in Kent, about 6 km east of the London district) have yielded some of the oldest hominid fossils so far found in Britain.

4.198 Tools are found in deposits dating from the subsequent two interglacials, at about 320 000 years ago (associated with the Lynch Hill and Hackney gravels) and 250 000 to 200 000 years ago (associated with the Taplow Gravel). The fossil record indicates that humans were then absent from Britain until about 70 000 years ago (Stringer, 2006).

4.199 From the late 19th century onwards, archaeologists realised that flint weapons and tools were contemporary with the remains of many extinct animals, representing a long period of time prior to the appearance of modern man. Gradually, distinctive assemblages of tool types were identified, coincident with the cultural evolution of man. For further details see Sumbler (1996).

CHAPTER FIVE

GEOLOGICAL RESOURCES AND BUILT HERITAGE

Mineral resources

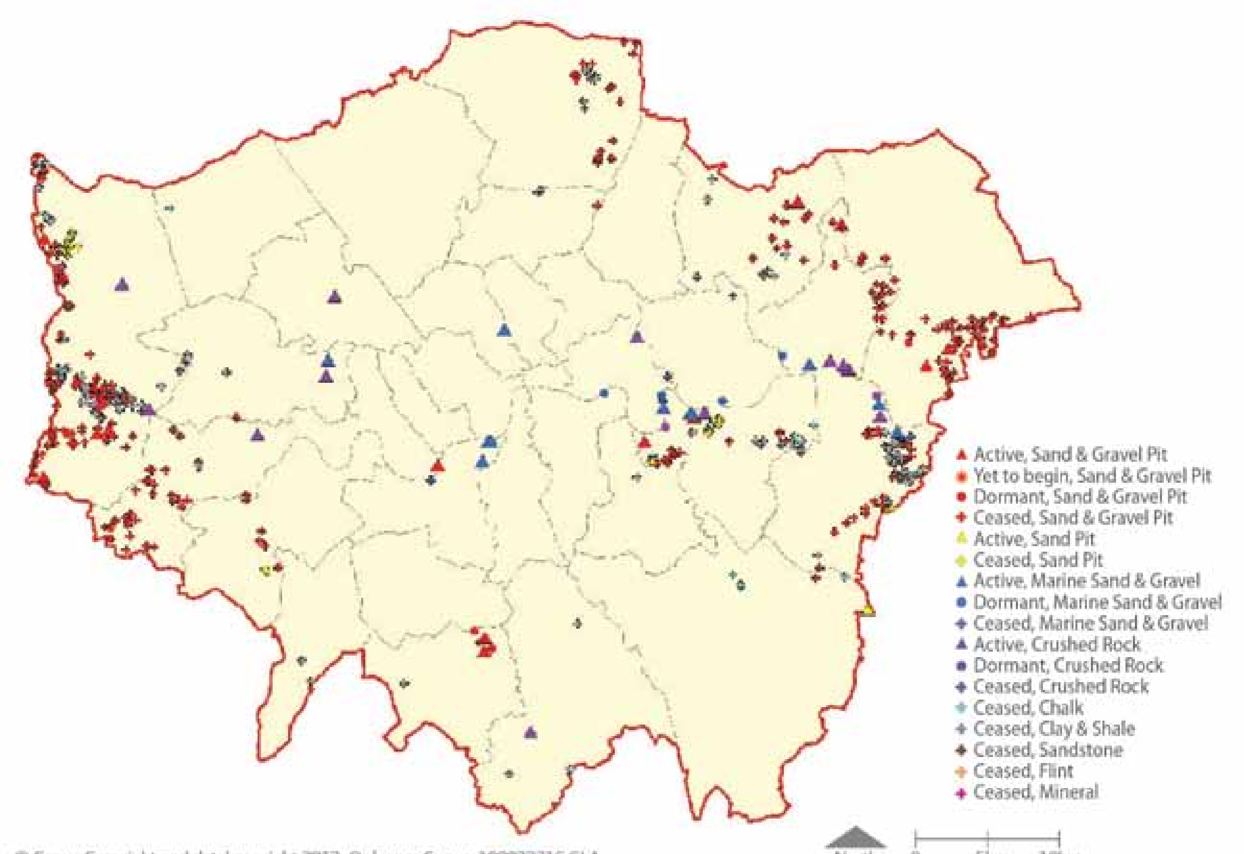
5.1 The most valuable mineral resources of Greater London are those used by the construction industry, notably sand and gravel, brick clay and cement-making materials. The rapid growth of London from the 19th century onwards created great demands for these products, much of which were met from outside London.

Sand and gravel

5.2 There are relatively small reserves of land-won sand and gravel in London. Most aggregates used in London come from elsewhere including marine sand and gravel and land-won materials from other regions. The main sources of aggregate both historically and at the present day are the Thames river terrace deposits (paragraphs 4.138-4.145). The current regional apportionment for land-won sand and gravel, set by the Mayor, indicates a commitment to a significant level of ongoing aggregates extraction in London across the region.

5.3 The impact of former aggregates extraction on the region is further evidenced by the fact that the BGS database of mines and quarries contains over 250 entries for sand and gravel extraction. In London, however, modern levels of extraction are not representative of the scale of extraction which has occurred over the centuries.

Figure 21 Mines and quarries of Greater London



Brick Clay

5.4 The London Clay Formation does not meet modern standards for brick-making due to its high smectite content, which causes extensive shrinkage and distortion during drying and firing. However, in the past it was used with the admixture of sand, or chalk, or in some instances blended with street sweepings of grit and cinder. The Claygate Member yielded more suitable material and was widely used, for example at Willesden Green. The London Clay was used more for tiles and pipes.

5.5 At Beddington, west of Croydon, the Thanet Sand Formation was once employed in the manufacture of 'sand-lime ' bricks. Although the Quaternary brickearths (paragraphs 4.146-4.148) are relatively thin deposits, they were once used extensively to manufacture bricks, and in some areas were completely cleared. Much development then took place in former brickfields. It has been reckoned that "an acre [of brickearth] yielded a million bricks for each foot of earth". The glacial till of Church End, Finchley, was at one time used, after washing, for making bricks, as was also the alluvial clay of Hackney Marsh. The Reading formation was used in Pinner, mixed with chalk from the mines.

Chalk and clay for cement

5.6 'Cementstone' beds, including septarian nodules, from the London Clay were formerly used for making cement, particularly during the 'stucco period ' of London architecture (paragraphs 5.15-5.21). The Chalk has been extensively worked for cement manufacture at several places just outside the London area.

Chalk mining

5.7 Man-made cavities in the Chalk have been made during flint mining and chalk extraction, probably from pre- Roman times until the 19th century. The smaller mines are typically narrow vertical hand-dug shafts 10 to 20 m deep, known as dene holes. Dene holes can occur singly or in groups of up to 70, or more, and in some areas may be only 20 m apart. At the base of the shaft there may be a bell-shaped excavation or a number of short galleries.

5.8 More extensive chalk mines are known at Pinner [TQ 114 906], Chislehurst [TQ 4275 7015], at several locations near Plumstead [e.g. 472 784; 464 774], and Blackheath [383 767]. Mined cavities are usually stable, but the material with which they have been backfilled may suddenly subside and collapse due to the effects of natural drainage, leaking surfaces or rainwater soakaways. Such instability may also occur due to slow deterioration of gallery roofs. In this case, the resultant collapse may lead to upward migration of the void and consequently sudden subsidence of the ground surface.

Flint

5.9 Flint occurs abundantly as nodules and tabular sheets in the Chalk and as clasts in terrace gravels. Historically, flint has been used for tool making by early man, for the manufacture of flint glass in the late 17th century, and for gun flint manufacture, which reached a peak during the Napoleonic Wars. It has also been used as a building material. The Romans used flint for the construction of fortification and defensive walls and the Normans continued the tradition with the erection of defensive sites and castles. In the absence of readily available alternative building stone, flint continued to be used in small vernacular buildings, as rubble flint walling and frequently in the base or plinth of timber framed structures and early brick buildings.

5.10 Flint was used extensively in the 18th and 19th centuries for road construction and maintenance where it was used to form a solid base for a gravel top surface prior to the widespread introduction of macadamized roads. In more recent times, flint was produced as a by-product of chalk working. The BGS BritPits database indicates that the Springwell Lock Chalk Pit used to supply flint for brick manufacture, but the pit has ceased operations.

Moulding sand and glass sand

5.11 The occurrence of easily accessible and large reserves of sand suitable for moulding led to the selection of Woolwich as the site of the principal arsenal in Great Britain. The sand lies towards the base of the Thanet Formation. It contains sufficient clay to give it 'binding' properties. Known as the 'Erith' or 'Blackfoot' moulding-sand, it was once sent to all parts of Great Britain and to many foreign countries, and was considered by some to be superior to the Triassic 'Bunter' sands of the English Midlands.

5.12 The uppermost metre or so of these beds was once worked for rough green bottle glass manufacture in the London district.

Building stone and built heritage

5.13 High-quality building stone is scarce in Greater London, but an interesting variety of local substitutes have been used. Rounded flint pebbles (paragraphs 5.9-5.10) and 'puddingstone' (ferricrete) from the Lambeth Group and the Thames terrace gravels have been used; the latter are best seen in the Norman churches around Heathrow, Greenford and Staines. Ferricrete from the Basghot Formation of Harrow on the Hill is well displayed in the tower and walls of the Norman church, Flints, septaria and ferricretes were usually framed and strengthened in building by quoins, string-courses and lintels of either Kentish Ragstone (Lower Greensand) from the Medway Valley, or the softer Reigate Stone (Upper Greensand) from northern Surrey. These stones were often replaced with Bath Stone (Great Oolite) by Victorian restorers.

5.14 Kentish Ragstone and Reigate Stone have been used extensively for more substantial buildings in London since Roman times, when they were used in the walls of Londinium. After the Great Fire of 1666, London, became a showcase for Portland Stone. The stone was transported in large quantities by sea from quarries on the Isle of Portland in Dorset. It was often used in combination with brick, or brick rendered with a white stucco finish which characterises the squares and terraces of Bloomsbury and Belgravia. The expansion of London and the building of new parish churches saw a resurgence of the use of Kentish Ragstone, mainly from the Medway Valley, and transported by barge to city wharves. Virtually all the London suburbs have a parish church of greyish buff Kentish Ragstone with yellowish brown Bath Stone dressings.

5.15 With the arrival of the railways, architects such as Sir Charles Barry and Gilbert Scott were able to utilise a wide range of materials such as Scottish, Irish and Cornish granites. The advent of cladding techniques in the 20th century, using thin slabs of stone over a concrete interior, has greatly increased the range of rock types utilised. For more information on the building stones of London see Robinson (1984a,b) and the University College London Earth Sciences website Building London. London Geodiversity Partnership has also produced a leaflet *Building London* which is displayed on the LGP website: www.londongeopartnership.org.uk.

5.16 A good example of the increasing choice of building materials available in London is the construction of the Houses of Parliament between 1840 and 1860. The old parliamentary buildings were destroyed by fire in 1834 and a competition was organised to design a new set of buildings. The winner, Sir Charles Barry, originally chose Portland Stone to be used in the building due to its known durability and ease of use. However, the air in London was becoming increasingly polluted and research had suggested limestones would not be sufficiently resistant to the more sulphurous air. Therefore a Select Committee was established comprising the architect, a mason/sculptor and two geologists. They surveyed 102 stone quarries across the country, inspected reference buildings and completed laboratory tests.

5.17 The dolomitic Bolsover Moor stone was the final choice due to its dense crystalline nature (less surface area for chemical agents to react upon) and the resistance of dolomite to dilute acid. Unfortunately the quarry was unable to provide enough stone of sufficient size and so two further quarries were used.

5.18 Unfortunately it was not long until the stone began to crumble, in particular the intricately carved detail. Further investigation revealed that much of the stone contains small crystal-lined cavities and is commonly minutely cellular: on weathered surfaces, randomly oriented calcite veins stand proud. These faults had been overlooked by the original surveyors but would eventually lead to the stone crumbling when exposed to the weather. As a consequence of this, much of the original stone has been replaced by the more durable Clipsham Stone (a pale yellow Middle Jurassic limestone from Lincolnshire).

5.19 A wider consequence of the publication of the Houses of Parliament stone survey was that it inspired architects to source stone from places other than Portland. This was helped by the expansion of the railways making quarries across the country accessible and their stone financially viable.

Water resources

5.20 The Chalk is the principal aquifer of London. It is mostly confined by the overlying London Clay and Lambeth Group and is in hydraulic continuity with the sands of the Thanet Sand and Upnor formations, which together are commonly referred to as the 'Basal Sands'. The upper boundary of the aquifer is generally regarded as a clay layer with a thickness greater than about 3 m. In most places this clay lies within the Lambeth Group; it is coincident with the Lower Shelly Clay in much of central London, the Reading Formation in the west and north of the district, but probably the London Clay in the south-east of the district where the older Palaeogene strata consist mainly of sand.

5.21 The Chalk aquifer is naturally recharged by rainfall at outcrops in the Chiltern Hills to the north and the North Downs to the south. The groundwater flows towards the centre of the London Basin. Prior to abstraction in the 19th century it discharged mainly at springs, many under artesian conditions, in Chalk valleys and along the Thames particularly between Erith and Gravesend.

5.22 Relatively minor aquifers in the district include the river terrace deposits, the confined Lower Greensand in the south-east and, locally for example Harrow on the Hill, the Bagshot Formation.

5.23 The majority of the Chalk public supply sources in the Chalk aquifer are in the North Downs and the Darent and lea valleys. Development is now taking place in the Greater London area to use the confined Chalk aquifer resource resulting from rising groundwater. Small quantities are abstracted from sources in the Lower Greensand from wells through the Chalk in the North Downs.

Development of groundwater resources in the London Basin

5.24 The growth of the city of London was constrained for many centuries by the availability of local water supplies, thus early expansion of the City was restricted to areas where river gravels are present. Until the 13th century water supplies for London were obtained from the Thames and its tributaries, and from springs and shallow wells in the river gravels. As the city expanded these resources became inadequate or polluted and further supplies were obtained via conduits, including the New River, which flowed from the Chiltern Hills. In the 18th century attempts were made to develop deeper groundwater resources beneath London. The first deep wells in the Chalk were constructed in the 1820s, although there was probably a reluctance to develop the confined aquifer because of difficulties in coping with the quicksands (or 'running sands') within the basal sands that were under artesian pressure. By the 1890s, many of the early large diameter wells in the Chalk also had horizontal entrance passages, some heading several hundreds of metres from the main shaft.

5.25 The rate of abstraction from the confined part of the aquifer peaked around 1940 and subsequently decreased, whereas that from the unconfined area continued to rise until the 1970s. Public water supply has dominated water use since the 1860s.

5.26 In the confined Chalk, groundwater is considered to flow in corridors of high permeability Chalk separated by blocks of low yield. There is a general decrease in aquifer permeability from the Chalk outcrop towards the centre of the London Basin. Where Chalk is deeply confined, yield is commonly low. Yields from individual large-diameter wells at favourable valley sites at outcrop may exceed 9000 m^3/day. Yields from pumping stations in the outcrop area, which may have several wells and may include adits, often exceed 14 000 m^3/day. By contrast, in the confined aquifer, yields are usually considerably less, commonly of hundreds of m3/day. Some very high yielding sites (in the order of 7000 to 10 000 m^3/day) in the confined aquifer are probably related to the high permeability corridors.

Groundwater management and protection issues

5.27 In central London the original natural groundwater level was 7.5 m above Ordnance Datum. By the mid-1960s this had been lowered by pumping from boreholes to around 88 m below Ordnance Datum. The fall in groundwater levels in the confined aquifer caused a reduction in spring flows and some river flows, and induced the intrusion of saline water from the Thames into the Chalk downstream of the Isle of Dogs. Reduction in groundwater abstraction since around 1965 has resulted in recovery of the groundwater level. Rates of water level rise approached 3 m/year in places in the 1990s. Left unchecked, rising groundwater beneath London would have several serious consequences including resaturation and a change in bearing strength of the London Clay and other bedrock formation, flooding of tunnels and basements, and a potential buoyancy effect on sealed structures. In addition, the groundwater rising through the Palaeogene formations can be sufficiently acidic, following oxidation of pyrite in the vadose zone, to cause corrosion of buried infrastructure.

5.28 Since 1995, rates of groundwater rise in central London have decreased to around 0.5 m/year due to a combination of natural causes and a strategy to manage the water levels.

Former spas

5.29 There were formerly many mineral springs in the London area – some were used for medicinal purposes and others for leisure. The water for many of these springs came from the London Clay. Having originally been derived from gravels overlying the clay, the water passed into the London Clay through cracks, passing along sandy layers. Whilst within the London clay the water absorbed salts, mainly magnesium sulphate or sodium sulphate. This saline water reached the surface at places such as Bagnigge Wells and Sadler's Wells in the Fleet valley, Kilburn Wells in the Westbourne valley, Beulah and Streatham. Other springs contained chalybeate (containing salts of iron) water. Hampstead Wells are an example of chalybeate waters that were derived from the base of the Bagshot Sand.

5.30 Well-known examples from the Greater London area are the springs at Epsom which gave the name to Epsom Salts – the magnesium sulphate which is the principal salt in the water. The springs at Epsom were discovered in 1618 and were regularly used in the 17th and 18th centuries.

CHAPTER SIX

EVALUATING LONDON'S GEODIVERSITY

Review of geodiversity guidance and assessment criteria

6.1 This chapter explains the auditing process and begins by reviewing current systems of geodiversity evaluation and site assessment criteria. The main systems in use in the UK for geodiversity auditing are:

- UKRIGS system
- BGS GeoDiversitY Database
- Geodiversity Profile Handbook (David Roche Geo Consulting)

UKRIGS

6.2 In consultation with their Member Groups, Geoconservation UK has developed a standardised procedure for recording, assessing, designation and notification procedures for RIGS sites. The assessment proposed includes general criteria, such as access, safety and condition of exposure, and scientific criteria, the latter showing the type of geological feature(s) exposed. Scott (2005) noted that "RIGS groups do not have a coordinated approach to site assessment. This is a strength in that local criteria are used, but also a weakness that relative values of sites across county or area boundaries cannot be established."

6.3 The assessor records the site name, location, and a description, and assesses the sites by scoring from 1 to 10 in four main categories: access and safety; education and science; culture, heritage and economic; and geodiversity value. In practice the procedure is not easy to use; the explanations in the notes do not cover all scores and the wording is subjective. It is also not appropriate to score access to the site and safety issues.

6.4 The Geoconservation UK site recording system is, however, the most widely adopted process for the selection of Local Geological Sites in the UK and is recommended by the Defra Local Sites guidance. Selection is based on four broad criteria or values: scientific, educational, historical and aesthetic which are central to the Geoconservation UK approach which assesses the quality of access (UKRIGS, 2001).

6.5 To maintain consistency with Local Site selection elsewhere the UKRIGS system has been adapted in London. Access and safety are assessed but not scored and the four main criteria are assessed and scored in two sections: 'Culture, Heritage and Economic' which corresponds to the Geoconservation UK system and 'Geoscientific Merit' which is equivalent to the Geoconservation UK assessment of Education and Scientific values. In addition, The BGS GeodiversitY Database (see below) provides a further mechanism for scoring the rarity and quality of sites as well as the quantity of published literature which allows a further useful refinement of the site assessment system.

BGS GeoDiversitY Database

6.6 The BGS GeoDiversitY database was designed in MS Access for rapid and objective geodiversity data collection in the field, either on a hard copy form, or direct input via PC. The database was set up and tested during BGS projects in the North Pennines, County Durham and West Lothian (Scotland). In this system, only geological scientific merit, education value and community site value are scored on a

0 to 10 scale. Access, site fragility, potential use and other site details are entered via tick-box, drop-down menu or free text. The database is designed as a front-end to tables stored in the BGS Oracle database system.

Geodiversity Profile Handbook (David Roche Geo Consulting)

6.7 A new procedure for the recognition of high value geodiversity was developed in the MIST (Mineral Industry Sustainable Technology Programme) funded project, GeoValue by David Roche GeoConsulting, and a book entitled 'The Geodiversity Profile Handbook' was published (Scott et al., 2007) (see also www.mi-st.org.uk/section_c.htm). It provides a standardised procedure for auditing the geodiversity at a defined geological site or area, followed by a numerical procedure for valuing it, known as the Geodiversity Profile. The criteria, namely scientific, educational, historical, cultural and aesthetic are broadly similar to that adopted in assessing RIGS of County Geology Sites, and promoted by UKRIGS. Examples of the valuing of sites with differing geodiversity are provided. The purpose of the Geodiversity Profile is to provide an independent procedure for valuing a geological site and thus aid decision-making on its future management. It is developed especially for use in quarries. It is not designatory or intended to replace existing statutory or other designations. The Geodiversity Profile is not available in database format.

System used for this project – London-GDY

6.8 Here, the BGS GeoDiversitY database is used. However, in order to make it more compatible with the UKRIGS Site Assessment procedures it adapts features from the UKRIGS system. The revised system is herein termed **London-GDY**. Access, fragility, potential use, other site details and geoscientific merit, community and education site values are retained from the original BGS GeoDiversitY database as the scoring system is more robust, logical and easier to use than the Geoconservation UK procedure. The classes used in Geoscientific merit scoring in the London-GDY and the scoring guidance are listed in Appendix 2. For the subsequent auditing of sites the technology has not been available to members of the Sites Working Group (SWG) and they reverted to paper and pencil notes in the field and completing site reports and auditing forms and maps as a desk job making use of the internet for Streetmap and BGS online maps for providing basic information for GiGL (see para 6.15 below) to convert into the GIS system. The SWG has adapted the auditing forms in order to retain the format used in the Site Assessment Sheets in Appendix 5. These are a combination of the Geoconservation UK/BGS forms used in the initial audits and the scoring criteria remain the same as those detailed in Appendix 3.

6.9 The London-GDY data entry forms were also redesigned to allow the system to run on BGS MIDAS (Mobile Integrated Data Acquisition System) ruggedised field notebook PCs (Figure 22). MIDAS allows collection of digital data/information in the field, including digitising geodiversity site boundaries. One of its main strengths is the facility to bring practically any digital dataset to the field including DiGMapGB (BGS digital geological map data), historic Ordnance Survey maps, scanned geological field maps, NEXTMap digital terrain/surface models etc. The system also has an inbuilt GPS. MIDAS uses a combination of heavily customised ArcGIS, MS Access and InfiNotes.

Figure 22 BGS MIDAS Tablet PC (GoBook) for digital field data capture

Geodiversity auditing

6.10 The GeoConservation UK system sets out a staged approach to Local Site assessment which is followed here. This involves desk and field based documentation of sites including a site description, boundary details, sketches and photographs. This is followed by an assessment of the 'value' of the site using various criteria, a comparative evaluation of assessed sites and the formal recommendation of the site to the local authority for designation.

6.11 The audit began with a review of the available documentation and datasets that could potentially provide information on geodiversity sites in the GLA. These sources included:

- South London RIGS Group list of potential RIGS
- SSSI and GCR documentation (Natural England)
- BGS 1:10 000 standards and field maps
- BGS BritPits database of Mines and Quarries (Map 4, Volume 2)
- BGS London Memoir (Ellison et al., 2004) and Regional Guide (Sumbler, 1996)
- Parcels of geology interest database (from GLA)
- Borough geology and landscape review documents (GLA)
- Additional sites recommended in the consultation for the first edition of London's foundations in 2009 and in the consultation for the Action Plan in 2010.

6.12 Information from these sources was entered into a spreadsheet, giving a total of around 470 potential sites. The site locations were then exported to a GIS and cross-checked against recent digital aerial photography (25 cm resolution) to further ascertain geodiversity value. This was backed up by BGS staff geological expertise to narrow the potential list for field checking and auditing to 100 sites (Appendix 1).

6.13 Field auditing was carried out between November 2007 and February 2008. As far as possible landowners were contacted prior to visiting or accessing sites, but ownership was not established for every site visited. From the list of 100 sites selected to be visited during field work (Appendix 1), access was not obtained for 16 of these sites and a further 11 sites were not visited for logistical reasons, with planned revisits not possible due to lack of time. A further 30 potential sites were identified during the consultation period of preparing this report. It is recommended that these 57 sites be assessed in the future.

6.14 For the 2009 study, 39 did not present any potential geodiversity value: 21 were found to have been restored and landscaped, particularly former aggregate extraction sites; 8 were developed for housing; and 8 used as landfill sites; 2 sites were not located or the features were no longer visible (Figure 23). In total, 35 were found to be suitable for auditing (Figure 24), including site information for 6 sites provided by South London RIGS Group. A further site was audited in November 2008 by the Harrow and Hillingdon Geological Society, bringing the total to 36 sites. For the 2012 update an additional 62 sites were assessed, with changes to designations set out in Section 7 and Appendix 1.

6.15 The auditing and updating of sites is an ongoing process. Auditing the further potential sites identified in Appendix 1 will be the next priority. This process may highlight additional sites that should be protected. Ongoing survey work by the London Geodiversity Partnership has resulted in recommended changes to the list of sites (see Section 7). By making this document a web-based document it is hoped that it will be possible to provide faster updates to the sites list. The current sites and the changes have also been passed to Greenspace Information for Greater London (www.gigl.org.uk) - the capital's environmental record centre which collates, manages and makes available data on London's greenspaces – so they can provide boroughs and developers with up to date information on sites of geological importance.

6.16 The experience of auditing sites in the urban landscape of Greater London was significantly different to the experiences of others auditing more rural areas. The urban nature of Greater London meant that access to sites is often more difficult. This leads to a greater requirement for advance planning – researching landowners and contacting them to gain access. Ensuring that access to sites is sought at an early stage and a detailed itinerary is completed prior to fieldwork is essential to the success of an urban audit. The quality of the sites in urban areas is often poorer than those in open countryside. Due to space being at a premium, most sites are redeveloped once they have ceased to be useful for an economic purpose (e.g. quarries). Many of the sites in London are already public open spaces where the geology happens to be associated with a green space, which is a positive aspect in terms of accessibility and protection.

Project GIS

6.17 A project GIS (in ESRI ArcGIS) was established to display the location of geodiversity information and examine spatial relationships between geodiversity and other environmental considerations. A wide range of digital data was acquired and the datasets translated to a suitable format for display in ArcGIS. The GIS was also used to produce figures and maps for this report. Datasets and their sources are listed in Appendix 4.

Figure 23 Selected visited and audited geodiversity sites in Greater London

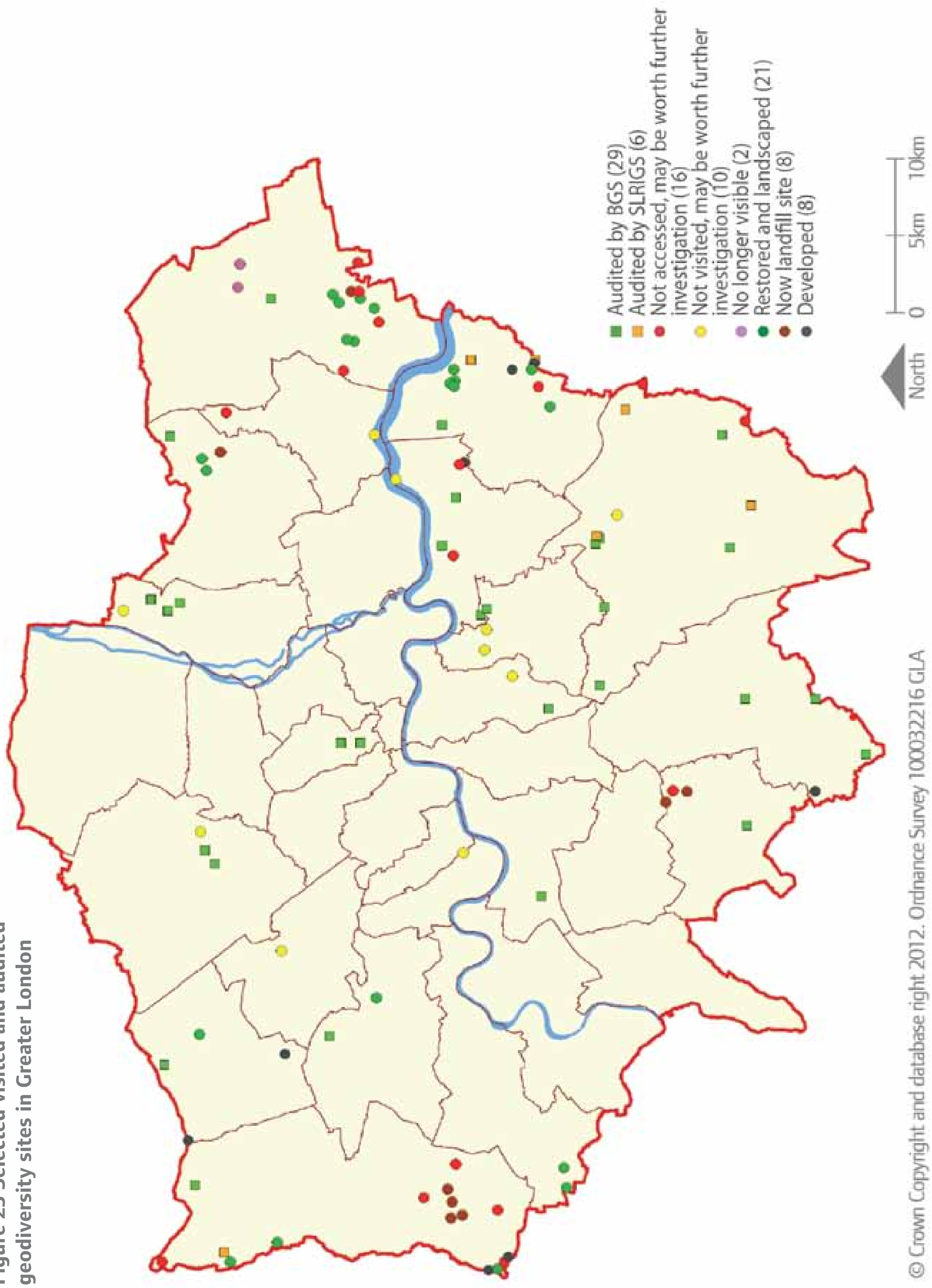
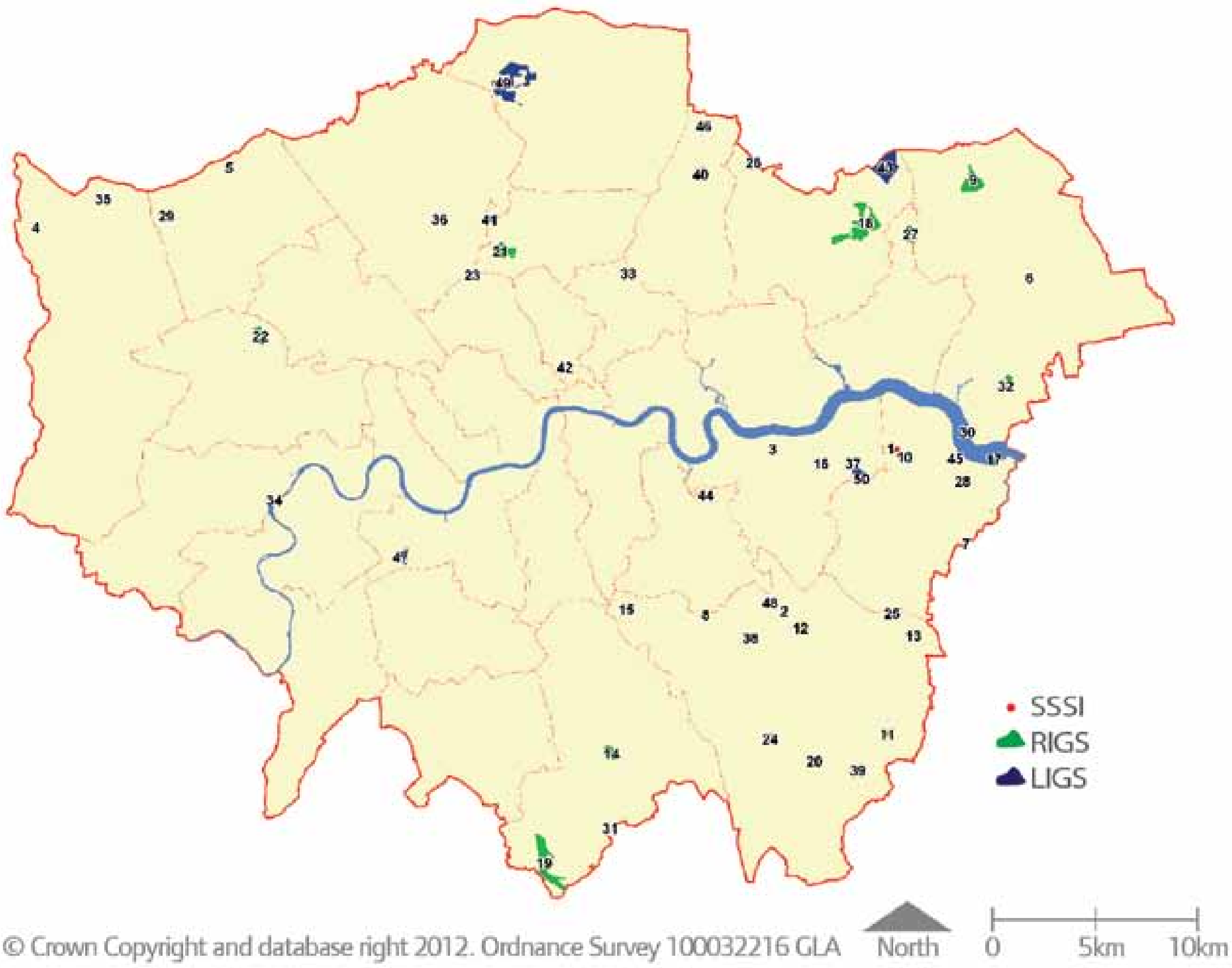


Figure 24 Greater London geodiversity sites



SSSI
1 Abbey Wood
2 Elmstead Pit
3 Gilbert's Pit
4 Harefield Pit
5 Harrow Weald
6 Hornchurch Cutting
7 Wansunt Pit

RIGS
8 Beckenham Place Pk
9 Bedfords Park
10 Chalky Dell
11 Chelsfield Gravel
12 Chislehurst Caves
13 Cray Valley Golf Course Sand Pit
14 Croham Hurst
15 Crystal Palace Geological Illustrations
16 Dog Rocks
17 Erith Submerged Forest
18 Fairlop Quarry Complex (Hainault Quarry)
19 Happy Valley
20 High Elms Dene Hole
21 Highgate Wood and Queen's Wood
22 Horsenden Hill
23 Kenwood House Quarry, Hampstead Heath
24 Keston Common
25 Klinger Pit, Foots Cray
26 Knighton Wood
27 Mark's Warren Fm Quarry Complex
28 North End Pit
29 Pinner Chalk Mines
30 Rainham Submerged Forest
31 Riddlesdown Quarry
32 Southall Fm/Spring Fm Quarry Complex
33 Springfield Pk
34 Thames Foreshore, Isleworth
35 The Gravel Pits, Northwood

LIGS
36 Avenue House
37 Bleak House
38 Bromley Palace Pk: Pulhamite &St. Blaise's Well
39 Charmwood Fm
40 Chingford Hatch
41 Coldfall Wood
42 Finsbury Gravel, Sadler's Wells
43 Hainault Forest Country Pk
44 Old Gravel Pit, Blackheath
45 Parish's Pit, Erith
46 Pole Hill
47 Putney Heath
48 Sundridge Pk Manor Pulhamite Grotto
49 Trent Pk
50 Wickham Ln Brickworks Complex

CHAPTER SEVEN

GEODIVERSITY AUDIT RESULTS AND RECOMMENDATIONS

7.1 On completion of the field audit, data was downloaded from London-GDY on the MIDAS tablet PC and exported to MS Word. Field-digitised site boundaries were placed on Ordnance Survey map extracts and digital site photographs added to illustrate the site descriptions and geodiversity scoring. The overall geodiversity value scores were then assigned to each site, using the professional judgement of the audit geologist (Appendix 5). Appendix 6 summarises the geological strata of the sites.

Criteria for selection of RIGS and LIGS

7.2 The main selection criteria for RIGS sites are covered by the four main themes in paragraph 3.6. Detailed site selection criteria are listed in Appendix 2. The main considerations for selecting RIGS and LIGS included quality of exposure/feature, access, rarity, community use and safety. Sites recommended in this report for RIGS designation are generally easy to access safely and have good exposure/features. Where a site lacks one of the features listed, it may still be recommended as a RIGS site due to the strength of other factors. For example, GLA 26 Riddlesdown Quarry (formerly Rose and Crown Pit) does not have good access but has excellent exposure of the Chalk and is in an area used frequently by the local community. GLA 4 Chelsfield Gravel is the only exposure of this deposit and therefore is suggested as a RIGS site despite limited exposure.

7.3 Potential LIGS sites suggested in this report are generally weak in several of the factors listed above but have value as local sites. They are commonly areas that are used daily by the local community and could easily be visited by local school groups. These sites would not necessarily be of interest to regional educational groups but may be of interest to researchers.

7.4 RIGS sites may be ideal for use as regional or national sites with potential for research. Those with good access are ideal for educational use and for tourism, for example with the creation of geological trails. LIGS may also be suited to local educational use. The installation of information boards provision of fact sheets, Leaflets and posters would be ideal at all sites that have good access. The London Geodiversity Partnership has begun to put some of these in place during 2010-11.

Audited SSSIs

7.5 Initially, seven sites were designated as SSSIs (GLA 1 Abbey Wood, GLA 14 Gilberts Pit, GLA 18 Harrow Weald, GLA 19 Hornchurch Cutting, GLA 33 Elmstead Pit, GLA 34 Harefield Pit and GLA 35 Wansunt Pit). The 2012 update proposes no changes to SSSIs.

Recommended and potential RIGS

7.6 Initially, fourteen sites were judged worthy of designation as RIGS (Figures 25 and 26), using the criteria outlined in paragraph 7.2. Of the 33 London boroughs, RIGS were proposed in seven, with five in

Bromley, three in Croydon and one each in Lewisham, Ealing, Greenwich, Harrow, Hillingdon and Bexley. It is recommended that these sites be designated by the boroughs in their Development Plan Documents and be protected and promoted in line with Policy 7.20 of the London Plan. For the 2012 update there are fourteen further RIGS proposed, these are shown in figure 25 with an asterisk and in figure 26 b. These are included as potential RIGS, these sites have not been subject to the same level of scrutiny by the boroughs or landowners. When boroughs produce development plan documents these sites should be included once boroughs have satisfied themselves about the extent of the designation, to be determined in discussion with the London Geodiversity Partnership and relevant landowners and following appropiate consultation with landowners and other stakeholders.

Potential LIGS

7.7 In 2009, fifteen sites were identified by the original audit to have the potential to be designated as LIGS (Figures 27 and 28), using the criteria outlined in paragraph 7.3. These sites were located in nine boroughs, three in Waltham Forest, two in Bromley, two in Islington and one each in Barnet, Lewisham, Redbridge, Wandsworth, Southwark and Sutton. Further auditing work could uncover further potential candidates for LIGS.

7.8 During 2010 and 2011 the London Geodiversity Partnership has re-evaluated a number of sites. Nine sites have been deleted from the LIGS list but they recommend that nine potential sites are promoted to LIGS, (see figures 27 and 28 b). The designation of local sites is purely a matter for the borough concerned and if a borough believes it has not had sufficient time to consider site designations in their DPDs, this is a matter for their discretion.

Figure 25 Recommended & Potential RIGS for Greater London

Source: GLA

Figure 26 Recommended RIGS for Greater London

Site Number	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 3	Beckenham Place Park Lewisham	TQ 385 703 0.51	No	5	Harwich Formation, Eocene
GLA 4	Chelsfield Gravel Bromley	TQ 476 642 9.55	No	5	Chelsfield Gravel Formation, Pliocene – Pleistocene
GLA 6	Croham Hurst Croydon	TQ 338 630 34.57	No	6	Harwich Formation, Eocene Lambeth Group, Paleocene – Eocene Thanet Sand Formation, Paleocene Chalk Group, Late Cretaceous
GLA 7	Crystal Palace Geological Illustrations Bromley	TQ 345 705 5.37	No	8	Geological illustrations
GLA 8	Dog Rocks Greenwich	TQ 443 779 0.02	No	5	Harwich Formation, Eocene
GLA 17	Happy Valley Croydon	TQ 309 568 142.21	No	6	Chalk Group, Late Cretaceous Geomorphology interest
GLA 20	Horsenden Hill Ealing	TQ 162 844 43.15	No	5	Dollis Hill Gravel Formation, Eocene Claygate Member, London Clay Formation and London Clay Formation, Eocene
GLA 22	Keston Common Bromley	TQ 417 638 11.82	No	5	Harwich Formation, Eocene
GLA 26	Riddlesdown Quarry (Formally Rose and Crown Pit) Croydon	TQ 338 594 3.66	No	7	Chalk Group, Late Cretaceous
GLA 29	The Gravel Pits, Northwood Hillingdon	TQ 084 913 5.47	Yes	4	Lambeth Group, Paleocene – Eocene
GLA 30	Cray Valley Golf Course Sand Pit Bromley	TQ 489 692	Yes	7	Thanet Sand Formation, Paleocene
GLA 31	North End Pit Bexley	TQ 515 771 0.43	No	6	Crayford Silt Formation, Pleistocene
GLA 32	High Elms Dene Hole Bromley	TQ 439 627 0.02	No	7	Chalk Group, Late Cretaceous
GLA 36	Pinner Chalk Mines Harrow	TQ 116 905	Yes	9	Chalk Group/Upnor Formation, Upper Cretaceous/Paleocene

Figure 26b Potential RIGS for Greater London

Site Number	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 37	Mark's Warren Farm Quarry Complex Barking & Dag.	TQ 488 895 31. 06	Yes	6	Pleistocene Black Park Gravel still exposed. Need to obtain RIGS status for future conservation. 'Whin Sill 'boulder found within gravel awaiting a permanent home at the Bedfords Park Visitor Centre
GLA 38	Chalky Dell Bexley	TQ 4814 7846 0.54	Yes	5	Chalk Group, Late Cretaceous overlain by Thanet Sand Formation, Paleocene. Important for Bullhead Bed at junction which could be revealed and access constructed if conserved.
GLA 39	Erith Submerged Forest Bexley	TQ 526 776 6.28	No	6	Best exposure of the Neolithic submerged forest with reasonable access for local community
GLA 40	Chislehurst Caves Bromley	TQ 431 696 1.74 (c.8 Underground)	Yes	6	Chalk Group, Late Cretaceous/ basal Thanet Sand Formation Accessible mines with good exposure of junction showing Bullhead Beds
GLA 41	Klinger Pit, Foots Cray Bromley	TQ 478 703 0.69	Yes	6	Good exposure of Paleocene Thanet Sand Formation in disused quarry privately owned – protection from development urgently sought
GLA 42	Kenwood House Quarry Hampstead Heath Camden	TQ 2685 8745 0.07	Yes	6	Eocene Bagshot Formation, omitted from 2009 edition. Potential for conserving old quarry face near Kenwood House (details of small exposures on Sandy Heath included)
GLA 43	Springfield Park Hackney	TQ 345873 13.58	partially	6	Only London Geological Nature Reserve, designated for spring lines associated with junctions of Pleistocene Langley Silt (brickearth) on top of Hackney Gravel overlying Eocene London Clay Formation. Villas on site built from the brickearth.

Site Number	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 44	Highgate Woods & Queens Wood Haringey	TQ 280 885 TQ 285 885 Total 51.16	?partially	6	Newly established Claygate Member of London Clay Formation in Highgate Woods overlying London Clay that is deeply incised by 'glacial gorges' in Queens Wood. Highgate Woods was called Gravel Pit Wood on old maps although gravels are not shown on current BGS maps. The Anglian ice sheet was very close and the road between the 2 woods is the interfluve between the Lea & Brent tributaries. The Romans exploited the Claygate Beds for making pottery.
GLA 45	Bedfords Park, Havering Ridge Havering	TQ 517 930 (Ent) TQ 519 922 (VC) 86.82	No	6	Eocene London Clay, Claygate Member and Bagshot Sand overlain by Pre-Anglian Stanmore Gravel and Anglian Lowestoft Till. Recommended for variety of rock types although exposure not always good. Visitor Centre has terminal with interactive geology and there is potential for a Geotrail to accompany existing trail. The 'Whin Sill' boulder from Black Park Gravel at Mark's Warren Quarry will be moved here.
GLA 46	Rainham Submerged Forest Havering	TQ 5160 795 2.29	No	5	Best example of Neolithic submerged forest on north bank of the Thames
GLA 47	Southall Farm/ Spring Farm Quarry Complex Havering	TQ 535 818 33.54	Yes	6	Pleistocene Taplow Gravel still exposed. Need to obtain RIGS status for future conservation.
GLA 48	Thames Foreshore, Isleworth Hounslow	TQ 168 760 0.56	No	6	Natural exposure of London Clay Formation with septarian nodules at low tide. It is the best exposure of several in the area and the only place, apart from temporary exposures and worn patches, where septarian noldules and London Clay can be seen.

Site Number	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 49	Fairlop Quarry Complex (Hainault Quarry) Redbridge	TQ 462 896 173.9	Yes	6	Pleistocene Boyne Hill Gravel still exposed. Need to obtain RIGS status for future conservation.
GLA 50	Knighton Wood Redbridge	TQ 413 935 14.92	probably	6	Probably best example of Pleistocene Woodford Gravel. Additional feature of Pulhamite Rock Work. Easy access

Figure 27 LIGS for Greater London

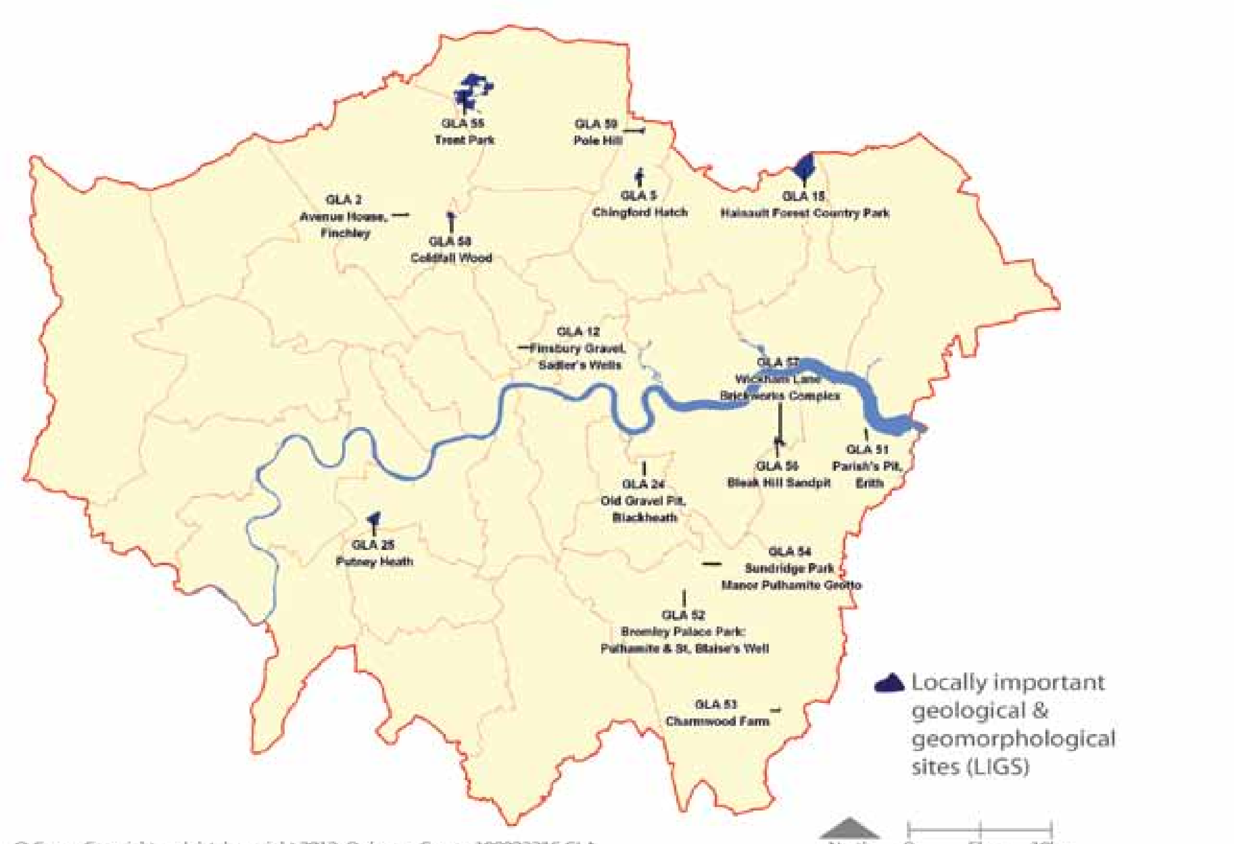


Figure 28 Potential LIGS for Greater London

Site	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 2	Avenue House Barnet, Finchley	TQ 252 903 3.17	No	3	Lowestoft Formation, Pleistocene
GLA 5	Chingford Hatch Waltham Forest	TQ 384 927 17.87	No	4	Woodford Gravel Formation, Pleistocene
GLA 12	Finsbury Gravel Islington, Sadler's Wells	TQ 315 828 0.23	No	3	Finsbury Gravel Member, Maidenhead Formation, Pleistocene
GLA 15	Hainault Forest Country Park Redbridge	TQ 475 926 119.45	No	4	Head, Pleistocene Lowestoft Formation, Pleistocene Claygate Member, London Clay Formation, Eocene
GLA 24	Old Gravel Pit Blackheath, Lewisham	TQ 385 763 0.84	Yes	2	Harwich Formation, Eocene
GLA 25	Putney Heath Wandsworth	TQ 235 735 35.30	No	3	Black Park Gravel Formation, Pleistocene London Clay Formation, Eocene
GLA 51	Parish'sPit, Erith Bexley	a) TQ 510 0 7815 b) TQ 5095 7800 0.98	Yes	3-4	Former quarry primarily for Thanet Sand Formation but originally displaying Lambeth Group & Harwich Formation as well, both now obscured by vegetation. 2 faces of Thanet Sand still visible.
GLA 52	Bromley Palace Park: Pulhamite & St. Blaise's Well	TQ 408 691 0.35	No	4	Waterfall structures at the inflow and an outflow of a lake in the grounds of the former Bishop's Palace now the Bromley Civic Centre. Formed of artificial rockwork, Pulhamite and constructed in 1865. The inflow structure is adjacent to a modern fountain in a circular basin on the site of St Blaise's Well, a chalybeate spring which was used for its curative properties in the 18th century

Site	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 53	Charmwood Farm Bromley	TQ 4616 6244 1.64	Yes	4	Chalk Group, Late Cretaceous. Small mine on private farmland with entrance covered by grille
GLA 54	Sundridge Park Manor Pulhamite grotto. Bromley	TQ 4184 7063 0.09	No	3-4	Artificial rockwork 'grotto' worth listing by English Heritage and worth conserving even though on private land
GLA 55	Trent Park Enfield	TQ 281 969 183.83	No	3-4	Recommended LIGS for variety of rock types (London Clay Formation, Claygate Member, Dollis Hill Gravel and Lowestoft Till), spring lines and deeply incised glacial valleys.
GLA 56	Bleak Hill Sandpit Greenwich	TQ 4606 7776 0.23	Yes	4	Only remaining faces of 3 former pits which in 19th century worked for sand and In 20th century worked for sand and chalk. The quarry extended upwards through the Lambeth Group to the Blackheath Pebble Beds but these are now obscured by vegetation and only sand is visible
GLA 57	Wickham Valley Brickworks Complex Greenwich	TQ 4604 7743 12.75	Yes	4	The complex is all that remains of three adjacent pits, the rest of the area has been built over. The tall cliff forming the southern edge of the former South Metropolitan Quarry can still be seen through the trees with Woolwich Cemetery is at the top still be seen. The Wickham Valley Brickworks sites were primarily quarrying the Thanet Sand but also exploited the Brickearth in the Valley. Chalk was extracted from underground mines which are now pumped full of fly-ash slurry and sealed off.
GLA 58	Coldfall Wood Haringey	TQ 276 903 13.43	No	3-4	Pleistocene Lowestoft Till overlying Dollis Hill Gravel and Eocene London Clay formation cut by 'glacial gorges'. Site of discovery of glaciation this far south,

Site	Site Name Borough	NGR Area (ha)	Created by Aggregate Extraction	Geo-diversity Value	Comments and stratigraphy
GLA 59	Pole Hill Waltham Forest	TQ 3835 9485 7.02	partially	4	Isolated London Clay Formation hillock capped by Claygate Member formally utilised for brick making. Meridian passes top marked by an obelisk. Public access

CHAPTER EIGHT

GEODIVERSITY GUIDANCE TO BOROUGHS

Policy

8.1 This chapter provides advice which is intended to guide the development and implementation of policy at the borough level. Chapter 7 of this report illustrates the relationship between geodiversity designations that are appropriate in London, and lists those areas which require special consideration in planning in London.

8.2 In the draft NPPF the planning system is advised to 'aim to conserve and enhance the natural and local environment by protecting valued landscapes' (para 164) and to 'prevent harm to geological conservation interest' (para 168).

8.3 As set out in Chapter 2 of this report, London Plan policy 7.20 (Figure 2) states that planning policy and decisions should provide protection for important geological sites. Development and regeneration proposals should take geodiversity into account and incorporate positive elements that contribute to improving and enhancing geological conservation. Development should avoid any adverse impact on geological interest, or where this is not possible, to minimize the impact and seek mitigation measures.

8.4 Monitoring of the condition of RIGS and LIGS is also important. A standard approach to Local Geological Site monitoring has recently been established and is recommended for use in London (Geology Trusts and Geoconservation UK 2008). Critically, it provides a basis for assessing the condition of a site linked to the site's management requirements and whether positive conservation management is being undertaken.

Geodiversity and the wider landscape

8.5 The geodiversity auditing described in paragraphs 6.10-6.12 concentrated on individual geodiversity sites. However, geodiversity also includes assessing, valuing and protecting the wider landscape. PPS9 states "In taking decisions, local planning authorities should ensure that appropriate weight is attached to designated sites of international, national and local importance; protected species; and to biodiversity and **geological interests within the wider environment**" (GLA emphasis). Although PPS 9 is due to be replaced by the NPPF, the NPPF continues to emphasize the importance of landscape. Consideration of how landscape sets the context for shaping neighbourhoods and future development will be addressed in SPG on shaping neighbourhoods, due for consultation in late 2012.

8.6 Greater London has distinctive natural landscapes shaped by geological processes:

- undulating chalk downlands with dry valleys in south London
- gentle escarpment of older Palaeogene strata rising up to the Chalk dip slope in southern and south-west London
- Palaeogene outliers of low, well-drained hills with convex slopes, occurring in the floors of shallow valleys to the south and east
- a broad swathe of low-lying, subdued topography of the London Clay in the Thames Valley. Even where dissection has been most pronounced (as

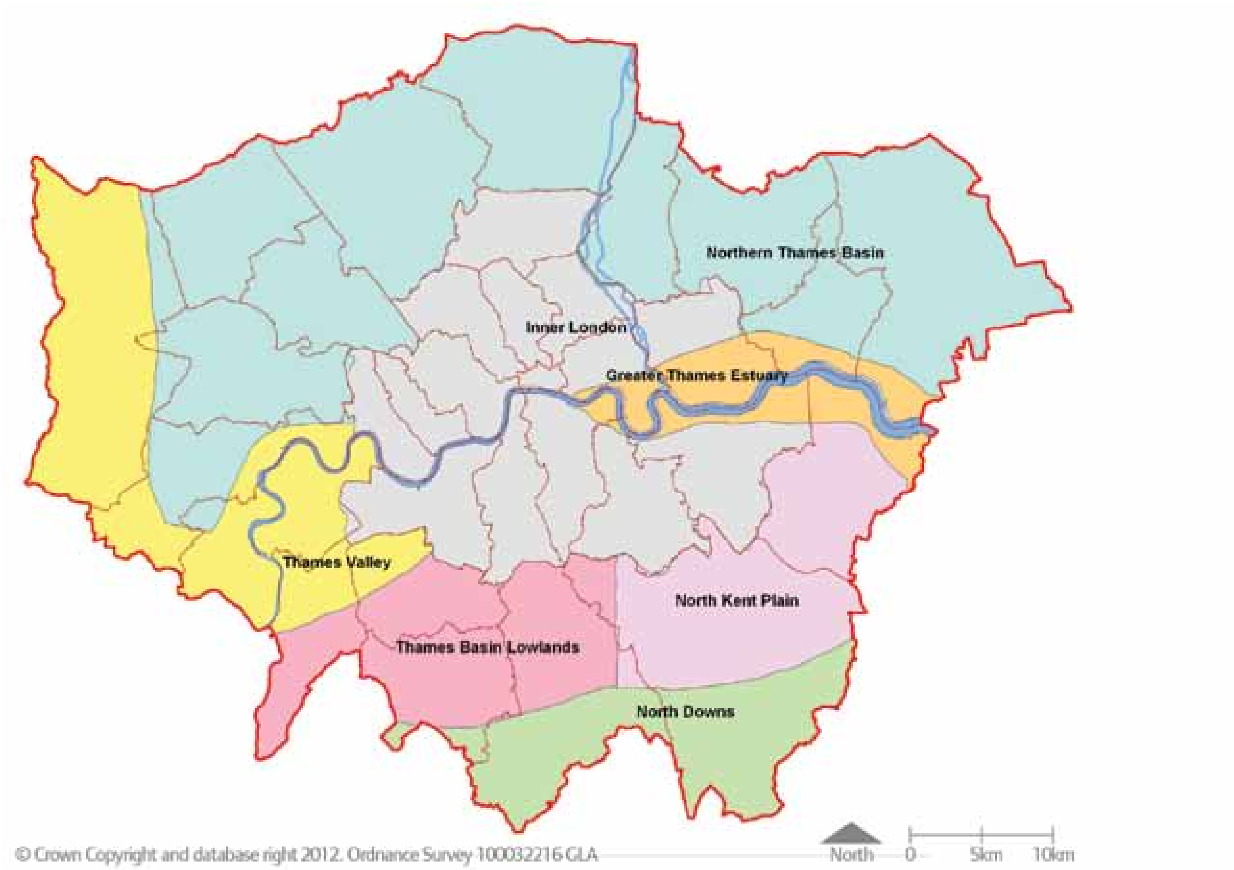
between Stanmore and Hampstead) only gently rolling ground with convex slopes of generally less than 4° is found

- the prominent Bagshot Formation hills of Hampstead Heath and Highgate in north London, Harrow On The Hill in the north-west, and Havering-atte-Bower in the north-east. It gives rise to relatively steep convex slopes up to 12°. It is characteristically free-draining and in a natural or semi-natural state supports typical heathland vegetation

- river terraces forming long flat areas e.g. underlying Heathrow airport or Hyde Park, separated by steeper areas of terrace front slopes, e.g. Leading from the Strand to Temple tube.

8.7 Natural England has devised Landscape Character Areas (LCA) for Greater London (Figure 29), but these largely do not reflect the wider geodiversity of London described above. Natural England have now published London's Natural Signatures, a framework for London (2011).

Figure 29 Greater London Landscape Character Areas



8.8 The natural topographic geodiversity underlying London should be understood, respected and altered only in the knowledge of its origin and form. This would require planning policies rather different to those used to protect individual geological sites:

- landforms - maintain integrity of landform(s). Encourage authentic contouring in restoration work and new landscaping schemes
- landscape - maintain contribution of natural topography, rock outcrops and active processes to landscape. Encourage authentic design in restoration work and new landscaping schemes
- processes - maintain dynamics and integrity of operation. Encourage restoration of process and form using authentic design principles
- soils - maintain soil quality, quantity and function.

Implementation

8.9 In order to implement the policy aims set out in the London Plan, the following guidance indicates when geodiversity considerations should be taken into account. This advice should be used by local authorities and developers when considering planning proposals and the preparation of Supplementary Planning Documents where a geodiversity issue is clearly involved.

Have regard to geodiversity in planning proposals

8.10 Perhaps the greatest threat to geodiversity is inappropriate development. New developments often destroy or conceal valuable geological exposures and disrupt the natural processes that helped form them. New development should assess the potential impacts on geodiversity, take steps to mitigate any damage that cannot be prevented, and identify opportunities that might benefit geodiversity. For example, some developments might allow the creation of more rock exposures, or offer an opportunity to re-establish natural systems; in others, planning permission may insist on mitigation, such as future monitoring and maintenance work. Traditionally, the conservation of geodiversity has focused on individual sites but, in the future, effective conservation will need to integrate the efforts of all interested parties and seek to conserve geodiversity in the wider landscape (paragraphs 8.5-8.8). However, geodiversity is not and should not be regarded merely as concerned with conservation of geological sites or features. As an essential part of natural heritage it can have a profound and long term effect on fields as varied as economic development and historical and cultural heritage. As such the issue of geodiversity will be relevant to work on the SPGs on the All London Green Grid and Shaping Neighbourhoods.

8.11 Where development proposals may have an impact on geodiversity an evaluation of the geological significance of an area should be required prior to undertaking any reclamation, groundworks, re-working or planting. Recommendations relating to the geodiversity interest should be fully taken into account in undertaking any such works.

Protect, manage and enhance geodiversity

8.12 Sites should be monitored for condition and threats to geological features. Opportunities should be sought to implement maintenance appropriate to maintaining the quality of the exposure of geological features at the site and opportunities sought to enhance the condition and interpretation of such features where appropriate. Advice for the conservation of sites is provided by Prosser et al. (2006). In addition to nationally designated sites, boroughs should seek to establish and maintain a series of regional and local sites representative of the geology in the London area. The recommended RIGS sites in this report should be identified in borough LDDs. Boroughs should consider whether the potential LIGS sites identified in this report should also be identified and protected.

8.13 Using the method and criteria set out in Chapters 6 and 7 and Appendices 2 and 3, the boroughs should also consider auditing further sites that may be of local importance. Table A1 in Appendix 1 identifies sites (prefix PS1-PS62) that may be of potential value. These sites will all need to be audited in the future to determine whether they are worthy of protection as a RIG or LIG. Additional guidance is available in the Defra Local Sites Report (Defra, 2006).

8.14 In order to protect, manage and enhance geodiversity, boroughs are encouraged to:

- review any buildings or structures for which conservation measures are proposed to establish the presence of any features of geodiversity interest. Appropriate recommendations can then be made to ensure the safeguarding of significant features
- integrate geodiversity interest on all sites or features of archaeological, wildlife or other interests, where conservation management is taking place or being contemplated. Equally, the other conservation interest of what might be primarily considered 'geological sites' should also be assessed and secured in any management works
- work with quarry operators to promote active conservation and enhancement work on geological sites.

Enhance geodiversity in new developments

8.15 When geodiversity is identified as an appropriate issue, new development proposals may provide opportunities to enhance the geodiversity of a site. Road improvement works, for example, may require the construction of new cuttings. Such operations offer opportunities to reveal hitherto unexposed geological sections, either temporarily during construction, or as permanent features. The geological features exposed in cuttings or quarries should be viewed in a positive light as contributing to the natural heritage of the area. It is common practice in road construction to cover rock exposures in cuttings, thus permanently obliterating potentially important geological exposures. Whereas a normal reaction at such an important site might be to resist any planned clearance of vegetation, road widening or similar work, the exposure, and thus its scientific value, could be very greatly enhanced by such operations. Such enhancement would, of course, be dependent upon effective liaison between road engineers and geologists, and would require suitable provision for retaining the exposure upon completion of any works. Similarly, quarries often provide superb opportunities to examine, record, study and perhaps to establish permanent sections of key geological features.

8.16 In order to integrate geodiversity enhancements in new development, boroughs are encouraged to:

- work with developers and quarry operators to liaise with local and national museums, the BGS, local university earth science departments, and other appropriate bodies, in the recovery and recording of important geological material and information

- ensure proposals for permanent sealing of underground workings should include provision for appropriate recording of geological features prior to sealing

- work with landowners who propose to re-establish access to underground workings to record geological features exposed in the re-opened workings, or to invite qualified geologists to visit the site to make such records. All such records should be lodged with a permanent public archive.

Promote public access, study, interpretation and appreciation of geodiversity

8.17 Positive measures to enhance geodiversity can include the promotion of the geodiversity resource. Opportunities can include:

- encouraging local community involvement in identifying and developing initiatives

- providing for controlled, safe access to sites for educational, interpretational and recreational use

- developing access arrangements to quarries for educational and interpretational use on specified occasions, or as part of geological events

- providing on and off-site interpretation.

CHAPTER NINE

GEODIVERSITY ACTION PLANNING

9.1 Geodiversity Action Plans (GAPs) provide a long-term framework for the conservation of geodiversity, in the same way that Biodiversity Action Plans work for nature conservation. A GAP should take into account both local and strategic needs and involve a wide range of partners, from local community bodies and conservation organisations, to local government and industry. A GAP should establish objectives and targets for audit, conservation, management, education and communication as well as the influencing of local development documents and policies and the securing of resources to implement the plan.

9.2 The London Geodiversity Partnership has produced a GAP for London 2009-2013. It can be found on their website www.londongeopartnership.org.uk. Its aim is *'to provide a framework for understanding, conserving and using the unique wealth of geodiversity resources found within our capital, so that social, economic and environmental benefits are provided to London's urban communities and many visitors.'* This aim is underpinned by 6 objectives;

- Increase our understanding of the Geodiversity of London,
- Manage and Conserve the Geodiversity of London,
- Deliver sustainable social, economic and environmental benefits to London,
- Promote and care for London's Geodiversity,
- Sustain geodiversity activities,
- Influence London-wide and London borough planning and environmental policies.

9.3 Boroughs, community groups and developers should familiarise themselves with the Action Plan and seek to implement its objectives where appropriate.