West Lothian Geodiversity

Volume 1 – Report

Geology and Landscape North Programme
Commissioned Report CR/06/008N8N

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE NORTH PROGRAMME

COMMISSIONED REPORT CR/06/008N

West Lothian Geodiversity

Volume 1 – Report

H F Barron, M A E Browne and A Finlayson

Contributors

S L B Arkley, S M Clarke, A Matthewson, A Pickering , K I G Lawrie and E K Hyslop

Editor

D J D Lawrence

Keywords

Geodiversity; West Lothian.

Front cover

Five Sisters Bing, West Calder

Bibliographical reference

BARRON, H F, BROWNE, M A E, AND FINLAYSON, A. 2005. West Lothian Geodiversity. *British Geological Survey Commissioned Report*, CR/06/008N8N. 168pp.

Keyworth, Nottingham British Geological Survey 2006

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham, Edinburgh and London; see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.geologyshop.com

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

☎ 028-9038 8462 Fax 028-9038 8461

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

☎ 01491-838800 Fax 01491-692345

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff, CF15 7NE

☎ 029–2052 1962 Fax 029–2052 1963

Parent Body

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

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

Foreword

Increasing pressure on land and the environment demands a greater awareness and understanding of the dynamics of our natural world in order to deliver a sustainable environment for the future. Biodiversity and the need for the Government to recognise, audit and plan for habitat and ecology is widely accepted and enshrined in UK legislation. However the importance of the complementary concept of Geodiversity is only now gaining recognition, despite providing the foundations for habitats and species.

Nationally important geological sites have been assessed and are protected by statutory measures, but there is little systematic inventory and evaluation of local sites and development of management measures for these sites.

A first step in addressing this imbalance is to conduct geodiversity audits. This report documents the first geodiversity audit of a local authority area conducted in Scotland and provides a foundation for developing a West Lothian Geodiversity Action Plan (WLGAP).

Acknowledgements

The authors wish to express their thanks to John Sheldon of West Lothian Council, John Gordon and Rachel Wignall of Scottish Natural Heritage and David McAdam of Lothian and Borders RIGS Group for support and advice throughout the project.

Particular thanks are offered to the Scottish Executive Sustainable Development Directorate for funding most of the project with a grant from the Aggregates Levy Fund. Martin Smith is thanked for co-funding the project from the BGS Geology and Landscape North Programme.

Sarah Arkley and Stu Clarke are thanked for their contribution to field work, Alastair Matthewson for data compilation, Ken Lawrie for database design, Amelia Pickering for supporting the GIS work, Ewan Hyslop for information on the built heritage and Dave Lawrence for advice on geodiversity, report editing and general encouragement.

The field work could not have taken place with the co-operation of a large number of farmers and landowners; their permission is gratefully acknowledged.

Contents

TABLES

Summary

For its size, Scotland has the most varied geology, natural landscapes and landforms of any country on the planet. This variety, or geodiversity, has resulted in the dramatically different landscapes we see in Scotland today. Although not as striking as some of the iconic landscapes in other parts of Scotland, West Lothian's Carboniferous bedrock and skin of glacial deposits nevertheless exhibit a large variety of rock types, structures, fossils, processes and landforms set within a varied landscape.

This report describes a geodiversity audit of West Lothian – the first to be conducted in Scotland. It was undertaken as a means of informing the framing of recommendations and action points designed to guide the sustainable management, planning, conservation and interpretation of all aspects of the earth science heritage of West Lothian. The audit was not intended to be comprehensive survey of all potential geodiversity sites in West Lothian, but rather an evaluation of a representative selection of sites and features of geological and landscape importance in West Lothian.

The project was funded by the Aggregates Levy Fund via Scottish Executive Sustainable Development Directorate, and from the British Geological Survey Geology and Landscape Programme.

A database of 204 potential geodiversity sites for the West Lothian area was compiled from the geological literature, BGS staff expertise and information from the local RIGS Group. This database was used to target sites for geodiversity field auditing, which took place between August and December 2005.

During the field work, 86 sites were visited and information recorded on site ownership, access, fragility, geological merit, potential use and relevance to other interests, at local, regional, national and international level. This information was then entered in the BGS GeoDiversitY database, designed specifically for geodiversity auditing. Details of a further 36 sites which were not visited, but were potentially significant, were also added, giving a total of 122 sites and features of potential geological and landscape importance in West Lothian.

From this list of 122 sites, 51 were selected as being representative of particular geodiversity features in the context of West Lothian and are classed as West Lothian Geodiversity Sites (WLGSs). Of these 51 sites, four are currently protected nationally as SSSIs and six protected locally as RIGS. The new WLGSs selected expand this list of important sites to provide much better geodiversity coverage at the local level.

A draft West Lothian Geodiversity Action Plan (WLGAP) is presented. The main objectives of this plan are: to 'embed' geodiversity into future planning, management and interpretation policies; to recommend strategies for continued monitoring of WLGSs; and to increase overall awareness, understanding and appreciation of West Lothian's geodiversity.

1 Introduction

1.1 PROJECT AIMS

Geological and landform diversity, or geodiversity, is becoming an increasingly important topic when planning for sustainable development within Scotland. In seeking to take account of geodiversity in the Local Plan and planning applications, planners require baseline information in a readily accessible format to allow the sustainable management of West Lothian's natural heritage.

This pilot project aims to:

- initiate the process of geodiversity auditing and action planning in Scotland and act as a guide further work in other areas of the country.
- review the component elements of West Lothian's geodiversity, and its relevance to other interests
- allow incorporation of geodiversity into the planning system through integration with the Local Biodiversity Action Plan (LBAP) process.

The audit was not intended to be comprehensive survey of all potential geodiversity sites in West Lothian, but rather an evaluation of a representative selection of sites and features of geological and landscape importance in West Lothian, a small proportion of which currently enjoy national recognition and protection as Sites of Special Scientific Interest (SSSIs), and some have regional status as non-statutory Regionally Important Geological and Geomorphological Sites (RIGS). Existing conservation designations in West Lothian are listed in Appendix 1.

The study has shown that, whereas the existing network of such sites reflects the most significant elements of the area's geology in a national or regional context, there is considerable scope to expand the network to provide better coverage at the local level.

1.2 PROJECT BACKGROUND

This project was instigated by the British Geological Survey (BGS) Geology and Landscape North (GLN) programme, based in Edinburgh. A BGS-led bid in 2003 to the Forward Scotland Community Environmental Renewal Scheme (CERS) for a geodiversity audit of the Lothians had been rejected for lack of community involvement, but GLN remained convinced of the merit of geodiversity auditing in Scotland. Other partners in this CERS bid included Lothian and Borders RIGS Group (LaBRIGS) and the four Lothian councils.

The GLN programme has carried out several Geodiversity audits and assisted in the preparation of Local Geodiversity Action Plans (LGAPs) in northern England and, along with LaBRIGS and UKRIGS saw a need to begin this process in Scotland. Scottish Natural Heritage (SNH) were consulted in late 2004 and it was agreed that West Lothian would be a suitable area for a Scottish geodiversity pilot project, particularly as West Lothian Council (WLC) had identified a need for a geodiversity plan in their document *'Planning for Biodiversity Action 2005 – 2009'*.

A proposal for a collaborative project between the BGS, SNH, WLC and LaBRIGS was submitted to the Scottish Executive Sustainable Development Directorate in December 2004. A positive response was received, including personal support from Lewis Macdonald MSP, the then Deputy Environment Minister. Funding was awarded from the Scottish Executive Aggregates Levy Fund, with co-funding from the BGS GLN programme.

The main purpose of the project should be to conduct a geodiversity audit in order to provide a resource for the planning process in West Lothian, with the secondary aim of assisting WLC and LaBRIGS designate additional RIGS in West Lothian. A draft West Lothian Geodiversity Action Plan (WLGAP) would be prepared, but completion of a comprehensive plan and the wider stakeholder consultation required to reach agreement was outside the timeframe and resources of the project.

Key project deliverables were agreed as:

1. Geodiversity data as GIS layers
2. Geodiversity database
3. Project report, including site photographs

Partners in this project and main contacts are:

- British Geological Survey, Edinburgh (Hugh Barron)
- Scottish Natural Heritage, Edinburgh (John Gordon)
- West Lothian Council (John Sheldon)
- Lothian and Borders RIGS Group (David McAdam)

1.3 POLICY CONTEXT

The introduction of Planning Policy Statement 9 (PPS9): *Biodiversity and Geological Conservation* by the Office of the Deputy Prime Minister (ODPM) has elevated the importance of geological diversity or geodiversity to a new level in England and Wales. In PPS9, the Government's objectives for planning include:

- **to promote sustainable development** by ensuring that biological and geological diversity are conserved and enhanced as an integral part of social, environmental and economic development, so that policies and decisions about the development and use of land integrate biodiversity and geological diversity with other considerations.
- **to conserve, enhance and restore the diversity of England's wildlife and geology** by sustaining, and where possible improving, the quality and extent of natural habitat and geological and geomorphological sites; the natural physical processes on which they depend; and the populations of naturally occurring species which they support.

The first of six key principles in the document states:

- Development plan policies and planning decisions should be based upon up-to-date information about the environmental characteristics of their areas. These characteristics should include the relevant biodiversity and geological resources of the area. In reviewing environmental characteristics local authorities should assess the potential to sustain and enhance those resources.

No equivalent Scottish Planning Policy (SPP) covering geodiversity yet exists; however, three recent developments present opportunities to raise awareness of geodiversity within Scotland:

- The Nature Conservation (Scotland) Act 2004
- Modernising the Planning System White Paper
- Strategic Environmental Assessment (SEA)

1.3.1 Nature Conservation (Scotland) Act 2004

This Act provides the legislative components of a new integrated system for nature conservation in Scotland. It sets out a series of measures which are designed to conserve biodiversity and to protect and enhance the biological and geological natural heritage of Scotland.

The Act supersedes the SSSI provisions of the Wildlife and Countryside Act 1981, providing for the enhanced protection and management of SSSIs. The provisions place a duty on public bodies to further the conservation and enhancement of SSSIs, provide a new offence whereby third parties can be convicted for damaging SSSIs, and enable the making of byelaws for the protection of SSSIs. It also enables Scottish Ministers to make a Nature Conservation Order to protect a nature conservation feature which is of special interest, or which is contiguous with land containing such a feature, to ensure its protection.

In an effort to limit the damage inflicted on Scotland’s fossil resources, the Act also requires SNH to prepare and issue a Scottish Fossil Code setting out recommendations, advice and information relating to fossils. The production of this code is progressing and should be launched in late 2006 or early 2007.

1.3.2 Modernising the Planning System

A key theme in the Scottish Executive’s recent White Paper *Modernising the Planning System* is the role of planning in delivering sustainable development. The modernised system will use the new SEA regime to help deliver sustainable development and will give environmental considerations the attention they deserve. In the current system, 70% of local plans are over 5 years old and around 20% are more than 15 years old. The new system will require all plans to be updated every 5 years. This more regular updating should allow greater attention to be paid to geodiversity.

1.3.3 Strategic Environmental Assessment

In heralding the new Strategic Environmental Assessment (SEA) regime for Scotland, Environment and Rural Development Minister Ross Finnie MSP stated in October 2003 that:

> *'At a minimum SEA will mean that every public official preparing a strategy, plan or programme will have to think about its environmental effects. If these are significant, the plan will have to undergo an Assessment. This will highlight both the negative and positive environmental impacts across the full range from water, land and air quality, biodiversity and human health to the built and archaeological heritage of Scotland.'*

The Environmental Assessment (Scotland) Act 2005 came into force on 20 February 2006. The Scottish Executive states that ‘SEA is a key component of sustainable development establishing important new methods for protecting the environment and extending opportunities for participation in public policy decision making. SEA achieves this by:

- systematically assessing and monitoring the significant environmental effects of public sector strategies, plans and programmes;
- ensuring that expertise and views are sought at various points in the process from SNH, SEPA, Historic Scotland and the public; and
- requiring a public statement as to how opinions have been taken into account.’

SNH has a statutory role as an SEA Consultation Authority. It can provide advice on a wide range of topics in relation to the natural environment and will normally give particular attention to biodiversity, landscape and geological features (indicating if appropriate where these are the subject of national or international protection), access and recreational use of the natural heritage and where relevant, the soil, water, and material assets that are necessary to support these environmental features. Therefore, as a Consultation Authority, SNH has a key role in increasing the attention paid to Scotland's geodiversity, if it so chooses.

BGS is the United Kingdom's premier centre for earth science information and expertise, and as such, BGS can assist SNH by providing authoritative advice on the geology and geomorphology of Scotland, particularly in relation to sites that are not existing SSSIs or included in the Geological Conservation Review (GCR).

1.3.4 West Lothian Local Plan

The 2005 West Lothian Local Plan (WLLP) commits WLC *to producing a geodiversity plan to address the planning and conservation needs of geology and geomorphology* (see WLLP section 3.20). The plan also includes a strategy to protect and enhance the built and natural heritage of West Lothian by:

a. conserving and enhancing green spaces, rivers, the coastline and water features and promoting the principles of biodiversity;

b. protecting habitats, landscapes, archaeological features and the built heritage from damaging development;

c. rehabilitating the environment where it has been scarred by previous industrial and development activities;

d. improving and, where appropriate, managing native and mixed woodlands; and

e. improving public access to the countryside, coastline and heritage features, in a manner that preserves the quality of those features.

WLC will subject any proposals which affect the integrity or quality of any designated site (including non-statutory sites such as RIGS) to particular scrutiny. There is a presumption against development which could affect any such designated site and in determining such planning applications, WLC will use the precautionary principle where there is uncertainty of the environmental impact.

1.3.5 Guidance note Geodiversity to Biodiversity Groups

The Scottish Biodiversity Group (now the Scottish Biodiversity Forum) published a guidance note in 2000 on geodiversity. This is intended to inform local biodiversity groups about the importance of geodiversity and the necessity of linking the two together (Appendix 2).

1.3.6 Guidance on Local Nature Conservation Site Systems in Scotland

A working group comprising BGS, COSLA, Scottish Environment LINK, RTPI, SNH, SWT and UKRIGS has prepared the document *Guidance on Establishing and Managing Local Nature Conservation Site Systems in Scotland.* This document, to be published by SNH in 2006, includes sections on:

- GCR and RIGS Handbook
- Local geodiversity sites
- Local Geodiversity Action Plan: West Lothian Study
- A combined approach for biodiversity and geodiversity
- Criteria for selecting local geodiversity sites

2 Geodiversity and its importance

The outworking of 4,600 million years of geological processes on Earth has resulted in a huge variety of rocks and landscapes. This is geodiversity. It has been defined as:

'the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (land-form, processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems'.

A more holistic definition is:

'the link between people, landscape and their culture: it is the variety of geological environments, phenomena and processes that make those landscapes, rocks, minerals, fossils and soils which provide the framework for life on earth'.

Geodiversity is a dynamic subject. Rocks and landforms change over time. Today's living plants and animals, decayed plants in peat bogs and loch sediments, and soil washed from fields during storms are part of the soil and rock formation cycle that creates the rocks of the future. Habitats and species (both now and in the future) cannot exist without this cycle.

2.1 GEODIVERSITY – WHY IS IT IMPORTANT?

Geology is fundamental to almost every aspect of life – all raw materials that cannot be grown and all energy that cannot be generated by renewables have to be found using geological science.

A clear understanding of geology is also vital to the design and location of buildings, roads, railways and airports as well as to the safe control of waste disposal, and the management of a wide range of natural and man-made natural hazards. All are aspects of geodiversity.

Understanding geodiversity helps us to understand our environment and predict environmental change in the future. Geological 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. Exhaustion of finite resources such as fossil fuel and global climate change are two of the most pressing. Only by studying the geological record can we hope to predict the earth's response to these changing conditions.

The recognition of natural and cultural heritage features and their sustainable management are today accepted as important functions within a civilised society. The importance of the range and diversity of earth science features – the 'geodiversity' - of any area is as important a facet of its natural heritage as its wildlife interests. Conservation, sustainable management, educational use and interpretation of geodiversity is thus as important as that of biodiversity or archaeology.

Geodiversity may be one of the most significant areas of heritage interest in areas of high landscape value, or areas previously or currently affected by significant mineral extraction. Geodiversity interests need to be integrated into management and conservation strategies for related or parallel interests, including wildlife and archaeological features. Geodiversity issues may contribute significantly to informing a wide range of planning and environmental policies.

An appreciation of geodiversity is important to a comprehensive understanding of many aspects of biodiversity. It also offers substantial opportunities to enhance the conservation, management, educational use and interpretation of such related features. Because it has hitherto received little serious consideration, geodiversity needs to be addressed and evaluated by expert earth scientists.

2.2 SCOTLAND'S GEODIVERSITY

For its size Scotland has the most varied geology, natural landscapes and landforms of any country on the planet. This variety has resulted in dramatically different landscapes and coastlines, such as the machair and beaches of the Western Isles, the fjords and mountains of the western Highlands, the Arctic plateau of the Cairngorms, the plains of Strathmore and East Lothian, to the rolling hills of the Southern Uplands.

The rocks that fashioned Scotland's landscapes have formed over millions of years. Some of the oldest rocks in the Highlands were formed about 3 billion years ago when Scotland was located near the South Pole. Over time, the Scottish landmass drifted north towards the equator. The Midland Valley's coal reserves formed around 300 million years ago, when Scotland was sitting at the equator, covered in tropical forests. As Scotland 'drifted' northwards and passed through the northern desert belt, red sandstone rocks were formed. The dynamic earth forces that drove Scotland north across the globe produced heat and pressure and caused earthquakes and volcanic eruptions. These forces folded, faulted and heated rocks, producing volcanoes such as Edinburgh's Arthur's Seat. Many of the rocks altered or produced by these forces are hard and resistant to erosion. They thus have a strong influence on the landscape.

The rocks that underlie the surface are sometimes exposed on hillsides, in coastal cliffs, in river banks and in artificial excavations such as quarries and road cuttings. Rocks can also be seen in building stones, giving areas their own local architectural distinctiveness. The effects of past land-uses such as mining or quarrying can seem an eyesore, but may provide excellent habitats especially for pioneer species, and have good restoration potential. Quarries also provide excellent locations for recreation and earth heritage interpretation, and oil-shale bings can provide distinctive habitats in which orchids, *lycopodium* and staghorn mosses can thrive.

Scotland has been covered by ice sheets many times in its history. Moving ice rounded the hills and scratched and polished the rocks. It also created the wide straths and glens that today have small 'misfit' streams within them. As ice shaped the existing rocks, it left behind the eroded material (i.e. 'subsoils') as mounds of sand and gravel on the floodplains. These deposits often have distinctive terraced or mound shapes and can be very important for habitat. They are also an important economic resource. However, because the processes that formed them are no longer active, they are a finite resource that cannot be re-created (unless Scotland is once again covered by ice-sheets). When the ice sheets melted, the resultant rise in sea level of up to 45 m left old shorelines and raised beaches around the Scottish coast.

2.3 GEODIVERSITY – LINKING WITH BIODIVERSITY

It has long been known that there are strong ties between geology and biodiversity. Recent ecological work has highlighted the complexity of these relationships and the large number of factors that come in to play.

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.

At the larger scale tectonic processes 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, fluvial and other processes such as slope failure produce new habitats that promote ecological succession and cyclicity and increase overall biodiversity.

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 influence are soil chemistry, grain size, texture, porosity and permeability. Extreme soil conditions such as the high calcium carbonate content in shell sands on the west coast of the Western Isles have created the unique flora of the machair.

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 serpentine (for example, in Shetland), gabbro and dolostone. Rock type also influences chemistry of both ground and surface waters which give rise to differing aquatic communities.

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.

2.4 GEODIVERSITY AS A RESOURCE

The geodiversity of an area may be considered as one of its chief natural resources. A key starting point is an appreciation of the most up to date available understanding of the area's geological deposits and features, together with the processes and phenomena which have formed them and continue to influence them. An area's geodiversity thus encompasses:

- The historical legacy of research within the area
- Sites or features at which representative examples of the area's geological deposits and features may be seen
- Sites or features which are deemed worthy of some form of designation or protection for the quality of earth science features displayed
- The whereabouts and nature of past and present working of mineral products
- Sites and features currently employed in interpreting earth science
- The influence of earth science in shaping the built and man-made environment
- Materials collections and site and other records
- Published literature and maps
- The inter-relationship and inter-dependence between earth science and other interests

International recognition of the need to conserve biological diversity led to the UN Convention on Biodiversity agreed at the Rio Earth Summit in 1992 and the subsequent signing by over 160 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. Biodiversity is now accepted as an essential element in sustainable planning and management strategies. Until relatively recently the parallel concept of geodiversity had attracted little interest, despite its fundamental importance in underpinning biodiversity.

West Lothian Council adopted its first Local Biodiversity Action Plan (LBAP) in 1998 and a revised version was published in 2005. A section on Geodiversity is included in both these documents.

Geological and landscape features, other than those already afforded some measure of protection such as SSSIs, are often seen as sufficiently robust not to require active management or action planning. All geological features are potentially vulnerable. In addition to threats posed by inappropriate site development and the infilling of quarries, the encroachment of vegetation, natural weathering and general deterioration with time may threaten to damage or obliterate important geological features. This situation would not be tolerated in wildlife or archaeological sites of comparable scientific or educational value.

However, geodiversity is not, or should not be regarded merely as concerned with conservation of geological sites or features – it has a vital place in all aspects of natural heritage and impacts in fields as varied as economic development and historical and cultural heritage.

3 The Geodiversity of West Lothian

3.1 GEOLOGICAL BACKGROUND

West Lothian's geology is typical of much of the Midland Valley, though older Silurian and Devonian rocks seen elsewhere are not represented at surface – Carboniferous rocks comprise the entire bedrock surface area of West Lothian (Figures 1, 2). This does not necessarily lead to low geodiversity as they comprise a wide variety of rock types including oil-shale, limestone, sandstone and dolerite, which demonstrate a wide range of geological processes and structures. Nearly 92% of this bedrock is covered by a variety of glacial deposits; both these deposits and the underlying bedrock have been sculpted into an array of landforms. A detailed account of the geology of West Lothian can be found in Appendix 3.

3.1.1 Geological history

West Lothian lies in the Midland Valley of Scotland between the Highland Boundary Fault to the north and the Southern Upland Fault to the south. The Midland Valley is considered to be a displaced 'terrane' – a north-east to south-west-orientated sedimentary basin emplaced in its present relationship with the Highlands and Southern Uplands by large-scale horizontal fault movement (strike-slip) during the end-Silurian to mid-Devonian times.

The nature of the basement rocks in the Midland Valley is known only from indirect evidence. Geophysical studies indicate that a metamorphic basement lies at a depth of between 7 and 9 km. The basement is 20 to 25 km thick and the base of the crust is at a depth of about 33 km. The composition of the basement is indicated by the occurrence of metamorphic fragments carried to the surface as exotic fragments (xenoliths) in volcanic vents.

The Carboniferous of West Lothian comprises both sedimentary and igneous rocks. Geologists have classified the sedimentary and extrusive igneous rocks into five main groups (Figures 1B, 2):

1. Inverclyde Group
2. Strathclyde Group
3. Bathgate Group
4. Clackmannan Group
5. Coal Measures (Scotland) Group

In addition three groups of intrusive igneous rocks are recognised (Figures 1A, 2):

1. Volcanic Vents and Plugs
2. Alkali-dolerite sills
3. Quartz-dolerite sills

Subaerial volcanic activity was widespread in the Midland Valley in Lower Carboniferous times. Eruption of volcanic rocks in the east ceased sometime in the Viséan, but persisted in the west well into the Namurian (Figure 1).

The sedimentary strata consist principally of sandstones and mudstones with relatively minor proportions of limestone, coal and oil-shale. They were deposited as part of an extensive fluviodeltaic system which occupied most of north-west Europe during the Carboniferous Period. Sediment was carried from Caledonian mountains to the north and deposited at or near sea level in a differentially subsiding basin. Early Carboniferous strata were deposited, in part at least, under lagoonal conditions and the strata include seams of oil-shale. Cyclic sedimentation, including the deposition of seams of economically valuable coal, lasted from the Viséan to the late Carboniferous.

Periodic marine incursions brought about the deposition of thin but widespread limestones mainly in the late-Viséan Lower Limestone Formation and in the Namurian Upper Limestone Formation. In the area of the Bathgate Hills, marine limestones were deposited fringing volcanic islands. An unusual fauna has been recently been recovered from one of the associated nonmarine limestones which included possibly one of the world's earliest known reptile, amphibians and various terrestrial invertebrates. A period of uplift and erosion in the source area and within the Midland Valley brought about mainly fluvial deposition during late-Namurian Passage Formation times, temporarily replacing the fluviodeltaic processes. Marine incursions were brief and largely confined to the lower part of the formation.

Two episodes of basaltic intrusion are known in the district. Most of the intrusive igneous rocks are quartz-dolerites which occur as east-west dykes and sills. They are of late-Carboniferous age. Alkali-dolerite sills, probably of contemporaneous in age to Viséan and Namurian volcanic rocks, are present. After deposition of the Carboniferous, the strata were folded to form the Falkirk-Stane Syncline. Faulting took place on east-west trending faults.

Little evidence of the interval between Carboniferous times and the Quaternary is preserved in West Lothian. During the Quaternary the entire region was overwhelmed by glaciers, on more than one occasion. The last widespread glaciation in Great Britain was the Main Late Devensian, during which the ice reached its maximum extent between 18,000 and 22,000 years ago. The Main Late Devensian ice sheet was less extensive than earlier glaciations, but it still covered much of Britain, stretching as far south as Bristol Channel (Figure 3). In the mountainous source regions of Scotland, Wales and Northern England, erosional processes dominated as ice carved out the deep corries and U-shaped valleys we associate with those areas today. In lower lying areas, such as that occupied by present-day West Lothian, depositional processes were more dominant releasing thick blankets of till from beneath the ice (Figure 4). Where ice flow was particularly fast, streamlining of the landscape occurred with the underlying terrain being shaped into a series of longitudinal landforms parallel to the direction of ice flow.

As climate warmed towards the end of the Main Late Devensian glaciation, meltwater from the retreating ice sheet laid down vast belts of sand and gravel along the major drainage pathways. The weight of the Main Late Devensian Ice Sheet depressed the earth's crust beneath it (a process known as isostatic depression). When the ice sheets melted, releasing water back in to the oceans, sea-level rapidly increased (glacio-eustatic sea-level rise). The depressed land, however, took a longer time to rebound after the removal of ice, allowing the sea to reach higher levels than today. Continued uplift has now elevated the shorelines from this period, so that today raised beach and estuarine clay deposits can be seen in the north-east of the district, bordering the Firth of Forth. Even now, 11,550 years after the final disappearance of ice in Britain, much of Scotland continues to rebound from the ice overburden. In parts of the Highlands uplift presently occurs at about 3 mm per year, while rates in West Lothian are around 1−2 mm per year.

3.2 USE OF GEOLOGICAL RESOURCES

3.2.1 Mineral resources and extraction

West Lothian has a long history of mineral production. A wide range of products have been worked within the county and mining and related industries have had an impact on its character.

3.2.1.1 COAL

The majority of formerly economic coal seams occur in the Limestone Coal Formation and Lower Coal Measures (Figure 1). Several seams exceed 1 m in thickness. A limited number of coals in the Upper Limestone Formation and the Passage Formation have also been exploited along with others such as the Hurlet Coal at the base of the Lower Limestone Formation and the Houston Coal in the West Lothian Oil-shale Formation. Deep (longwall) mining ceased with the closure of the Polkemmet Colliery in 1985. The most recent coal working in West Lothian has been restricted to licensed opencast mines which have concentrated on seams in the Coal Measures and Limestone Coal Formation. The largest opencast coal sites in the district have been located on the outcrop of the basal Coal Measures, where 'fireclay' and 'brickclay' have been extracted in addition to coal. Coal can be worked economically by opencast methods only where the ratio of coal to overburden is favourable. Past extraction of coal in shallow mines commonly used `stoop and room' methods whereby only about half the coal was taken, the remainder serving as pillars to support the roof. Despite the practice of `stooping' and `stoop-splitting', that is, of robbing all or part of the coal pillars when mining was coming to an end, sufficient reserves can nevertheless remain in the pillars to justify opencast working. On a small scale, ground which has been affected by shallow stoop and room mining can be stabilised prior to construction, by working the coal opencast, the value of the coal recovered partly offsetting the excavation costs.

Coal is being extracted following granting of planning permission for the extraction of opencast coal and fireclay at the former Polkemmet Colliery site. Owing to the paucity of geodiversity sites within the Coal Measures of West Lothian (see section 3.4.6), development or extraction activities that exposed and allowed the preservation of representative Coal Measures sections would be a valuable addition to the geodiversity of the district.

3.2.1.2 Oil Shale

West Lothian is unusual for the British Isles in having oil-shale seams that are thick and widely developed. The first plant in Britain to process mineral oil commercially, producing “Paraffin Oil”, was set up in Bathgate in 1851, utilising a cannel coal known as Boghead Coal or Torbanite which occurred at the base of the Coal Measures over a small area on the Torbanehill Estate south-west of Bathgate. It gave an oil yield of 535 to 580 litres/tonne, but the deposit was exhausted within 12 years. Around the same time oil-shale was discovered in West Lothian and identified as a raw material suitable for the production of shale-oil and, in due course, replaced cannel coal in the retorting and refining processes. It was mined in the district from then until 1962. Although oil-shales are developed at over a dozen horizons within the West Lothian Oil-shale Formation, three multiple, thick shales produced the bulk of the oil-shale mined: the Broxburn Shale, Dunnet Shale and Pumpherston Shale.

The oil-shale industry, which was situated very largely in West Lothian in the country between Cobbinshaw, Blackness and Dalmeny, with small outlying centres at Straiton and Carlops in Midlothian, reached its maximum productivity in the early years of the twentieth century with outputs of more than three million tons of oil-shale. It declined to 740,943 tons in 1950, produced at half a dozen mines and three opencast sites, of which three of the former and one of the latter were in the south of the West Lothian area near West Calder. By 1959, the workings were only in the Dunnet and Broxburn shales.

The process of retorting crude oil from oil-bearing shale resulted in a vast amount of waste. This waste was stored in large heaps, the red shale bings of West Lothian. These bings are an important element in the county’s landscape and make a major contribution to local biodiversity as well as providing opportunities for education and recreation.

3.2.1.3 Hydrocarbons

Natural gas and oil have their origin in organic-rich rocks which are common in the Carboniferous sedimentary sequence. Exploitable accumulations of oil and gas may be found where the rocks are folded and faulted to provide traps for the hydrocarbons. Within each trap, open-textured reservoir rocks are needed to hold the oil or gas. The Carboniferous rocks of the Livingston district include source rocks and reservoir rocks but the latter are probably too fractured to have retained significant quantities of oil or gas. There have been several reported occurrences of oil-impregnated sandstone and natural oil-seepages in the district and a deep oil-well was sunk unsuccessfully at West Calder between 1919 and 1921.

3.2.1.4 LIMESTONE

Almost all the limestones that have been worked in the district occur within the Upper and Lower Limestone formations and in the West Lothian Oil-shale Formation. However, one of the limestones in the Ballagan Formation was quarried at Selms [NT 084 661]. Some of these limestones were quarried and mined underground for agricultural and industrial uses. North-east of Bathgate, the East Kirkton and West Kirkton (Hurlet) limestones have both been quarried on a small scale near Limefield [NS 988 694], and the latter also at Addiewell [NS 994 624]. The overlying Petershill (Hillhouse) Limestone is up to 18m thick and has been quarried and mined almost continuously along its outcrop between Glenbare Quarry [NS 985 690] and Craigmailing [NS 994 722]. Small quarries in the thinner Blackhall Limestone were at Whitebaulks [NT 008 747] and Tartraven [NT 006 725] for example. The Burdiehouse Limestone at the base of the Hopetoun Member was quarried extensively along its irregular outcrop between Abercorn and Newton. Smaller quarries occur elsewhere along its extensive outcrop. In the Upper Limestone Formation, the Calmy Limestone has been mined in Carribber Glen [NS 969 752], and quarried near Leven Seat [NS 946 576]. The Castlecary Limestone was formerly mined beneath Bowden Hill [NS 977 747], at Standhill [NS 968 673], near Longridge [NS 961 621] and at Leven Seat where limestone quarrying then mining lasted almost 200 years, before terminating in 1900. The Castlecary Limestone was the most extensively worked in the district, probably owing to its reputation for producing excellent lime.

There are currently no active limestone quarries in the county, but a number of disused quarries provide some of the most important, and in one case unique, sites at which certain rock units may be seen. They contribute greatly to the area’s geodiversity.

3.2.1.5 FIRECLAY AND SHALE FOR BRICKMAKING

In the neighbourhood of Winchburgh and East Calder old small brickworks gave place to large works at Winchburgh, Camps and Ecclesmachan where 'blaes' and ‘boulder-clay’ (till) were excavated and mixed, but these long since ceased working. Passage Formation strata, which include the most valuable refractory fireclays in the United Kingdom, crop out widely around the rim of the Central Coalfield syncline, and underlie much of the district. Fireclays occur principally near the top and bottom of the Passage Formation and throughout much of the Lower Coal Measures.

The Glenboig Lower and Upper Fireclays of the Passage Formation, because of their high alumina content, were economically the most important. They are thought to be overbank deposits of a meandering river system, and are thus not true seatclays as they are not associated with coals. They were mined initially along the western outcrop of the Central Coalfield, but latterly the industry concentrated on the eastern outcrop where the quality was found to be better; a total of 12 mines were located between Birkhill near Linlithgow and Leven Seat, with the Ballencrieff Mine [NS 964 695] being the last to close in 1985.

Fireclays associated with coal seams belonging to the Lower Coal Measures, have also been mined throughout the district around Armadale. Latterly, fireclay production has been confined to a number of opencast coal sites located within the outcrop of the Lower Coal Measures where it was extracted in conjunction with coal.

3.2.1.6 Sandstone

Sandstone occurs in thick beds throughout the Carboniferous sequence of West Lothian and in the past considerable quantities of freestone was quarried for use in construction. Many of Edinburgh's buildings erected before the 20th century owe their character principally to the sandstone from which they were constructed. West Lothian quarries provided sandstone for a number of these; examples include the Bank of Scotland, the National Gallery on the Mound and Daniel Stewart's and Melville College (Binny Quarry). Active in the 18th and 19th centuries, the quarries are all long-since disused and mostly filled in.

The main beds that provided high quality sandstone were the Binny Sandstone and the Dunnet Sandstone in the middle of the West Lothian Oil-shale Formation. The most important quarries in the Binny Sandstone were at Binny; others were at Cockmuir, Craigton, Hermand, Hopetoun White and Humbie (Figure 5). The only quarry in the Dunnet Sandstone was Hopetoun Obelisk, although the sandstone is thought to be extensively developed in the Livingston area. Other sandstones have been quarried locally.

Certain sandstones of the Passage Formation are typically soft, friable, open-textured and are composed predominantly of quartz. Although the outcrop of the Passage Formation is extensive in the district, it is commonly concealed by superficial deposits. Silica sand is produced from one quarry located at Leven Seat, where sandstone production has continued for over 70 years. The iron oxide content of the sandstone precludes its use for most types of glass manufacture, though recent exploration at Levenseat Quarry indicates some sandstone of glass-making quality may be present. It is not known whether purer sandstone, suitable for colourless glass manufacture, occurs elsewhere in the district.

Although sandstone is not extracted for building stone within West Lothian at the moment, sandstone quarries are being opened up in adjacent districts. The Sir Walter Scott Monument in Edinburgh was recently repaired by 'snatch' quarrying at Binny. Sections can still be seen in some of the ancient quarries and are valuable both as geological sections in their own right and as a link to the built heritage of the region. Some stone quarries offer the potential to be re-opened as a resource for repairs and conservation work.

3.2.1.7 Metalliferous minerals

The district has limited occurrences of economic metalliferous minerals. The ironstone industry of West Lothian was represented for example by furnaces operated at Causewayend [NS 961 760] beside the Union Canal during the latter half of the 19th century, coinciding with the peak in local ironstone mining. Blackband and clayband ironstones were formerly mined extensively throughout the district with the principal centre at Armadale. Bedded ironstones were the main source of iron ore during the industrial revolution in Scotland, but production declined rapidly around the end of the 19th century. Among the ironstones exploited were the Curdly Ironstone and Crofthead Slatyband (Passage Formation).

The discovery of native silver in vein mineralisation associated with faulting and emplacement of a quartz-dolerite dyke at Hilderston [NS 990 715] in 1606 resulted in intermittent mining activity for silver, lead and nickel between 1607 and 1898. The silver lode, which unusually included native silver, was exhausted within a few years and the presence of nickel ore in the vein mineralisation was not recognised until about 1870. The mineral suite included niccolite, bravoite, annabergite, erythrite, native silver and galena, in a gangue comprising baryte, calcite and dolomite. Minor stratabound lead-zinc mineralisation has also been discovered in the same neighbourhood in the lower, argillaceous part of the Petershill Limestone.

3.2.2 Built heritage

West Lothian has a rich and varied built heritage, much of which reflects the underlying geology. The earliest example is the outstanding prehistoric monuments of Cairnpapple Hill; later historic buildings include, Hopetoun House, the House of the Binns, Blackness Castle and Dalmeny.

Other notable buildings include St Michael's Parish Church, one of Scotland's finest parish churches, or to Torphichen Preceptory – the tower and transepts of a 13th century church built by the Knights of St. John of Jerusalem.

West Lothian has a rich resource of good quality building stone and, as well as supplying stone for some of Edinburgh's finest buildings (see 3.2.1.6), most of West Lothian's historic buildings and all older buildings in the towns and villages are built from stone sourced within the area; two examples are given below:

3.2.2.1 LINLITHGOW PALACE

Construction of Linlithgow Palace (Figure 153), the birthplace of Mary Queen of Scots, began in 1424 under James 1 and was completed by James VI in 1624. It is largely built from thinly bedded or laminated sandstone which weathers to a distinctive variable orange and cream colour. Historical records indicate that the stone used to build Linlithgow Palace was obtained from Kingscavil Quarry, situated a few kilometres to the east of the town. The quarry is now infilled and long disused.

The older parts of the external walls, on the east, north and parts of the west side, are composed of random-sized, roughly squared blocks built into rough courses. Parts of the later south range, particularly near the entrance, are constructed from the same type of sandstone, but used in a more formal way with squared blocks of uniform size built into regular courses.

In contrast, the King's Fountain situated within the Palace was made from a different sandstone type. This has a more uniform nature, and is finer grained and slightly softer, making it easier to carve and produce the sculptural detail seen on the fountain. The stone may also have been obtained locally, but from a different quarry.

Because there are no building stone quarries operating in West Lothian today, all the stone used for repairs to the Palace have to be imported from other parts of the United Kingdom. As there are no working stone quarries in West Lothian, the stone used for the recent major repairs to the King's Fountain was obtained from a quarry in Yorkshire.

3.2.2.2 BLACKBURN HOUSE

Blackburn House, located between Blackburn and Seafield, was constructed around 1760 with some later additions. It was built using locally-sourced sandstone, limestone and dolerite. The portico was added some time later and is made from Binny Sandstone (see 3.2.1.6) from Binny Quarry near Broxburn.

Blackburn House is about to be renovated at a cost of £3.4 million to create a bespoke centre for the Creative Industries in West Lothian, with funding from the Heritage Lottery Fund, the European Union, Historic Scotland and West Lothian Council. Like Linlithgow Palace, stone for this renovation will be obtained from Yorkshire.

3.3 EVALUATING THE GEODIVERSITY OF WEST LOTHIAN

3.3.1 Site desk study

The first stage of the project involved compiling a database of potential geodiversity sites for the West Lothian area. This was done by utilising the geological literature (much of it is over 50 years old), BGS staff expertise and additional local knowledge afforded by the LaBRIGS Group on the key geological localities of West Lothian. A preliminary list of 204 potential sites was drawn up and used to targets sites for the field audit. The locations of these sites are plotted in Figure 6 and details presented in Appendix 4. The list could be used to augment the audit in the future.

3.3.2 Field audit

Field work was carried out between August and December 2005. Of the 204 potential geodiversity sites, 86 were visited during the course of the audit. Data was recorded in BGS notebook record cards or recorded directly on to forms designed for use with the BGS GeoDiversitY database (see Appendix 5 for examples). Digital cameras were used to record the site locality, features and general site condition (see Volume 2, Figures). Garmin 12XL handheld GPS units were used for site location.

As far as possible landowners and farmers were contacted prior to visiting or accessing sites, but ownership was not established for every site visited. Most landowners or farmers were helpful and allowed access, a few allowed access reluctantly, and access permission was denied by one large estate, on the grounds that any site designation arising out of the work would interfere with 'lawful estate business'.

3.3.3 Project database (GeoDiversitY)

A corporate database had been designed for previous geodiversity work in northern England (North Pennines AONB, County Durham and Northumberland National Park). This GeoDiversitY database, consisting of a number of tables stored in the BGS corporate Oracle database with front-end data entry and browsing capability implemented in Microsoft Access. To accommodate the different natural heritage designations used in Scotland, the database structure and entry forms were re-built.

Data from the 86 sites visited were entered into the database. Details of a further 36 sites were added – these were sites where the geodiversity was likely to be important but:

- Ownership could not be determined
- Access was denied during the audit visit
- No time was available for visiting

This gave a total of 122 sites, which form 122 records in the GeoDiversitY database (see Appendix 5 for sample records). This data was then exported to DBF files to allowing building of ArcGIS shape files.

3.3.4 Project GIS

A project GIS was established to display the location of geodiversity information and to enable it to be examined in relation to existing scientific, historical and cultural designations. A wide range of digital data was acquired and the datasets translated to a suitable format for display in ESRI ArcGIS (Table 1).

Most of these datasets were available under licence for no cost from their owners, but fees were payable in order to licence the 1:25,000-scale soils data (£1308) from the Macaulay Institute and the West Lothian wildlife site data (£734) from the Lothian Wildlife Information Centre. Both these datasets were licenced for one year. Use of Ordnance Survey mapping in the project was covered by BGS membership of the OS Pan Government Agreement, Licence Number: 100017897.

Dataset	Figure No.	Format	Supplier	Licence req. for BGS use	Licence fee
Earth science					
1:50k Digital Geology (DiGMapGB-50)		ESRI shape files	BGS	No	No
Geological Conservation Review sites (GCR)	7	Web table	JNCC	No	No
Sites of Special Scientific Interest (SSSI)	7	ESRI shape files	SNH	Yes	No
1:25k soil classification		ESRI shape files	Macaulay	Yes	Yes
Regionally Important Geological and Geomorphological Sites (RIGS)	7	Excel table	LaBRIGS	No	No
Topography and landscape					
NEXTMap Britain DSM from radar altimetry	8	Raster images	Intermap	Yes	Yes
1:250k, 1:50k, 1:25k, 1:10k topography, National Grid, Admin Meridian		Raster and vector	OS	Yes, PGA	Yes
Landscape Character Assessment	9	ESRI shape files	SNH	Yes	No
Habitats, ecology and biodiversity					
Country Parks, Historic gardens and Designed Landscapes	10	ESRI shape files	SNH	Yes	No
Areas of Great Landscape Value	10	ESRI shape files	WLC	No	No
Habitat mapping		ESRI shape files	WLC	No	No
Special Protection Areas (SPAs)	10	ESRI shape files	JNCC	No	No
Special Areas of Conservation (SACs)	10	ESRI shape files	JNCC	No	No
Ramsar sites	10	ESRI shape files	JNCC	No	No
Sites of Special Scientific Interest (SSSI)	10	ESRI shape files	SNH	Yes	No
National Nature Reserves (NNR)	10	ESRI shape files	SNH	Yes	No
Ancient and semi-natural woodland inventory	10	ESRI shape files	SNH	Yes	No
Raised and intermediate bog inventories	10	ESRI shape files	SNH	Yes	No
Great Crested Newt Sites (Scotland)	10	ESRI shape files	SNH	Yes	No
Listed Wildlife Sites &Wildlife Sites (1993)	10	ESRI shape files	LWIC	Yes	Yes
Archaeology					
Sites and Monument Records	11	ESRI shape files	WOSAS	No	No
Scheduled Ancient Monuments	11	ESRI shape files	Historic Scotland	Yes	No

Table 1 Digital datasets used in the project GIS.

3.4 THE GEODIVERSITY RESOURCE

3.4.1 Geodiversity site review

The 122 geodiversity sites are separated into four classes for GIS display using the ranking criteria applied in the GeoDiversitY database (see Appendix 5, ranking criteria window) and the overall geological context within West Lothian.

The classes applied are:

3: Geological features of great value, worthy of interpretation & conservation – 34 sites

2: Geological features of some value, may be worthy of interpretation & conservation – 33 sites

1: Geological features of limited value – 34 sites

0: Geological features destroyed, no longer visible, or of no value – 21 sites

The 67 class 3 and class 2 sites are considered to be representative of particular geodiversity features in the context of West Lothian and classed here as West Lothian Geodiversity Sites (WLGS). For numbering and description purposes, a number of these localities have been considered together to give a total of 51 WLGSs (Table 2, Figure 12).

Of these 51 WLGS sites, four have statutory protection as geological or mixed geological and biological SSSIs (4−East Kirkton, 25−Skolie Burn, 26−Petershill Quarries and 27−Rifle Ranges Quarries). The remaining 47 WLGSs form a reservoir of non-statutory, but significant geodiversity sites. Five of these 47 sites are existing RIGS and LaBRIGS have a further 16 localities on a 'proposed' RIGS list for possible future designation.

Table 2 WEST LOTHIAN GEODIVERSITY SITES (WLGS)

WL GS No.	Site name	Group	Formation	Geol Theme	WLGS class	Other Designation	Site Potential / Issues / Management
1	Baad Park Burn	Inverclyde Quaternary	Ballagan	LthSt Sed Struc GDep	2	PHRP AGLV	Potential interpretation leaflet for Pentlands walk. Good viewpoint
2	West Cairn Hill, East Burn	Inverclyde	Kinnesswood	LthSt Sed	2	PHRP AGLV	Potential interpretation leaflet for Pentlands walk. Good viewpoint
3	Linhouse Water - Above Carstairs	Inverclyde	Ballagan	LthSt Sed	2	B-SSSI LWS, SWT AGLV	Potential for Linhouse Water geotrail
4	East Kirkton	Strathclyde	West Lothian Oil-shale	Pal Sed	3	G-SSSI, GCR RIGS AGLV	Potential for on-site interpretation board and/or part of a Bathgate Hills geotrail. Rubbish dumping, burning, and overgrowing
5	Five Sisters	Strathclyde	West Lothian Oil-shale	MnHe	2	SAM	Potential for on-site interpretation, oil-shale mining heritage
6	Seafield Law	Strathclyde	West Lothian Oil-shale	MnHe	3	P-RIGS	RIGS, potential for on-site interpretation − artificial Crag and Tail, interpretation leaflet
7	Greendykes	Strathclyde	West Lothian Oil-shale	MnHe	3	SAM P-RIGS	RIGS, interpretation leaflet, oil-shale mining heritage
8	Almond Valley Heritage Centre	Strathclyde	West Lothian Oil-shale	MnHe	2	(LWS)	Current museum displays on the oil shale industry, geology, mining, oil refining and social history.

WL GS No.	Site name	Group	Formation	Geol Theme	WLGS class	Other Designation	Site Potential / Issues / Management
9	Murieston Water 2	Strathclyde	Gullane	Struc	3	B-SSSI, CP LWS, AGLV AWI SNWI	Potential for on-site interpretation or leaflet on faulting
10	Almondell and Calder Wood	Strathclyde	West Lothian Oil-shale	LthSt MnHe	3	B-SSSI RIGS LWS, WS AWI SNWI AGLV, CP	Potential for on-site interpretation
11	Upper Uphall	Strathclyde	West Lothian Oil-shale	MnHe	3	P-RIGS	RIGS, potential for on-site interpretation board and / or leaflet on stoop and room mining
12	Union Canal, Winchburgh	Strathclyde	West Lothian Oil-shale	LthSt	3	SAM P-RIGS LWS	RIGS, potential for interpretation leaflet
13	Hopetoun Obelisk Quarry	Strathclyde	West Lothian Oil-shale	Sed LthSt BSt	3	HGDL (LWS)	Potential for on-site interpretation Soil dumping
14	Society East Shore	Strathclyde SSDPV	West Lothian Oil-shale SSDLO	Sed LthSt Ign GDep	2	AGLV (HGDL) (AWI)	Potential for Society East Shore to Abercorn Point geotrail, interpretation leaflet and/or on-site interpretation board.
15	Society Point	Strathclyde	West Lothian Oil-shale	Sed LthSt Struc	3	AGLV (HGDL) (AWI)	RIGS, potential for Society East Shore to Abercorn Point geotrail, interpretation leaflet and/or on-site interpretation board
16	Society Shore	Strathclyde	West Lothian Oil-shale	LthSt Pal	2	AGLV (HGDL) (AWI) (LWS)	Potential for Society East Shore to Abercorn Point geotrail, interpretation leaflet and/or on-site interpretation board.
17	Hopetoun Shore	Strathclyde MCPAS	West Lothian Oil-shale LAFAS	Sed LthSt Struc Ign, Pal	3	AGLV P-RIGS (HGDL) (AWI), (LWS)	Potential for Society East Shore to Abercorn Point geotrail, interpretation leaflet and/or on-site interpretation board.
18	Abercorn Point	Strathclyde Quaternary	West Lothian Oil-shale	Sed LthSt Struc PGDep	3	AGLV (HGDL) (LWS)	Potential for Society East Shore to Abercorn Point geotrail, interpretation leaflet and/or on-site interpretation board.
19	Midhope Burn	Strathclyde	West Lothian Oil-shale	LthSt	2	AWI SNW HGDL	Potential to extend Society East Shore to Abercorn Point geotrail?
20	Cairnpapple Hill	Bathgate	Bathgate Hills Volcanic	BtHe Ign	3	SAM P-RIGS AGLV HPWG	RIGS, interpretation leaflet, good viewpoint
21	Wairdlaw Quarry	Bathgate LCTS	Bathgate Hills Volcanic MVSC	Pal BtHe	3	AGLV P-RIGS (CP), (AWI)	RIGS, interpretation leaflet, Wairdlaw Limestone
22	Union Canal Museum	Bathgate	Bathgate Hills Volcanic	BtHe	2	SAM LWS	Potential for museum exhibit, geology of Union Canal
23	Levenseat working quarry	Clackmannan	Passage	Sed LthSt	3	P-RIGS	Potential for excellent sections in Passage Formation once quarry ceases operation
24	Levenseat quarries & mines	Clackmannan	Passage	LthSt MnHe	3		Potential for interpretation leaflet on limestone mines, Levenseat to Fauldhouse walk, but marred by windblown rubbish from landfill site. Good viewpoint.

WL GS No.	Site name	Group	Formation	Geol Theme	WLGS class	Other Designation	Site Potential / Issues / Management
25	Skolie Burn	Clackmannan	Lower Limestone Limestone Coal	LthSt Sed Ign, Pal	3	M-SSSI GCR P-RIGS	RIGS, prone to rubbish dumping and vegetation overgrowth,
26	Petershill Quarries	Clackmannan	Lower Limestone Limestone Coal	Pal Sed LthSt Ign	3	M-SSSI GCR, RIGS WS, SWT AGLV	Interpretation board vandalised, vegetation overgrowth
27	Rifle Range Quarries	Clackmannan	Lower Limestone	Pal Sed LthSt MnHe	3	M-SSSI P-RIGS GCR HPWG AGLV	Vegetation overgrowth
28	Hilderston Silver Mine Quarry	Clackmannan	Lower Limestone	Sed	3	P-RIGS HPWG, WS AGLV	RIGS, potential interpretation leaflet, vegetation overgrowth
29	Hilderston Silver Mine	Clackmannan	Lower Limestone	MnHe Min	3	P-RIGS HPWG AGLV	RIGS, potential interpretation leaflet, vegetation overgrowth and flooding
30	Hillhouse Quarry and Mine	Clackmannan MCPAS	Lower Limestone LAFAS	LthSt Ign MnHe	2	AGLV P-RIGS (CP)	RIGS, potential interpretation leaflet on stoop and room workings, but subsidence problems
31	Muiravonside, Carribber Glen	Clackmannan	Upper Limestone	LthSt MnHe	3	B-SSS P-RIGS, LWS AWI SNW AGLV	RIGS, potential interpretation leaflet and/or geotrail
32	Wallace's Arch	Clackmannan	Passage	GeoM	2	P-RIGS LWS AWI SNW AGLV	Potential interpretation leaflet and/or geotrail
33	Barbauchlaw Quarries	Coal Measures (Scotland)	Lower Coal Measures (Scotland)	LthSt	2	WS	Perhaps the only Coal Measures exposures in West Lothian? Visit required to determine potential
34	Barbauchlaw Burn Quarries	Coal Measures (Scotland)	Lower Coal Measures (Scotland)	LthSt	2	WS	Perhaps the only Coal Measures exposures in West Lothian? Visit required to determine potential
35	Carsie Hill	SSDPV Clackmannan Quaternary	SSDLO Lower Limestone	Ign GeoM	2	AGLV	Volcanic vent sculpted into Crag and Tail, potential interpretation leaflet, small exposures, vegetation overgrowth
36	Auchinoon Quarry	MCPAS Strathclyde	LAFAS Gullane	Ign Meta LthSt	3	P-RIGS AGLV	RIGS, potential interpretation leaflet and/or on-site interpretation board, good viewpoint for Pentland Hills
37	Linhouse Water - Glasgow Viaduct 2	MCPAS	LAFAS	Ign	2	AGLV AWI SNW LWS	Potential for Linhouse Water geotrail
38	The Knock	LCTS Quaternary	MVSC	Ign GeoM	3	AGLV P-RIGS (WS) (HPWG)	Potential to include on Bathgate Hills geotrail, interpretation leaflet, good viewpoint
39	Witch Craig Viewpoint	LCTS Bathgate Quaternary	MVSC Bathgate Hills Volcanic	Ign GeoM	3	AGLV RIGS LWS, WS AWI SNW	Existing stone shelter with 43 rocks from the Midland Valley. Potential to include on Bathgate Hills geotrail

WL GS No.	Site name	Group	Formation	Geol Theme	WLGS class	Other Designation	Site Potential / Issues / Management
40	Cockleroy	LCTS Bathgate Quaternary	MVSC Bathgate Hills Volcanic	Ign GeoM	3	AGLV P-RIGS LWS AWI SNW SAM	RIGS. Potential to include on Bathgate Hills geotrail, on-site interpretation/ interpretation leaflet. Good viewpoint across the whole of the Midland Valley
41	Beecraigs Quarry	LCTS	MVSC	Ign	3	AGLV P-RIGS (LWS)	RIGS, potential to include on Bathgate Hills geotrail, interpretation leaflet.
42	Binny Craig	LCTS Quaternary	MVSC	Ign GeoM	3	RIGS AGLV	Potential to include on Bathgate Hills geotrail. Good viewpoint
43	Kildimmery Fishery Quarry	LCTS	MVSC	Ign	2	AGLV	Potential to include on Bathgate Hills geotrail.
44	Craigton (Hill) Quarry	LCTS	MVSC	Ign Struc	3		Best example of quartz-dolerite sill, but access problems with Hopetoun estate
45	Linhouse Water - Calderwood 1	LCTS	MVSC	Ign Struc LthSt	2	AGLV LWS B-SSSI AWI SNW	Potential for interpretation leaflet and/or on-site interpretation board
46	Tophichen HIll	LCTS Quaternary	MVSC	GeoM Ign	2	SAM AGLV	Potential to include on Bathgate Hills geotrail.
47	Linlithgow Loch	Quaternary		GeoM BtHe	2	B-SSSI AGLV SAM	Existing on-site board at the west end of the loch could be up-dated to include some info on the landforms and glaciofluvial deposits
48	Tailend Moss	Quaternary		PGDep	3	B-SSSI P-RIGS WS RBI SWT	RIGS, potential for interpretation leaflet and/or on-site interpretation board
49	Longridge Moss	Quaternary		PGDep	3	B-SSSI P-RIGS WS RBI SWT	RIGS, potential for interpretation leaflet and/or on-site interpretation board
50	Easter Inch Moss	Quaternary		PGDep	2	WS GCNS	Potential to combine with proposed RIGS at Seafield Law (see 6 above). Interpretation leaflet and/or on-site interpretation board
51	Calder Wood	Quaternary		PGDep ActPr	3	RIGS AGLV LWS B-SSSI AWI SNW	Potential for on-site interpretation

Abbreviation	Explanation	Abbreviation	Explanation
SSDPV	Southern Scotland Dinantian Plugs and Vents Suite	(CP)	Designations in brackets indicate that geodiversity site is adjacent or close to designated site
SSDLO	Southern Scotland Dinantian Plugs and Vents Suite, Lothian Subsuite	AGLV	Area of Great Landscape Value
MCPAS	Midland Valley Carboniferous to Early Permian Basic Alkaline Sill Suite	AWI	Ancient Woodland Inventory
LAFAS	Dinantian to Westphalian Sills of Lothians and Fife	B-SSSI	Site of Special Scientific Interest (Biological)
MVSC	Midland Valley sill complex	CP	Country Park
LCTS	North Britain Late Carboniferous Tholeiitic Suite	GCNS	Great Crested Newt Site (Scotland)

LthSt	Lithostratigraphy	GCR	Geological Conservation Review Site
Sed	Sedimentology	G-SSSI	Site of Special Scientific Interest (Geological)
Struc	Structural geology	LWS	Listed Wildlife Site
Ign	Igneous geology	HGDL	Historic Garden & Designed Landscape
Pal	Palaeontology	HPWG	High Priority Wildflower Grasslands
Meta	Metamorphic geology	M-SSSI	Site of Special Scientific Interest (Mixed geological and biological)
Min	Minerals	PHRP	Pentland Hills Regional Park
GDep	Glacial deposits	RBI	Raised Bog Inventory
PGDep	Post-glacial deposits	SAM	Scheduled Ancient Monument
GeoM	Geomorphology	SNWI	Semi-Natural Woodland Inventory
ActPr	Active processes	SWT	Scottish Wildlife Trust Reserve
MnHe	Mining Heritage	WS	Wildlife Site (1993)
BtHe	Built Heritage		

Table 2 West Lothian Geodiversity Sites (WLGS) and explanation of abbreviations.

Sections 3.3.2 to 3.3.11 describe the WLGSs within their component geological groups and themes. Further details on the site access, site fragility and the importance of the geological features are available in the GeoDiversitY database.

3.4.2 Inverclyde Group rocks

The oldest Carboniferous rocks in the Midland Valley of Scotland belong to the Inverclyde Group. In West Lothian the group comprises the Kinnesswood and Ballagan formations

Outcrops of Inverclyde Group rocks comprise approximately 3,300 hectares, or 7.7% of the surface area of West Lothian. They crop out in a strip south-east of the A70 between East Cairn Hill and Henshaw Hill, forming the high ground of the Pentland Hills, and a smaller area to the south-east of Livingston between Linhouse Water and Kirknewton (Figure 13).

The Inverclyde Group was laid down between 345 m and 355 million years ago (Ma) whilst Scotland lay in low latitudes south of the Equator. At this time, the climate was generally considered to be semi-arid and seasonally wet. A rather discontinuous vegetational cover of the land surface was probably the norm. Locally in the Pentlands, the base of the group is taken at an unconformity on Lower Devonian and older strata. It is because of the semi-arid climate that the sandstone-dominated **Kinnesswood Formation** contains calcareous and dolomitic pedogenic (soil profile) horizons (calcrete) and the overlying **Ballagan Formation** is characterised by grey mudstone and siltstone with nodules and beds of ferroan dolostone (cementstone), and evaporite (mainly gypsum). The group is also characterised by an absence of carbonaceous rocks especially coal seams and oil shales in comparison with overlying rocks.

3.4.2.1 INFLUENCE ON BIODIVERSITY

The hard resistant and largely glacial till-free Kinnesswood Formation sandstones that form the Cairn Hills have favoured the development of freely-draining humus-iron podzol soils. The main habitats here are dry and wet dwarf shrub heath. On the lower ground at the foot of the hills, the softer Ballagan Formation is mostly till-covered and gives rise to very poorly-drained blanket peat or peaty podzols which support wet heath, acid grassland, marshy grassland and mire.

The mostly till-covered Ballagan Formation in the area to the south-east of Livingston has developed mostly poor to imperfectly-drained gley soils. There are small areas of grassland and wet heath, but the area is mostly devoted to agriculture and forestry.

3.4.2.2 WEST LOTHIAN GEODIVERSITY SITES

Given the limited coverage of Inverclyde Group rocks, four sites described below are considered to adequately represent the group.

WLGS 1 BAAD PARK BURN [NT 1125 6014 AND NT 1103 6037] (FIGURES 14 TO 18)

These two sites are on the Baad Park Burn to the south-east of Harperrig Reservoir (Figure 13). They are within the Pentland Hills Regional Park and close to a popular walking route following an old drove road over the Pentland Hills (Figure 14) from Little Vantage on the A70 to West Linton. At Baad Park Burn [NT 1125 6014] (Figure 15) a section of the lower part of the Ballagan Formation is exposed. This location also gives views of the Cairn Hills (Figures 16, 17). At Baad Park Burn 2 [NT 1103 6037] (Figure 18) good sedimentary structures are present in red sandstone outcrops), the former demonstrating good small-scale scarp featuring.

WLGS 2 WEST CAIRN HILL [NT 1042 5832] (FIGURES 16)

Although not visited during the audit, the BGS 1:10,000 map (surveyed in 1995) shows an outcrop of pink Kinnesswood Formation sandstone with sedimentary structures in the East Burn on the north-west slopes of West Cairn Hill.

WLGS 3 LINHOUSE WATER [NT 0730 6425]

The Linhouse Water – above Carstairs Viaduct site is a useful site for demonstrating the upper part of the Ballagan Formation and the overlying Corston Hill lavas (Arthur's Seat Volcanic Formation).

3.4.3 Strathclyde Group rocks

The Strathclyde Group is a varied sequence of rocks, sedimentary and volcanic, characterised by the presence of carbonaceous beds, including coal, oil-shale and limestone. The local Strathclyde Group strata are assigned to the Arthur's Seat Volcanic, Gullane and West Lothian Oil-shale formations.

Outcrops of Strathclyde Group rocks comprise approximately 19,966 hectares, or 46.3% of the surface area of West Lothian. They crop out in a broad area covering most of the eastern half of West Lothian, from the coast at Abercorn – Society to the southern slopes of the Pentland Hills at Colzium and Crosswood (Figure 19).

The Arthur's Seat Volcanic Formation, at the base of the group in the Lothians, is 342 Ma old. The sedimentary rocks were laid down between 345 Ma and 326 Ma. Deposition of the Strathclyde Group marks a lithological change from concretionary limestone and dolostone-bearing strata typical of the Inverclyde Group to a coal-bearing sequence in which volcanic rocks may be common.

The group is largely fluviatile and lacustrine in origin, with a few marine incursions from time to time. The palaeoclimate during deposition of the Strathclyde Group was mainly humid (coals, oil-shales and sideritic mud grade palaeosols) but the presence of calcretes and calcareous mudstones ('marls') in the West Lothian Oil-shale Formation point to periods of semi-arid climatic conditions.

The **Arthur's Seat Volcanic Formation** consists of extrusive igneous rocks belonging to a suite of mildly alkaline basaltic lavas which is recognised across the Midland Valley and is chemically distinct from the Lower Devonian igneous rocks of the Pentlands. Volcaniclastic rocks known as tuffs and lapilli-tuffs also occur; these may be air-fall or water-lain in origin. The formation is up to 200 m thick in this area and absent in places.

The **Gullane Formation** consists of a cyclical sequence predominantly of pale-coloured, fine- to coarse-grained sandstones interbedded with grey mudstones and siltstones. Subordinate lithologies are coal, seatearth, ostracod-rich limestone and dolostone, sideritic ironstone and, rarely, marine beds with low diversity faunas lacking for example corals. The depositional environment was predominantly fluviodeltaic, into lakes that only occasionally became marine. Desiccation cracks, soft sediment deformation textures and bioturbation are sedimentological features typical of this formation.

The **West Lothian Oil-shale Formation** is characterised by several, well-developed distinctive seams of oil-shale (see section 3.2.1.2 for historical significance) within a cyclical sequence dominated by pale-coloured sandstones interbedded with grey siltstones and mudstones. Sections in most parts of the formation can be seen on the coast from South Queensferry to Blackness. Subordinate lithologies are coal, ostracod-rich limestone (see section 3.2.1.4 for economic geology) and dolostone, sideritic ironstone and beds of fossiliferous mudstone deposited in a marine environment, including limestones with rich and relatively diverse faunas. Thick, pale green-grey or grey argillaceous, calcareous beds containing supposed volcaniclastic detritus described as 'marl' are also present and may have formed on extensive semi-arid plains. The 'marl' can rest directly on the mud-cracked top of an oil shale. The maximum thickness of the formation is in excess of 1120 m in West Lothian.

The environment of deposition was of fluviolacustrine deltas, subject to periodic inundation by incursions of marine water, with large freshwater lagoons rich in algae and other organic matter in which accumulated oil-shales and, less commonly, but significantly, limestones. The East Kirkton Limestone represents a world famous, development of non-marine limestone

3.4.3.1 INFLUENCE ON BIODIVERSITY

Compared to the Kinnesswood Formation sandstone of the Inverclyde Group, the relatively soft rocks of the Strathclyde Group rock have been easily eroded by the successive Quaternary ice-sheets leaving thick deposits of glacial till. Although there is much variety in the lithology of the Strathclyde Group rock, the thick till blanket probably masks the effects of this lithodiversity on the biodiversity. Most soils are thus derived from glacial till and the dominant soil types are imperfect to poorly-drained non-calcareous gleys and brown forest soils with gleying. Much of the area is given over to agriculture and urban settlement with consequent limited biodiversity. Greater biodiversity is found in scattered pockets of ancient and semi-natural woodland, Listed Wildlife Sites, oil-shale bings and SSSIs.

3.4.3.2 WEST LOTHIAN GEODIVERSITY SITES

The Strathclyde Group is well represented by geodiversity sites, though the best of these are located in the centre and north of the outcrop (Figure 19).

WLGS 4 EAST KIRKTON QUARRY (GEOLOGICAL SSSI, RIGS) [NS 9901 6913] (FIGURES 20–23)

East Kirkton Quarry exposes the Upper Viséan East Kirkton Limestone, a laterally impersistent sedimentary sequence within a thick succession of basaltic lavas and tuffs. The succession consists of limestones overlain by black mudstones. Within the limestones are contorted horizons with common spherulitic structures and chert nodules – these are interpreted as having formed in a hot spring environment. The site has yielded the world's earliest known terrestrial tetrapods. Specimens include the first complete articulated amphibians found in the Scottish Carboniferous this century − seven species have been recognised so far, with the commonest a form of primitive temnospondyl (ancestors of modern frogs and toads). Two or possibly three species of anthracosaur have been found including the first articulated anthracosaur skeleton from the Scottish Lower Carboniferous. Anthracosaurs are known from both aquatic and terrestrial forms and recent work suggest a link between these amphibians, early reptiles and amniotes. Another new species is the earliest known loxommatid. This group are poorly known, and there is an important possibility of finding the first ever articulated skeleton at this site during future research. Recent research has also revealed a wealth superbly preserved arthropods, particularly scorpions and eurypterids. New eurypterid material from East Kirkton is also under study, as are superb scorpion remains. By far the best complete Lower Carboniferous scorpions (internationally) are currently being studied. The oldest harvestman (opilionid) known was found here. East Kirkton Quarry is a Geological Conservation Review (GCR) (Arthropoda and Carboniferous–Permian Fish/Amphibians) site.

WLGS 5 TO WLGS 7 FIVE SISTERS, SEAFIELD LAW, FUACHELDEAN AND GREENDYKES OIL-SHALE BINGS (FIGURES 24–28)

The oil-shale bings are unique in Britain and north-west Europe and form a significant part of the industrial heritage of West Lothian. The Five Sisters (WLGS 5) [NT 009 641], Faucheldean [NT 085 742] and Greendykes [NT 087 736] bings are protected as Scheduled Monuments. Seafield Law (WLGS 6) [NT 005 667] and Greendykes (WLGS 7) bings are proposed RIGS. Seafield Law [NT 005 667] (Easter Inch Moss) and Faucheldean are also Wildlife Sites (1993). Seafield Law is unique in that it has been re-profiled to replicate one of the most distinctive natural landforms of West Lothian – a ‘crag and tail’ feature sculpted by the erosive power of successive glaciations during the Quaternary.

Oil-shale waste is non toxic, alkaline and free-draining, unlike acidic coal spoil. The shale particles are also more cohesive than coal waste, and allow stable steep bing sides which are not prone to slippage. Burnt oil-shale is initially dark blue-grey (“blaes”), but rapidly oxidises to a characteristic red colour in contact with the elements (Figure 28). Variations in the chemical composition at the different bings produce a wide range of habitats and new niches for plants and animals and are a wildlife haven in a primarily agricultural and urban landscape.

WLGS 8 ALMOND VALLEY HERITAGE CENTRE [NT 0325 6689] (FIGURE 29)

The Almond Valley Heritage Centre Museum has an “oilshale adventure zone” display on the oil shale industry in West Lothian. Geological, mining, oil refining and the social history aspects of the oil shale industry are covered. The AVHC web pages also have a link to the “Secrets of the Bathgate Hills” leaflet and board game (www.almondvalley.co.uk/secrets/secrets).

WLGS 9 MURIESTON WATER 2 [NT 0733 6658] (FIGURE 30)

The Calder Fault is exposed at this locality on the Murieston Water. Thin (1–10 cm) beds of Gullane Formation sandstone and siltstone are exposed in the hanging-wall of the fault with a steep (~40°) dip to the north. The beds exhibit much fault-related deformation. The Footwall strata are largely overgrown and poorly exposed.

WLGS 10 ALMONDELL AND CALDERWOOD (RIGS) [NT 0908 6918] & RIVER ALMOND [NT 0859 6836] (FIGURES 31–33)

Almondell and Calderwood Country Park is a 90-hectare Country Park in Mid Calder, offering woodland and riverside walks, picnic areas and barbecue facilities. The Park's Visitor Centre has leaflets on the Oakbank oil-shale bing and on the rocks found within the park. In the past they have had geological displays. The West Lothian Ranger Service based at the park arranges talks, school visits and summer events. A good example of a *Stigmaria* tree root fossil in the Calders Member (West Lothian Oil-shale Formation) can be seen in the bank of the river at NT 0887 6885. At the River Almond site the Burdiehouse Limestone (Hopetoun Member, West Lothian Oil-shale Formation) can be seen in the bed of the river (Figure 32). For the Calder Wood RIGS see WLGS 51 (section 3.4.10.10).

A good example of an overfold occurs in the Broxburn Shale (West Lothian Oil-shale Formation) on the west bank of the Linhouse Water in Calder Wood [NT 0790 6710] (Figure 33). This locality is about 50 m downstream (north) of WLGS 45.

WLGS 11 UPPER UPHALL (PROPOSED RIGS) [NT 0550 7225] (FIGURES 34–36)

This site displays excellent examples of the features typically seen as a result of worked ground. There is a small oil-shale bing, sitts (areas of surface collapse) from underground stoop and room workings, uneven/low ground from quarrying and nearby remains of a dismantled railway. The site is currently used for cattle grazing, although is located on the outskirts of Uphall and could therefore be under threat from residential development in the future.

WLGS 12 UNION CANAL WINCHBURGH (PROPOSED RIGS) [NT 0868 7510]

Exposures of sandstones, siltstones and mudstones of the Hopetoun Member (West Lothian Oil-shale Formation) can be seen in canal bank. This site was not visited.

WLGS 13 HOPETOUN OBELISK QUARRY [NT 0942 7859] (FIGURES 37–40)

This disused quarry in the Dunnet Sandstone (Hopetoun Member, West Lothian Oil-shale Formation) was worked to provide the building stone for Hopetoun House. At the south-west corner of the quarry [NT 0942 7859] there is good face approximately 5–6 m high displaying grey to pale brown, fine grained sandstone, with interbeds of very fine grained sandstone and laminated carbonaceous siltstone ("tiger-stripe"). Cross bedding and cross laminations are also evident at this locality. Since the audit visit in November 2005, large quantities of soil have been tipped into the southern part of the quarry. The largest worked faces can be seen at the north-east corner of the quarry, though at the present time (February 2006) are inaccessible due to waterlogging at the base. The most accessible face is located at the north-west corner of the quarry beside some small stables [NT 0942 7871].

WLGS 14 TO WLGS 18 SOCIETY EAST SHORE [NT 107 788] – ABERCORN POINT [NT 0827 7954] (FIGURES 41–58)

The shoreline from Society East Shore to Abercorn Point displays a reasonably well-exposed, gently-folded section through the Calders and Hopetoun Members of the West Lothian Oil-shale Formation. Sixteen individual localities within this formation were recorded along this shore section.

At Society East Shore 1 (WLGS 14) [NT 107 788] a sandstone dyke cuts across the Burdiehouse Limestone and the Camps Shale. Within the Dunnet Sandstone of the Hopetoun Member, sandstone can be seen overlying a thin oil-shale (Society East Shore 2 [NT 1058 7879], Figure 41), a limestone and sandstone with carbonate nodules (Society East Shore 3, WLGS 14) [NT 10538 78805], Figure 42), and cross-bedded sandstone (Society East Shore 4 [NT 1052 7882], Figure 43). The large outcrop of Binny Sandstone at Society Point (WLGS 15) [NT 1009 7902] (Figures 45–48) is an excellent locality with sedimentological features such as trough cross-bedding and pebbly and carbonaceous lags. There is also a good example of a sandstone dyke-injection (Figure 47). At Society Shore1 (WLGS 16) [NT 0967 7910] (Figure 49), a *Stigmaria* root fossil can be seen in a beach outcrop of the Barracks Limestone (Hopetoun Member, West Lothian Oil-shale Formation).

To the west on the foreshore opposite Hopetoun House and its grounds, both limbs of the Hopetoun anticline can be seen (WLGS 17, Proposed RIGS) (Figures 51, 53). Small-scale folding and faulting are visible in the Burdiehouse Limestone on the west limb [NT 0894 7935] (Figures 53–55). At Abercorn Point 3 (WLGS 18), good examples of cross-bedded sandstone can be seen on the foreshore [NT 0827 7954] (Figures 56-58) (Hopetoun Member, West Lothian Oil-shale Formation).

WLGS 19 MIDHOPE BURN (FIGURES 59–61)

Along the Midhope Burn to the south-west of Abercorn Point, a small quarry beside a footpath exposes a coarsening-up sequence of siltstones and sandstones within the Hopetoun Member of the West Lothian Oil-shale Formation (Midhope Burn 2 [NT 0784 78918] (Figures 59, 60). Further downstream, the Broxburn Shale can be seen beside the footpath about 30 m upstream from a small bridge at Midhope Burn 1 [NT 0787 7898] (Figure 61).

3.4.4 Bathgate Group rocks

The Bathgate Group is a persistent group of volcanic rocks which interdigitate with the sedimentary rocks of the upper part of the Strathclyde Group and the larger part of the Clackmannan Group (Figure 1B). In West Lothian the group comprises the Bathgate Hills Volcanic Formation.

Outcrops of Bathgate Group rocks comprise approximately 3,185 hectares, or 7.4% of the surface area of West Lothian. They crop out in a north–south strip from north of Linlithgow to just south of Bathgate (Figure 62).

The **Bathgate Hills Volcanic Formation** occurs in the north-western part of the district where it is intercalated with and replaces sedimentary formations. It is up to 600 m thick. The basal beds of the formation are tuffs which lie at a widespread horizon just above the Two Foot Coal in the Hopetoun Member. Towards the top of the volcanic pile, olivine-basalt lava becomes predominant, occurring in layers or flows with vesicular or rubbly tops. The central parts of lava flows are commonly hard, compact and very fresh, hence well exposed at outcrop. The top and base of flows are typically amygdaloidal and/or scoriaceous with much hydrothermal alteration and are consequently less well exposed, giving rise to a conspicuous ridged topography (trap featuring) in places which reflects the alternating hard and 'soft' parts of the flows. Coals and seatclays with rootlets are commonly developed directly on top of lava flows and fragments of fossil wood have been found incorporated in the base of flows, including some 'trunks' in apparent position of growth recorded at Grangepans by Cadell in ‘The Story of the Forth’ in 1925. In the northern part of the outcrop, between Linlithgow and Bo'ness, there is evidence to suggest that magma was erupted on to, or even intruded into, wet unconsolidated sediments. Irregular blocks of lava and rounded pillow-like masses are wrapped in a matrix of disturbed sediment, and sediment infills cavities or occurs as clasts within the lavas. Petrographically the lavas are remarkably uniform. Large areas of basalt are exposed in a belt running through the Riccarton Hills but this belt dies out to the north. A more widespread belt of basaltic rocks lies to the west and is exposed on the hills to the north and south of Linlithgow. The basalts and tuffs are thought to have erupted from local volcanic vents, such as those now exposed to the south-east of the extrusive rocks at Tar Hill and The Binns. These vents are now filled with volcaniclastic rocks (agglomerate).

The overall regional setting of the Bathgate Hills volcanicity has been described and a detailed account given of the interaction between eruption, erosion, clastic deposition and carbonate precipitation in Lower Limestone Formation time. Jameson (1987) envisaged the volcanic rocks accumulating above sea level to form islands surrounded by coastal plains, restricted lagoons and a variety of carbonate reef facies, which accumulated during longer periods of volcanic quiescence. This succession was terminated by subaerial exposure and erosion followed by renewed volcanic activity.

3.4.4.1 INFLUENCE ON BIODIVERSITY

The hard lavas and tuffs of the Bathgate Hills Volcanic Formation have resisted glacial erosion better than the softer sedimentary rocks of the Strathclyde, Clackmannan and Coal Measures Groups, resulting in the uplands of the Bathgate Hills, which reach an altitude of 312 m at Cairnpapple. Bedrock with brown forest soils occurs on most of the hill tops, though most of the lower ground and the lee slopes of the crags are till covered with non-calcareous gleys and brown forest soils with gleying present . The hilly topography with its variable microclimate and the greater variety of soil types and drainage status has probably resulted in a wider variety of habitats than any other part of West Lothian. Agriculture, forestry and the urban area of Linlithgow are the dominant land uses.

3.4.4.2 WEST LOTHIAN GEODIVERSITY SITES

Although the coverage of Bathgate Group rocks is limited, three sites described below are considered to be just about adequate to represent the group. Further quality sites may not exist.

WLGS 20 CAIRNPAPPLE HILL (PROPOSED RIGS) [NS 9872 7174] (FIGURES 63–66)

Cairnpapple Hill is one of the best known and most important pre-historic sites on the mainland of Scotland. The site consists of both ceremonial and burial monuments. Human activity on Cairnpapple dates back 5,500 years to the Neolithic period. During the Bronze Age the site was used as a burial site. Burials were placed under cairns, in shallow graves and in unlined pits. The site builders used the local rock types – basalt from the Bathgate Hills Volcanic Formation and quartz-dolerite from the dyke to the north or the sill to the east of the site.

The site offers one of the best viewpoints in central Scotland – on a clear day it stretches from Arran in the west to the Bass Rock in the east. Between the Rifle Range Quarries (WLGS27) and the 312 m Trig point 600 m south of Cairnpapple Hill several low scarp features trending north-north-east pick out fresh, fine-grained basalt are interpreted as the central parts of lava flows.

WLGS 21 WAIRDLAW QUARRY (PROPOSED RIGS) [NS 9952 7313] (FIGURES 67–73)

Although this locality is included with the Bathgate Group sites, the quarry at Wairdlaw was formerly worked for limestone occurring in a small outcrop of the Wairdlaw Limestone (Lower Limestone Formation, Clackmannan Group) within the lavas of the Bathgate Hills Volcanic Formation. Well-preserved lime kilns can be seen near Wairdlaw Farm.

WLGS 22 UNION CANAL MUSEUM [NT 0036 7692]

The Union Canal Museum in Linlithgow exhibits records, photographs and artefacts associated with the Union Canal. It is housed in a former canal stable situated on lavas and tuffs of the Bathgate Hills Volcanic Formation.

3.4.5 Clackmannan Group rocks

The Clackmannan Group is characterised by strongly cyclical sequences of sandstone, siltstone, mudstone, limestone, coal and seatearth. It includes the Lower Limestone, Limestone Coal, Upper Limestone and Passage formations.

Outcrops of Clackmannan Group rocks comprise approximately 8,276 hectares, or 19.2% of the surface area of West Lothian. They crop out in a north–south strip from north-east of Linlithgow to the Gladsmuir Hills in the south-west corner of the district (Figure 74).

These units are the presence (or absence especially of limestone) and proportions differing in each of the formations. Thus, beds of limestone are more conspicuous in the Lower and Upper Limestone formations than elsewhere, coals are most common in the Limestone Coal Formation, and sandstones and seatearths are the most prominent constituents of the Passage Formation. Depositional environments, likewise, show an underlying similarity, being related to the repeated advance and retreat of fluviodeltaic systems into an embayment of varying salinity. Scotland during the Namurian and succeeding Westphalian was located more or less on the Equator. Its climate was essentially tropical with extensive swampy forests (mires and 'mangrove' swamps) rapidly producing large trees that subsequently died to produce great thicknesses of peat that with time and deep burial became transformed into coal. The Lower and Upper Limestone formations contain the highest proportion of marine deposits, while alluvial deposits dominate the Passage Formation; the Limestone Coal Formation occupies an intermediate position. The base of the Clackmannan Group is taken at the base of the Lower Limestone Formation, where a cyclical sequence of marine limestone-bearing strata rests conformably on the West Lothian Oil-shale Formation of the Strathclyde Group. This group is mostly Namurian in age .

The **Lower Limestone Formation** comprises repeated upward-coarsening cycles of limestone, mudstone, siltstone and sandstone. Thin beds of seatrock and coal may cap the cycles. The limestone beds are fossiliferous and pale to dark grey in colour, most were deposited in a tropical marine environment. The mudstone (which may also contain marine fossils) and siltstone are predominantly grey to black. A few non-marine faunal beds are also known. Nodular clayband ironstone and limestone are well developed in the mudstone sequences. The Hurlet Limestone defining the base of the formation, the Inchinnan Limestone, the Blackhall Limestone, the Main, Mid and Second Hosie limestones and, defining the top of the formation, the Top Hosie Limestone. The thickness of the formation is not well constrained but in the range of 100 to 200 m. In the Bathgate Hills the formation is interbedded with and replaced by basaltic tuffs and lava flows of the the Bathgate Hills Volcanic Formation and the key limestone horizons are more diffficult to identify, may be undeveloped or be fused together.

The marine bioclastic limestone exposed at Wairdlaw [NS 994 731] appears to be isolated within the Bathgate Hills Volcanic Formation.

The **Limestone Coal Formation** comprises sandstone, siltstone and mudstone in repeated cycles. The majority coarsen upwards, but others fine upwards. The cycles are usually capped by seatearth and coal (3-10% of the total succession). The siltstone and mudstone are usually grey to black, while the sandstone is usually fine- to medium-grained and off-white to grey.

The **Upper Limestone Formation** is characterised by repeated upward-coarsening cycles comprising grey limestone overlain by grey to black mudstones and calcareous mudstones, siltstones and paler sandstones capped by seatrocks and coal. The main limestones are the Index, Orchard, Calmy and Castlecary limestones. A persistent development of lavas, up to 40 m thick, is present between Kipps Hill [NS 986 738] and Bathgate. Some of the flows on Kipps Hill are very fresh glassy basanites with well-developed columnar jointing. The youngest recorded volcanic activity in the district occurs above the Castlecary Limestone in the base of the Passage Formation.

The **Passage Formation** is characterised by an alternation of fine- to coarse-grained sandstones (with some conglomerates) and structureless clayrocks (including some high-alumina seatclay and fireclay). The petrography and provenance of the Passage Formation sandstones has been studied. These sandstones were derived from a low-grade metamorphic source intruded by acid igneous masses comparable to the Upper Dalradian rocks of the Highlands. A sandstone in the lower part of the formation at Leven Seat [NS 943 580] has been worked for many years as a silica sand and used for moulding sand and several other non-industrial uses. A thin bed of tuffaceous siltstone close above the Castlecary Limestone has been recorded north-west of Torphichen [NS 967 723]. This is believed to be the highest stratigraphical level at which the Bathgate Hills Volcanic Formation occurs.

3.4.5.1 INFLUENCE ON BIODIVERSITY

Like the Strathclyde Group, the rocks of the Clackmannan Group rocks are predominately glacial till covered, though a belt of fluvioglacial sand and gravel runs from the north-west around Westfield south-eastwards to Bathgate, and around Boghall in the north of the district. Also, much of the till is peat covered along the boundary with south Lanarkshire in the south-west. The resulting soils are very variable with drainage status varying from free to very poor, with non-calcareous gleys, peaty-gleys, brown forest soils with gleying and brown forest soils predominating. The topography is also variable with the Bathgate Hills in the north, the flatter ground of the Almond Valley in the middle and the upland fringe moorland in the south. Urban areas and agriculture are the main land uses for most of the area, with forestry predominating south of the A71.

The area has less AWI and SNWI woodland than the Strathclyde Group to the east, but has three Listed Wildlife Sites and 12 Wildlife Sites (1993).

3.4.5.2 WEST LOTHIAN GEODIVERSITY SITES

The Clackmannan Group is well represented by good-quality geodiversity sites (Figure 74).

WLGS 23 Levenseat working Quarry (Proposed RIGS) [NS 940 575] (Figures 75–77)

Levenseat quarry is the last remaining full-time operating quarry in West Lothian. It is owned by WBB Minerals and produces silica sand used mainly for rootzone and top dessing material for sports fields and golf courses. Planning permission has been granted to extend the quarry by 12 hectares to the west of current operations. The quarry manager reported that the quarry faces adjacent to the access road at Levenseat working quarry and Levenseat working quarry 2 will be retained and will be available for conservation once the quarry ceases operation. The faces show excellent examples of Passage Formation stratigraphy and sedimentology.

WLGS 24 Levenseat quarries and mines [NS 9547 5799] (Figures 78–80)

A line of old quarries delineate the outcrop of the Castlecary Limestone (Upper Limestone Formation) a few hundred metres to the east of the current working quarry at Levenseat. Several mines entrances can be seen, just west of the public footpath between Leven Seat and Fauldhouse. Part of Levenseat Quarry immediately west of Leven Seat hill is now used as a landfill site (Figure 80) and the surrounding area is disfigured with much wind-blown plastic rubbish.

WLGS 25 Skolie Burn (Mixed SSSI, Proposed RIGS) [NS 984 619 – NS 987 624] (Figures 81–84)

Skolie Burn, a tributary of the Breich Water south of Stoneyburn, provides the best section of the upper part of the Lower Limestone Formation and the basal beds of the Limestone Coal Formation on the eastern side of the central coalfield of the Midland Valley. The section lies above an intrusive picrite sill (alkali-dolerite) and the basal beds are baked at the contact with the sill. The 20 m thick sequence dips to the west and is and dominated by mudstone with several beds of sandstone and at least three marine limestones. The sequence is fossiliferous and these fossils are of vital stratigraphical importance in correlating late Dinantian and early Silesian rocks of the Midland Valley. Skolie Burn is a GCR (Dinantian of Scotland) site.

WLGS 26 Petershill Quarries (Mixed SSSI, RIGS) [NS 9849 6952] (Figures 84–88)

Petershill Quarries are located in the Bathgate Hills about 1 km north-east of Bathgate and show a sequence of bedded and slightly argillaceous limestones through the Petershill Limestone of the Lower Limestone Formation. The limestone is a classic locality famous for its well-preserved marine fossils including corals, brachiopods, bivalves and echinoids. These faunas are of immense taxonomic significance, and many type species have been described from this location. A quiet sedimentary environment is indicated by the good fossil preservation. The lateral and vertical facies variations of the Petershill Limestone are of great interest to carbonate sedimentologists and palaeoecologists. Massive limestones (biohermal buildup) occur at the southern end of the quarry. Petershill Quarries are well-known and a lot of material has been removed in the past by fossil collectors. The site is a GCR (Dinantian of Scotland) site.

WLGS 27 RIFLE RANGE QUARRIES (MIXED SSSI, PROPOSED RIGS) [NS 9890 7087] (FIGURES 89–92)

These quarries are situated approximately 1 km north-north-east of Petershill Quarries and south-west of The Knock. They also expose the Petershill Limestone of the Lower Limestone Formation, though a more nearshore and turbulent environment is interpreted, as the fauna is not as well-preserved as in the Petershill Quarries. The site is a GCR (Dinantian of Scotland) site.

WLGS 28 AND WLGS 29 HILDERSTON SILVER MINE QUARRY (PROPOSED RIGS) [NS 9908 7135] AND SILVER MINE [NS 9917 7158] (FIGURES 93–99)

These sites are located north-north-east of The Knock and approximately 500 m south-east of Cairnpapple Hill. Native silver occurs in a vein on the margin of a thin east–west trending dolerite dyke which cuts sandstones and siltstones above the Petershill Limestone. The mine was in operation between 1606 and 1614, then reopened in the 18th century to work lead and zinc in a vein in the Petershill Limestone. The original workings were re-excavated during the 19th century, but no further economic deposits of silver or lead were found. Although the Petershill Limestone is no longer visible in the Silver Mine Quarry, a 3–4 m section through the overlying mudstones, siltstones and sandstones sediments is seen (Figure 96). These display an excellent coarsening upward sequence with good sedimentary structures, including ripples and burrowing (Figure 97). There is no exposure left at the Hilderston Silver Mine site, although spoil heaps may still reveal some interesting minerals from the silver-lead-zinc mining.

WLGS 30 HILLHOUSE QUARRY AND MINE (PROPOSED RIGS) [NT 0040 7487] (FIGURES 100–104)

This site is located within the Beecraigs Country Park three km south of Linlithgow. The Hillhouse Limestone (Lower Limestone Formation) has been worked by both underground and surface methods. The 9 to 12 m thick massive and fossiliferous limestone dips to the west at 30 – 40^0 with consequent steep stoop and room workings, some of which have collapsed recently leading to subsidence in the overlying road. The limestone is overlain by a sill of basalt with columnar jointing – this is the type locality of the Hillhouse type of olivine-basalt in the 1928 MacGregor basalt classification.

WLGS 31 MUIRAVONSIDE, CARRIBER GLEN (PROPOSED RIGS) [NS 9690 7518]

This site was not visited, but the Calmy Limestone (Upper Limestone Formation) was formerly mined in several quarries south of the River Avon in Carriber Glen.

WLGS 32 WALLACE'S ARCH (PROPOSED RIGS) [NS 9459 7305] (FIGURES 105, 106)

Wallace's Arch is an excellent example of a natural arch landform, which can be walked under safely. The arch is formed from Passage Formation sandstone and is situated on the south bank of the River Avon about 2 km north-west of Torphichen. It is on the River Avon Heritage Trail.

3.4.6 Coal Measures (Scotland) Group rocks

The Coal Measures Group (Scotland) is sub-divided into three formations; Upper, Middle and Lower. Only the Lower Coal Measures and, to a minor extent, the Middle Coal Measures are represented in West Lothian. The Group comprises sandstones, siltstones and mudstones with coal and seatearth. Outcrops of Coal Measures (Scotland) Group rocks comprise approximately 5,029 hectares, or 11.7% of the surface area of West Lothian. They crop out in the westernmost part of the district from Westfield in the north to Fauldhouse in the south (Figure 107).

The Coal Measures were deposited in a warm and humid climate and palaeomagnetic evidence indicates that, at that time, the area lay in equatorial latitudes. The strata are believed to have been deposited in delta-plain and alluvial-plain environments with drainage generally from a large continental area to the north. The sediments accumulated under conditions of continuous but non-uniform subsidence modified by eustatic (ice age driven) changes in sea level. Periodic brief incursions by the sea left important marine horizons which are the basis of the subdivision of the succession. A wide range of alluvial and lacustrine environments of deposition is represented. These include tropical wetland forested mires and soils (coal and seatearth), floodplain (planty or rooted siltstone and mudstone), river and delta distributary channel (thick sandstones), prograding deltas (upward-coarsening sequences) and shallow lakes (mudstones with non-marine faunas). Marine bands are rare but provide important stratigraphical markers.

The **Lower and Middle Coal Measures** comprise sandstone, siltstone and mudstone in repeated cycles commonly 8-12 m thick which most commonly coarsen upwards, but also fine upwards, with seatearth and coal at the top. The mudstone and siltstone are usually grey to black, while the sandstone is fine- to medium-grained and off-white to grey in colour. Coal seams are common and many exceed 0.3 m in thickness amounting cumulatively to 5% – 8% of the total succession.

There are more than 11 seams that have been mined in the Lower Coal Measures. The main seams formerly mined are the Colinburn, Armadale Main, Armadale Ball, Mill, Shotts Gas, Lower Drumgray, Mid Drumgray, Upper Drumgray, Kiltongue, Ladygrange and Airdrie Virtuewell coals. Middle Coal Measures are restricted to a small area west of Fauldhouse where the Airdrie Blackband Coal may have been mined. These seams have been exploited recently in opencast sites. The Lower Coal Measures are over 150 m thick.

3.4.6.1 INFLUENCE ON BIODIVERSITY

Coal Measures Group rocks are almost entirely covered by glacial till, though some of this has been subsequently stripped off in open-cast mined areas. In other areas the till is covered by colliery tips and by peat deposits, particularly in the south and west. . The resulting soils are of variable with drainage status varying from imperfect to very poor, with non-calcareous gleys, peaty-gleys, deep peat and brown forest soils with gleying predominating. The topography is almost entirely lowland plateaux. Forestry, agriculture and urban (Armadale and Fauldhouse) are the main land uses, with forestry predominating south of the A71.

The area has less AWI and SNWI woodland than the Strathclyde Group to the east, but has three Listed Wildlife Sites and 12 Wildlife Sites (1993) where biodiversity is likely to be greater.

3.4.6.2 WEST LOTHIAN GEODIVERSITY SITES

No geodiversity sites of significant value were found in the Coal Measures Group. Most of the sites mentioned in the earlier literature are quarries or mines that have since been infilled or are no longer accessible. BGS would welcome any development or extraction activities that exposed and allowed the preservation of representative Coal Measures sections.

BRAEHEAD QUARRIES [NS 9205 6055] (FIGURE 108)

Braehead Quarry [NS 9205 6055] west of Fauldhouse was a former building stone quarry working Lower Coal Measures sandstone. The quarry, closed in 1939 and is now filled in and partially landscaped. No rock sections are currently exposed. Stone from the quarry was used to build Edinburgh villas in Mayfield Road, Esslemont Road, Ross Road, Grange Loan, Midmar Drive and Comiston Drive. Note this locality is not a WLGS.

WLGS 33 AND WLGS 34 BARBAUCHLAW QUARRIES [NS 9871 6240] AND BARBAUCHLAW BURN QUARRIES [NS 9290 6907]

Neither of these sites west of Armadale was visited but the Coalfield memoir indicates that 10 m thick section of sandstones above Mill Coal (Lower Coal Measures) was formerly quarried here. It is recommended that these sites are visited when the opportunity arises.

3.4.7 Volcanic vent rocks

Outcrops of volcanic vents rocks comprise approximately 120 hectares, or 0.3% of the surface area of West Lothian. About 20 plugs and vents crop out as isolated subcircular areas in the northern part of the district (Figure 109). Only two sites were visited – Carsie Hill and Society East Shore 8, but other potential geodiversity sites occur at Niddry Castle, Tar Hill, Pilgrim's Hill and Binn's Hill.

There are about 20 vents in West Lothian representing the subterranean plumbing of Lower Carboniferous volcanoes. These cylindrical to ellipsoidal shaped pipes are between 100 m and 1000 m across (greatest axis) and usually infilled with massive to poorly stratified, greenish-grey, coarse, basaltic volcaniclastic and sedimentary detritus (pyroclastic agglomerate) and are therefore vents. The largest vent is at The Binns and this is associated with two integral small plugs of olivine basalt. The next largest is Tar Hill and the most complex set is at Parkley Fisheries associated with two plugs of basalt and a late Carboniferous Quartz-dolerite dyke.

3.4.7.1 INFLUENCE ON BIODIVERSITY

The hard pyroclastic breccias and basalts of the volancic vents are more resistant than the surrounding sedimentary rocks of the West Lothian Oil-shale Formation and mostly form hills or prominent features in the landscape, e.g. Tar Hill, Carsie Hill, Jock's Hill, Peet Hill, Pilgrim's Hill and Binns Hill. These hills are mostly till-free and the predominant soil type is the free-draining brown forest soil. Land use on these hill is mostly rough grazing with a relatively limited biodiversity, though Binns Hill and the Society East Shore vents have more varied habitats in the form of AWI woodlands.

3.4.7.2 WEST LOTHIAN GEODIVERSITY SITES

Given the very limited coverage of volcanic vents, the two sites described below are considered to adequately represent these rocks. Permission was refused to visit Tar Hill and Niddry Castle (see 4.3).

WLGS 35 CARSIE HILL [NT 0150 7547] (FIGURES 110, 111)

Carsie Hill, 1.5 km south-east of Linlithgow, is one of the best examples of the dozen or so scattered volcanic vents in this area. The hill is also a good example of an ice-sculpted Crag and Tail landform (Figure 110). Outcrops of Pyroclastic breccia can be seen around the crag end of the hill. Further to the east small exposures of the Mid Hosie Limestone (Lower Limestone Formation) containing the coral *Siphonodendron junceum* are also seen.

WLGS 13 SOCIETY EAST SHORE 8 [NT 1021 7886] (FIGURES 112, 113)

Pyroclastic breccia from a vent centred on East Lodge outcrops just below the High Water Mark around 200 m south-east of Society Point. The vent intrudes the Binny Sandstone of the West Lothian Oil-shale Formation.

3.4.8 Alkali-dolerite sills

Alkali-dolerite sills comprise approximately 1,268 hectares, or 2.9% of the surface area of West Lothian. They outcrop principally in the east of the district and mainly intrude Strathclyde Group rocks (Figure 114).

Sills of alkali-dolerite generally occur in the eastern part of the district. They intrude the Lower Carboniferous sedimentary succession of the Strathclyde Group stratigraphically mainly below the Bathgate Group volcanic rocks of the Bathgate Hills. These dolerites are generally medium to fine-grained and of olivine-basalt composition. They are similar petrographically and compositionally to the lavas of the Bathgate Hills and could be coeval with them.

3.4.8.1 INFLUENCE ON BIODIVERSITY

The alkali-dolerite sills are variable in their topographic expression. Most are intruded into Strathclyde Group rocks and have little or no impact on landform and are till-covered, except the Auchnoon Sill which forms the till-free Auchinoon Hill. The sills intruding the Inverclyde Group between the Linhouse Water and Kirknewton also form positive landforms – Selms Top [NT 089 658], Hallcraigs [NT 106 667] and the Linhouse Water – Glasgow Viaduct 2 locality sill (Figure 120). These till-free sill have developed mainly brown forest, peaty gleys and peaty podzol soils with drainage varying from free to imperfect. As might be expected, the till covered sills develop mainly non-calcareous gleys and gleyed brown forest soils. The largest sill outcrops under the urban area of Livingston. On the other sills, land use is variable, but rough pasture predominates.

3.4.8.2 WEST LOTHIAN GEODIVERSITY SITES

Given the very limited coverage of alkali-dolerite sills, the three sites described below are considered to adequately represent these rocks.

WLGS 36 AUCHINOON QUARRY (PROPOSED RIGS) [NT 0919 6175] (FIGURES 115–119)

Auchinoon Quarry is situated beside the A70 north of Harperrig Reservoir. The site is an excellent example of a dolerite sill and the best example of contact metamorphism in West Lothian. In the quarry face the sill intrudes laminated siltstones of the Gullane Formation − for approximately 2 m above the contact the siltstones have been thermally altered to calcsilicate hornfels. Unmetamorphosed siltstones can be seen above the hornfels in the east side of the quarry. The southern top of Auchinoon Hill, about 200 m north-north-west of the quarry, is a good viewpoint for Pentland Hills.

WLGS 37 LINHOUSE WATER – GLASGOW VIADUCT 2 [NT 0772 6562] (FIGURE 120)

At this locality the Dalmahoy Sill is well-exposed in the north-east bank of the Linhouse Water around 200 m upstream from the railway viaduct east of Oakbank. The sill forms a prominent cliff above the river and marked ridge in the hillside above. The base contact may be exposed but the cliff section is inaccessible and can only be viewed from the opposite river bank.

WLGS 17 HOPETOUN SHORE 2 (PROPOSED RIGS) [NT 0932 7918] (FIGURE 121)

A teschenitic dolerite sill intruded into the Calders Member of the West Lothian Oil-shale Formation outcrops on the Hopetoun foreshore 450 m north-east of Hopetoun House [NT 0932 7918]. The Calders Member at this locality forms the core of the Hopetoun anticline.

3.4.9 Quartz-dolerite sills

Quartz-dolerite (and Quartz-tholeiite) has been intruded into the Carboniferous sedimentary and volcanic strata of West Lothian both as sills and as dykes.

Quartz-dolerite sills comprise approximately 1,949 hectares, or 4.5% of the surface area of West Lothian. They crop out in the north and north-west part of the district (Figure 122).

The quartz-dolerite sills of West Lothian form part of the south-western margin of the Midland Valley Sill Complex. The outcrop of this major sill is imperfectly annular and characteristically dips inward towards the centre of the carboniferous sedimentary basin. It forms part of a major suite of high-level tholeiitic intrusions extending throughout Scotland and into the North Sea. On the basis of radiometric dates of 302 to 297 Ma, the suite is generally accepted as being of late Westphalian to Stephanian age.

3.4.9.1 INFLUENCE ON BIODIVERSITY

Unlike the alkali-dolerite sills, most quartz-dolerite sills have a distinct landform expression, normally foming distinct areas of higher ground e.g. the ridge from Eastcraigs Hill to Gowanbank north-west of Armadale, Tophichen Hills, The Knock, Cockleroy and Binny Craig. Soil types are very variable on the sill outcrops, but poorly-drained non-calcareous gleys dominate the till covered parts and free to imperfectly-drained brown forest soils and soil complexes are most common on the till-free hill tops and slopes. Agriculture, particularly rough pasture is the main land use on the quartz-dolerite sill areas. Like the Bathgate Group, the hilly topography with its variable microclimate and variety of soil types and drainage status has probably resulted in a wide variety of habitats and consequent relatively high biodiversity.

3.4.9.2 WEST LOTHIAN GEODIVERSITY SITES

Given the limited coverage of quartz-dolerite sill rocks, the sites described below are considered to well represent the geodiversity of these rocks.

WLGS 38 THE KNOCK (PROPOSED RIGS) [NS 9906 7114] (FIGURES 123–127)

The rocky knoll of The Knock, 200 m south of Hilderston Silvermines quarry, is formed by a steep east-north-east dipping quartz-dolerite sill intruding basalt lavas of the Bathgate Hills Volcanic Formation and sedimentary rocks of the Lower Limestone Formation. Sphaeroidally-weathered dolerite can be seen on the slopes of hill (Figure 126). The summit of the hill (altitude 305 m) is an excellent viewpoint (Figure 123), with an indicator cairn listing the visible hills. The Knock is also a glacially-sculpted Crag and Tail.

WLGS 39 WITCH CRAIG WALL AND VIEWPOINT (RIGS) [NS 9908 7275] (FIGURES 128–132)

Witch Craig Viewpoint is situated above Witch Craig Wood and about 1 km north-east of Cairnpapple Hill. Access is by a path from the car park at the Scottish Korean War Memorial. On the summit a stone shelter (Figures 128, 129) incorporates 43 rock specimens from locations visible from this site, bringing the geodiversity across the Midland Valley to this one place (Figure 130). The site is a current RIGS site with a RIGS leaflet explaining the stones gathered at the shelter. There is a 'refuge stone' at [NS 9910 7273]. This is one of a number of stones that formed a circle at a distance of a mile around Torphichen Preceptory. All of the space within the circle formed by these stones formed a legal church sanctuary.

WLGS 40 COCKLEROY(PROPOSED RIGS) [NS 9894 7437] (FIGURES 133–136)

Cockleroy is a well known viewpoint across the Midland Valley situated immediately north-west of the Beecraigs Country Park. The hill is composed of Bathgate Hills Volcanic Formation basalts intruded by a quartz-dolerite sill. A park leaflet mentions a detour to the summit of Cockleroy but does not mention any geology or landforms. The Bronze Age hilltop fort known as Wallace’s Bed is a Scheduled Ancient Monument and a stone arrowhead has been found on the summit.

WLGS 41 BEECRAIGS QUARRY (PROPOSED RIGS) [NT 0080 7390] (FIGURES 137–139)

Beecraigs Quarry is situated in the south-east corner of Beecraigs Country Park. It shows a good section through an east–west trending quartz-dolerite dyke displaying fresh material and horizontal columnar jointing. The fine-grained margin of the dyke can be seen beside the ladder. The quarry is currently used as an outdoor climbing wall and the exposures are easily accessible and safe (no loose material). Existing park leaflets do not mention geology. A dry stone dyke lining the road is made of quartz-dolerite.

WLGS 42 BINNY CRAIG (RIGS) [NT 0432 7346] (FIGURES 140–143)

Binny Craig is a prominent landmark situated in the grounds of Oatridge Agricultural College at Ecclesmachan, north-west of Broxburn. It is best known for being a spectacular example of a Crag and Tail landform. The 'Crag' is formed from the Binny Craig Sill, a fine-grained quartz-dolerite (strictly a basalt) sill which has intruded the West Lothian Oil-shale Formation. The sill dips at 25^0 to the east and forms the cliffs on the west side of the hill and the dip slope to the east. Outrops of the basalt are extensive and display some columnar jointing (Figure 141) and exposures of the baked oil-shales also occur (Figure 143). On a clear day the summit (altitude 220 m) affords an excellent panorama from the Lammermuir Hills and Culter Fell in the south-east through to Ben Lomond and other Highland hill to the north-west.There is a RIGS leaflet which describes the landform, geology and other natural history features of the site.

WLGS 43 KILDIMMERY FISHERY QUARRY [NT 0220 7603] (FIGURES 144, 145)

Good exposures of an east–west trending quartz-dolerite dyke occur in the Kildimmery Fishery Quarry, on the north side of Nancy's Hill, 2 km south-east of Linlithgow. The quarry is now flooded and used as a fishery. Floating trackway up the middle of the quarry allows good viewing of the quarry faces. The Quarry was still being worked in the 1930's. The dyke intruded a volcanic vent of pyroclastic breccia and several of the hills nearby such as Jock's Hill, Peet Hill and Carsie Hill (WLGS 35) are also vent landforms.

WLGS 44 CRAIGTON (HILL) QUARRY [NT 0761 7684]

Craigton (Hill) Quarry lies 2 km north-west of Winchburgh and adjacent to the M9 motorway. Permission to visit this site was denied by the Hopetoun Estate Factor, but a previous visit indicates that it provides an excellent example of a 33 m thick quartz-dolerite sill with stepped contacts.

WLGS 45 LINHOUSE WATER – CALDERWOOD 1 [NT 0790 6705] (FIGURE 146)

At this locality in the Linhouse Water between Mid and East Calder, a quartz-dolerite dyke intruding the Gullane Formation forms a small (~1 m), but obvious waterfall in the river.

3.4.10 Quaternary deposits, landscapes and soils

During the Main Late Devensian glaciation a vast stream of ice flowed in a general eastward direction through the Midland Valley and out to sea via the Forth estuary. It is believed that this ice extended as far as 60 km beyond the mouth of the Firth of Forth into the North Sea. Initially, the primary source for this stream was ice accumulation centred in the north, from which ice flowed over the Ochil Hills and into the southern Midland Valley. As the Devensian glaciation progressed, however, the Southern Uplands also became a dominant source area, and ice was pushed in a north-easterly direction into the Forth estuary. The processes that occurred during this glacial episode, and since then, have had a significant influence on shaping the character of West Lothian's landscape.

Quaternary superficial deposits cover approximately 43,098 hectares, or 91.7% of the surface area of West Lothian (Figure 4).

Using the NEXTMap Britain shaded-relief Digital Surface Model (Figure 8) and the BGS DiGMapGB-50 superficial deposits theme, West Lothian's landscape can be divided up into a series of broad domains (Figure 147):

3.4.10.1 CRAG AND TAIL TOPOGRAPHY

The crag-and-tail topography is pronounced in the vicinity of the Bathgate Hills, where outcrops of resistant igneous rocks have withstood the erosive power of successive Quaternary ice sheets.

These outcrops, formed of Carboniferous basaltic lavas (Bathgate hills) and intrusive laccoliths and sills (Binny Craig, for example), have left a protected 'tail' of softer rock and sediment on their lee (down ice) side (Figures 140, 141, 148). The resulting topography is a prime indicator of the eastwards direction of ice flow in the West Lothian area during Quaternary glacial episodes.

As ice overrode this more elevated part of the landscape, pressurised subglacial meltwater was forced up and over the outcrops of igneous rocks. This is well illustrated at Torphichen Hill where meltwater has exploited weaknesses along faults in the quartz-dolerite sill, incising deep channels over the high ground (Figure 149).

3.4.10.2 Till Covered Lowland

Till is the material that is laid down beneath a glacier. It is present over much of the surface of West Lothian's lower lying terrain and in places exceeds 50 m in thickness. Tills tend to be an unstratified, heterogeneous mixture composed of a clay, silt or sand matrix supporting a variety of larger clasts ranging from pebbles to boulders. The stones contained in this mixture can give an indication of the source of the ice, and the route it took, before depositing material. In addition to local Carboniferous rocks (e.g. limestones, sandstones, siltstones, mudstones and basalts), tills in West Lothian contain porphyrites from the Ochil Hills and schists from the Grampian Mountains beyond. These exotic clasts indicate a general northern source for much of the ice that last overrode West Lothian. Clasts of red felsite derived from Tinto Hill in Lanarkshire, however, have been found near Calder House in Mid Calder, revealing the increasing influence of ice from a southern source during later stages of the Devensian glaciation.

Much of the till covered lowland in West Lothian is gently undulating. A number of dry gullies and over-deepened stream beds exist as a result of meltwater from retreating ice cutting through the till. In western West Lothian, near Blackridge, some subglacial streamlining of till is evident in the form of gentle southwest – northeast aligned ridges. These 'drumlin' features lie on the outskirts of a more pronounced drumlin zone, which lies farther to the west (Figure 150). Such elongated landforms are the result of powerful, rapidly flowing ice moving over soft deformable materials.

3.4.10.3 Glaciofluvial Sand and Gravel Belts

During deglaciation, higher ground in the district became ice-free first, leaving lobes of retreating ice in the lower lying areas. Fast flowing meltwater from this decaying ice was centred along major east – west trending belts, depositing sands and gravels while washing out finer silts and clays. The meltwater systems of this time are clearly seen to have been deflected around the Bathgate Hills. In places, moundy terrain is observed indicating the deposition of sediments into local pockets amongst the stagnating ice. Elsewhere, hollows have developed where detached blocks of ice were surrounded and buried by sands and gravels deposited by the meltwater. Subsequent melting of these ice blocks has left depressions in the land, referred to as 'kettle holes'. Linlithgow Loch, lying in a hollow bounded by high ground to the north and south, provides a large example of a kettle hole. While this hollow was choked by stagnating ice and glacial deposits, it is likely that meltwater was diverted northwest along the course of the present River Avon.

3.4.10.4 Upland, Streamlined

The upland, streamlined domain includes areas of higher ground that lie on the fringes of hills and plateaus to the south. When viewed from above, a degree of streamlining is evident, indicating that the overriding ice was still thick enough and moving fast enough to modify the underlying terrain. Ice moulding of bedrock is evident in areas such as Leven Seat where the underlying sedimentary rocks are shaped in alignment with ice direction (Figure 151). The streamlined upland landscape is also evident on areas underlain with harder bedrock, such as Corston and Auchinoon Hills (Figure 115).

3.4.10.5 UPLAND, LIMITED MODIFICATION

Lying at the margins of the Pentland Hills, these upland areas have experienced significantly less glacial modification than the lower lying landscape which lay within the main ice flow path. Rising up to 550 metres, the ground here will have supported a thinner, slower moving cover of ice, with a reduced capability to erode and modify the landscape. Although till is present in the Pentlands, it is thin and patchy compared to lower lying ground. Accumulations of coarse, angular clasts, derived from frost shattering and solifluction also occur here as a legacy of the cold conditions that persisted for a period following ice retreat from the Pentlands.

3.4.10.6 RAISED BEACH

Raised beaches comprise material, originally deposited in a coastal environment, which has since been elevated due to falling sea-level or uplifting land. In West Lothian raised beach deposits (Figure 152) occur as a result of glacio-isostatic uplift following the removal of ice overburden at the end of the Devensian glaciation. The deposits are primarily composed of sands, but also contain gravels and muds. They are found as areas of flat land or terraces bordering the Forth estuary.

3.4.10.7 MODERN BEACH

The modern beach can be defined as the area lying between the present low- and high-water marks, alternately covered by water and exposed to air during tidal cycles. In West Lothian the modern beach area comprises outcrops of bedrock and deposits ranging from cobbles through to silt. The most dominant deposit, however, is fine sand transported by river systems entering the Forth estuary (Figure 53).

3.4.10.8 ALLUVIUM

Alluvium is material deposited by a river. In West Lothian it is usually occurs as relatively flat ground lying adjacent to river systems that have been operating during the Holocene. Sediments can comprise clays, silts, sands and gravels depending on the velocity of water at the time of deposition. In upland areas, where river velocity is higher, larger pebbles and cobbles may be present, however, lowland alluvial deposits tend to contain finer sediments. In West Lothian most alluvial deposits have a high sand and clay content.

3.4.10.9 INFLUENCE OF QUATERNARY LANDSCAPE ON SOILS AND VEGETATION IN WEST LOTHIAN

Due to their direct superposition, soils and vegetation are heavily influenced by the characteristics of the Quaternary landscape.

Much of West Lothian falls within the till covered lowland domain. The high clay content and highly consolidated nature of this deposit has resulted in the formation of soils that are very slowly permeable to moisture. Brown forest soils with gleying, and peaty gleys predominate here, supporting grassland and rush pastures over undulating low ground. Where terrain is slightly higher and steeper, areas of moist Atlantic heather moor and blanket bog occur. Without drainage treatment, arable crops over much of the till covered lowland would likely be limited to those with a short growing season.

The crag and tail domain supports similar soils to the till covered lowland, with brown forest soils with gleying and peaty gleys commonly occurring. This is to be expected as crag and tail lee sides tend to support a till cover. The main difference between the domains is the soil parent material, with stones of basaltic rock having a greater presence in this domain.

The coarse nature of glaciofluvial sands and gravels have allowed the development of more freely draining brown forest soils and brown forest soils with gleying. Under natural conditions, such areas would have formerly supported broad leaved woodland. Soils in this domain now form prime agricultural land with few limitations to sustained agricultural use. Even under high rainfall, the soil can be readily cultivated.

Like glaciofluvial deposits, the sandy raised beach deposits lend themselves well to the development of freely draining soils. Brown forest soils and brown forest soils with gleying also occur here providing good agricultural land.

Soils in the upland areas develop on thin covers of till, or thin sandy stony slope deposits. With higher precipitation and lower temperatures, soils tend to be peaty podzols and humus-iron podzols with some gleys and peat. Hilltops and gentle slopes can carry blanket peat while gleys occupy slope bases. The uplands support a semi-natural habitat with Atlantic heather moor communities and flying bent grassland.

Alluvial soils in West Lothian tend to have a high clay content and are therefore relatively poorly drained. Soils are young and tend to be mineral alluvial soils or peaty alluvial soils where water logging occurs.

3.4.10.10 WEST LOTHIAN GEODIVERSITY SITES

WLGS 1 Baad Park Burn [NT 1125 6014] (Figure 15)

A section in the Ballagan Formation is capped by about 1 m of glacial till.

WLGS 42 Binny Craig [NT 0432 7346] (Figures 140–142, 148)

See section 3.4.9.2

WLGS 46 Torphichen Hills [NS 975 725] (Figure 149)

Excellent examples of glacial meltwater channels occur on the Torphichen Hill and Gormyre Hills. Glacial meltwater has exploited weaknesses along faults in the quartz-dolerite sill, incising deep channels over the high ground. The remains of a fort on the southernmost hill are a Scheduled Ancient Monument.

WLGS 47 Linlithow Loch [NT 004 776] (Figure 153)

Linlithgow Loch is a very large kettle hole formed by the melting of a large detached mass of ice trapped within glacial deposits.

WLGS 18 Abercorn Point [NT 083 795] (Figure 152, 154)

Post-glacial cemented raised beach deposits can be seen above the modern beach at Abercorn Point 2 [NT 0835 7952]. A large glacial erratic can be seen just below the High Water Mark at Abercorn Point 3 [NT 0827 7954].

WLGS 48 Tailend Moss (Proposed RIGS) [NT 009 678]

This site on the western outskirts of Livingston is one of the few remaining examples of raised bogs in West Lothian, though it has suffered damage by peat cutting and mining subsidence. It is a Scottish Wildlife Trust (SWT) Reserve and home to one of the few remaining populations of Water Voles in West Lothian.

WLGS 49 Longridge Moss (Proposed RIGS) [NS 958 620]

This relatively large raised bog is surrounded by many wildlife-rich habitats. It is a SWT Reserve and also home to one of the few remaining populations of Water Voles in West Lothian.

WLGS 50 Easter Inch Moss [NT 001 667] (Figures 155–158)

This site 3 km south-east of Bathgate and adjacent to Seafield Law is a good example of a lowland raised bog. There is some evidence of damage from past domestic peat cutting. Easter Inch Moss is 500 m west of Seafield Law (WLGS 6) [NT 005 667].

WLGS 51 Calder Wood (RIGS) [NT 076 664]

Active landslip activity in glacial till can be seen at this locality on the Linhouse Water south-east of Livingston. The site is within the Almondell and Calder Wood Country Park, is an AGLV and a Listed Wildlife Site, a biological SSSI and has AWI and SNWI woodlands. Around 430 m upstream from this locality there is a section in the river bank [NT 0734 6613] comprising a soil profile on terraced river gravels overlying glacial till. The locality is also an area of active river erosion and depositional processes (Figures 159)

4 West Lothian Geodiversity Action Plan (WLGAP)

4.1 INTRODUCTION

The Geodiversity Audit described in Chapter 3 reviewed the component elements of West Lothian's geodiversity, and its relevance to other interests, at local, regional, national and international levels. It was undertaken as a means of informing the framing of recommendations and action points designed to guide the sustainable management, planning, conservation and interpretation of all aspects of the earth science heritage of West Lothian.

The audit included evaluations of 122 sites and features of geological and landscape importance in West Lothian, four of which are currently protected nationally as SSSIs and six protected locally as RIGS. The list of 51 WLGSs (Table 2) selected expands these list of important sites to provide much better coverage at the local level.

A draft West Lothian Geodiversity Action Plan (WLGAP) has been prepared (Table 3). The WLGAP will require targeted consultation among partners to agree objectives, actions and timescales.

4.2 AIMS

The main objectives of the WLGAP may be summarised as follows:

- To increase overall awareness, understanding and appreciation, of West Lothian's geodiversity and its relationship with biodiversity
- To address those areas of geodiversity which are relevant to planning, development, and environmental monitoring and management
- To 'embed' geodiversity into future planning, management and interpretation policies
- To provide guidance to West Lothian planners, landowners and other individuals and organisations on sustainable management of geodiversity in the area
- To identify threats to geological sites or features
- To identify opportunities to enhance the value of geological features
- To recommend strategies to conserve and protect geological features
- To recommend strategies for continued monitoring of the West Lothian's geodiversity
- To engage industry, local communities and voluntary groups in West Lothian's geodiversity

Table 3 DRAFT WEST LOTHIAN GEODIVERSITY ACTION PLAN

Objective	Action	Lead	Key Partners	Timescale
1 Geodiversity audit	1. Desk study of potential geodiversity resources.	BGS	LaBRIGS	Completed May 2005
	2. Conduct field audit of selected sites.	BGS		Completed Dec. 2005
	3. Compile geodiversity database & GIS layers.	BGS		Completed March 2006
	4. Compile detailed geodiversity report including key list of geodiversity sites (WLGS).	BGS		Completed March 2006
	5. Supply GeoDiversitY database, GIS layers and report to WLC and SNH.	BGS	BGS, SNH	March/April 2006
	6. Keep GeoDiversitY database and GIS up to date with new data and additional site information	WLC	LaBRIGS, SNH, BGS	Ongoing
	7. Publish WLC geodiversity report.	WLC	BGS, SNH, LaBRIGS	Autumn 2006
	8. Attempt to gain access to major estates geodiversity sites.	WLC	SNH, LaBRIGS, Estates, BGS	2006−2007
	9. Visit potential geodiversity sites identified in desk study, but not visited in main 2005 audit.	LaBRIGS	BGS, WLC, SNH,	2006−2008
2 Monitor condition of WLGS, SSSIs and RIGS and seek to improve where necessary, and secure long-term future	1. Note site condition from Fragility and Fragility Notes fields in GeoDiversitY database.	WLC	SNH, LaBRIGS	2006
	2. Establish a site monitoring system and secure the resources to implement it.	SNH	WLC, LaBRIGS, BGS	Next Local Plan review cycle
	3. Seek to retain RIGS status for existing sites and consider listing additional RIGS from WLGS list.	LaBRIGS	WLC, SNH, BGS	2006−2010
	4. Consider what protection WLGS status should provide	WLC	SNH, LaBRIGS	2006
3 Greater collaborative working	1. Prepare guidance on the interpretation of the geodiversity audit for development management purposes	WLC	LaBRIGS, SNH	2007
	2. Plan the integration and implementation of the GAP with the next review of the LBAP-	WL LBAP partnership	LaBRIGS, SNH	2010
	3. Seek broader local membership for the West Lothian Geodiversity Partnership (?) within LaBRIGS Group	LaBRIGS	WLC, SNH etc	2006-7
	4. Work with landowners to develop/list further RIGS in West Lothian	LaBRIGS, WLC	landowners	2006-9
	5. Work with landowners to help manage the geodiversity resource at further RIGS in West Lothian	LaBRIGS, WLC	landowners	2006-9
	6. With WLC, work to place RIGS in planning context for next Local Plan Review	WLC, LaBRIGS	SNH, BGS	2006-2010?
4 Raise awareness of geodiversity	1. Promote geodiversity and WLGSs in publications, plans and strategies	WLC	SNH, BGS	Ongoing
	2. Write/publish at least one new RIGS leaflet per year	LaBRIGS	AVHC, WLC	Ongoing
	3. If required, provide basic geological training to rangers and seek funding for this purpose	BGS	WLC, SNH	2007 –
	4. Identify needs for new RIGS posters and seek funds	LaBRIGS	AVHC, WLC	2007
	5. Attend Annual Environment Fair at AVHC	LaBRIGS	BGS	2006-2010
	6. Consult ranger services to identify interpretive leaflet support needs and seek funding if required	LaBRIGS-	WLC, SNH	2007

Objective	Action	Lead	Key Partners	Timescale
5 Education and lifelong learning	Seek funding for education development project and project officer	LaBRIGS, UKRIGS, SESEF	SNH, BGS, WLC	2006-7
	Assess RIGS in terms of School National Curriculum and develop teaching materials at appropriate levels for selected sites	LaBRIGS, UKRIGS, SESEF, SAGT, ESTA	SNH, BGS, WLC	2007-8
	Write and publish landscape leaflet based upon Union Canal tourist potential	LaBRIGS, BWS	WLC, AVHC	2007
	Collaborate with Central Scotland Forestry Trust in River Avon Walkway Trail project	CSF, WLC, FCS, LaBRIGS	SNH, BGS, landowners	2006-7
	Collaborate with Pentland Hills Ranger Service in geodiversity project in Pentland Hills	MLC, WLC, CEC, LaBRIGS	BGS, landowners	2006-7
	Collaborate with all West Lothian Ranger services (including Hopetoun House and NTS) in further geodiversity projects	WLC, LaBRIGS	BGS, landowners	ongoing

Table 3 Draft West Lothian Geodiversity Action Plan (WLGAP).

SESEF–Scottish Earth Science Education Forum, SAGT– Scottish Association of Geography Teachers, ESTA–Earth Science Teachers Association, British Waterways Scotland, CEC–City of Edinburgh Council, MLC–Midlothian Council FCS–Forestry Commission Scotland, CSF–Central Scotland Forestry Trust.

5 Selected References

BARRON, H F. 2005. Lothian shapes up for its second first. *Earth Heritage*, Issue 24, 5.

BARRON, H F, and ARKLEY, S. 2006. West Lothian leads in Scotland. *Earth Heritage*, Issue 25, 12−13.

BRAZIER, V. 2001. Earth science and the natural heritage: developing agenda for Scotland. 305−313 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

BUREK, C. 2005. A tale of two sites: how RIGS can complement SSSIs. *Earth Heritage*, Issue 24, 24−25.

BUREK, C. 2006. Do we need a National GAP? *Earth Heritage*, Issue 25, 10.

BUREK, C, and POTTER, J. 2004. Local Geodiversity Action Plans: setting the context for geological conservation, *English Nature Research Report*, No. 560.

BUREK, C, and POTTER, J. 2004. Local Geodiversity Action Plans – sharing good practice workshop, Peterborough, 3 December 2003. *English Nature Research Report*, No. 601.

BENN, D I and EVANS, D J A. 1988. *Glaciers and Glaciation*. Arnold, London. ISBN 0 340 58431 9

BENTON, M J, and SPENCER, P S. 1995. Fossil reptiles of Great Britain. Geological Conservation Review Series No. 10. Joint Nature Conservation Committee. 386 pages (London: Chapman and Hall.) ISBN 0 41262 040 5

BOULTON, G S, JONES, A S, CLAYTON, K M and KENNING, M J. 1977. A British ice sheet model and patterns of glacial erosion and deposition in Britain. 231–246, in *British Quaternary studies: recent advances*. SHOTTON, F W. (editor). (Oxford: Oxford University Press.) ISBN 0 198544146

BROWN, C J and SHIPLEY, B M. 1982. *South-East Scotland: Soil and Land Capability for Agriculture.* (Aberdeen: The Macaulay Institute for Soil Research.) ISBN 0 708402259

CADELL, H M. 1913. *The story of the Forth.* (Glasgow: James Maclehose.)

CADELL, H M. 1925. *The Rocks of West Lothian.* (Edinburgh: Oliver and Boyd.)

CAMERON, I B, AITKEN, A M, BROWNE, M A E, and STEPHENSON, D. 1998. Geology of the Falkirk District. *Memoir of the British Geological Survey*, Sheet 33E (Scotland.) ISBN 0118845411

CAMERON, I B, and STEPHENSON, D. 1985. *British Regional Geology: The Midland Valley of Scotland* (3rd Edition). (London: HMSO for British Geological Survey.) ISBN 0 11 884365 6

COSSEY, P.J., ADAMS, A.E., PURNELL, M.A., WHITELEY, M.J., WHYTE, M.A. & WRIGHT, V.P., (2004), British Lower Carboniferous Stratigraphy. Geological Conservation Review Series No. 29, 617 pages, (London: Chapman and Hall.) ISBN 1 86107 499 9

COTTLE, R. 2002. Linking Geologoy and Biodiversity. *English Nature Research Report No. 562.* ISSN 0976 876X

CROFTS, R. 2001. Sustainable use of the earth's resources. 286−295 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

DINELEY, D and METCALF, S. 1999. Fossil Fishes of Great Britain. Geological Conservation Review Series No. 16, 675p, (London: Chapman and Hall.) ISBN 1 86107 470 0

ENGLISH NATURE. 2004. Geology and biodiversity – making the links (Peterborough: English Nature.) ISBN 1 85716 803 8

ELLIS, N V, BOWEN, D Q, CAMPBELL, S, KNILL, J L, MCKIRDY, A P, PROSSER, C D , VINCENT, M A, and WILSON, R C L. (1996) *An introduction to the Geological Conservation Review.* Geological Conservation Review Series No 1, (Peterborough: Joint Nature Conservation Committee.) ISBN 1861074034

GORDON, J E, and LEYS, K F. 2001. Earth science and the natural heritage: developing a more holistic approach. 5−18 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

GORDON, J E, and MACFAYDEN, C C J. 2001. Earth science conservation in Scotland: state, pressures and issues. 130−147 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

CARRUTHERS, R G, CALDWELL, W, BAILEY, E M, and CONACHER, H R J. 1927. The Oil-Shales of the Lothians.

(Third edition). *Memoir of the Geological Survey, Scotland*.

GRAY, M. 2004. *Geodiversity: valuing and conserving abiotic nature*. (Chichester: John Wiley & Sons.) ISBN 0 470 84896 0

GRAY, M. 2005. What's in a name? Geotope and Geodiversity? *Earth Heritage*, Issue 23, 6.

GRAY, M. 2005. Planning for geoconservation. *Earth Heritage*, Issue 23, 16−17.

HARRISON, S J, and KIRKPATRICK, A H. 2001. Climate change and its potential implications for environments in Scotland. 296−305 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

HARVIE, B. 2005. Oil Shale Bings. 2005. Report for West Lothian Local Biodiversity Action Plan.

HAYWARD, E, and MCDONALD, C. 2004. *West Lothian Soil sustainability report*. Report for West Lothian Council and Scottish Natural Heritage.

LARWOOD, J. 2004. How to mind the LGAP. *Earth Heritage*, Issue 22, 6.

LARWOOD, J. 2006. LGAPS: where are we now? *Earth Heritage*, Issue 25, 9.

LAWRENCE, D J D, VYE, C L, YOUNG, B. 2004. *Durham Geodiversity Audit.* (Durham: Durham County Council.) ISBN 0 902178 21 0

LOWE, J J, and WALKER, M J C. 1997. *Reconstructing Quaternary Environments (2nd Edition).* (Harlow: Prentice Hall.) ISBN 0582101662

MACGREGOR, A G. 1945. The mineral resources of the Lothians. *Wartime Pamphlet of the Geological Survey of Great Britain* 45.

MACGREGOR, M, and ANDERSON, E M.. 1923. The economic geology of the Central Coalfield of Scotland, area VI, Bathgate, Wilsontown and Shotts, with Braehead, Fauldhouse, Armadale and Harthill. *Memoir of the Geological Survey, Scotland*.

MACGREGOR, M, and HALDANE, D. 1933. The economic geology of the Central Coalfield, area III, Bo'ness and Linlithgow. *Memoir of the Geological Survey, Scotland*.

MADDOX, S J, and ANDREWS, J E. 1987. Lithofacies and stratigraphy of a Dinantian non-marine dolostone from the Lower Oil-Shale Group of Fife and West Lothian. *Scottish Journal of Geology,* Vol. **23,** 129–147.

MCADAM, A D. 2003. *Edinburgh and West Lothian* (Second edition). Landscape Fashioned by Geology. (Edinburgh: Scottish Natural Heritage.) ISBN 1 853973270

MCADAM, A D, and CLARKSON, E N K. 1986. *Lothian geology: an excursion guide*. (Edinburgh: Edinburgh Geological Society.)

MCADAM, A D, SMITH, R A, and ROSS, D L. 1993. Geology for land use planning: Livingston. *British Geological Survey Technical Report* WA/92/37.

MCFAYDEN, C C J. 1992. The East Kirkton Quarry proposed site of Special Scientific Interest, West Lothian. *Earth Science Site Documentation Series.*

MCFAYDEN, C C J. 1994. The Petershill Quarry proposed site of Special Scientific Interest. *Earth Science Site Documentation Series.*

MCKIRDY A P, and CROFTS, R. 1999 *Scotland – The Creation of its Natural Landscape*. A Landscape Fashioned by Geology. (Edinburgh: Scottish Natural Heritage.) ISBN 1 853970042

MCKIRDY, A P, THREADGOLD, R, and FINLAY, J. 2001. Geotourism: an emerging rural development opportunity. 255−261 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

MCMILLAN, A A, GILLANDERS, R J, and FAIRHURST, J A. 1999. *Building Stones of Edinburgh.* (Second edition edition). (Edinburgh: Edinburgh Geological society.) ISBN 0 904440 04 4

MITCHELL, G H, and MYKURA, W. 1962. The geology of the neighbourhood of Edinburgh. (3rd edition). *Memoir of the Geological Survey, Scotland,* Sheet 32. ISBN 0 11887408 X

MONAGHAN, A A, PARRISH R R. 2006. Geochronology of Carboniferous–Permian magmatism in the Midland Valley of Scotland: implications for regional tectonomagmamatic evolution and the numerical time scale. Journal of the Geological Society, London, Vol. 163, 15–28.

NATURE CONSERVANCY COUNCIL. 1990. *Earth science conservation 2004in Great Britain: A strategy.* (Peterborough: Nature Conservancy Council.) ISBN 0861396898

NORTH PENNINES AONB PARTNERSHIP. 2004. *North Pennines Area of Outstanding Natural Beauty: A Geodiversity Audit and Action Plan 2004–2009.*

OFFICE OF THE DEPUTY PRIME MINISTER. 2005. *Planning Policy Statement 9: Biodiversity and Geological Conservation.* (London: HMSO.) ISBN 0 11 75394 6

OWEN, D, PRICE, W, and REID, C. 2005. *Gloucestershire Cotswolds: Geodiversity Audit & Local Geodiversity Action Plan*. (Gloucester: Gloucestershire Geoconservation Trust.) ISBN 1 904530 07 9

PALMER, D, JARZEMBOWSKI, E, SIVETER, D J. and SELDEN, P. Due 2006. Fossil Arthropods of Great Britain. Geological Conservation Review Series No. XX. Joint Nature Conservation Committee. 280p. (London: Chapman and Hall.) ISBN 1 86107 486 7

BENTON, M J, and SPENCER, P S. 1995. Fossil reptiles of Great Britain. Geological Conservation Review Series No. 10. Joint Nature Conservation Committee. 386 pages. (London: Chapman and Hall.) ISBN 0 41262 040 5

PARKES, M. 2006. Geological heritage in the Emerald Isle. *Earth Heritage,* Issue 25, 20−22.

PEACH, B N, CLOUGH, C T, HINXMAN, L W, WILSON, J S G, CRAMPTON, C B, MAUFE, H B, and BAILEY, E B. 1910. The geology of the neighbourhood of Edinburgh. (Second edition). *Memoir of the Geological Survey of Great Britain*.

PROSSER, C. 2005. New Planning Policy Statement leaves scope for more emphasis on geology. *Earth Heritage,* Issue 23, 17−18.

PROSSER, C. 2006. Massive step for geological conservation. *Earth Heritage,* Issue 25, 8−9.

PROSSER, C, MURPHY, M, and LARWOOD, J. 2006. *Geological Conservation:a guide to good practice. English Nature* 8−9. ISBN 1 85716 906 9

PURRI, G, WILLISON, T, and WOOLGAR, P. 2001. The sustainable use of soil. 190−196 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The Stationery Office.) ISBN 0 11 497283 4

ROBERTSON, T, SIMPSON, J B, and ANDERSON, J G C. 1949. The limestones of Scotland. *Special Report on the Mineral Resources of Great Britain, Memoir of the Geological Survey of Great Britain* Vol. 35 (Scotland).

ROBSON, R. 2001. Skolie Burn Site Special Scientific Interest. *Earth Science Management Brief Project.*

ROYAL SOCIETY FOR NATURE CONSERVATION. 1999. RIGS Handbook [online]. Last update 2000 [cited 20 March 2006]. Available from http://www.ukrigs.org.uk/html/ukrigs.php?page=hbcontent&menu=promo

SCOTTISH BIODIVERSITY Group. 2000. *Local Biodiversity Action Plans in Scotland: Sector Guidance Note 1 – Geodiversity.*

SCOTTISH EXECUTIVE. 2005. Choosing Our Future: Scotland's Sustainable Development Strategy. (Edinburgh: Scottish Executive.) ISBN 0 7559 4851 3. Also avaible in PDF format from http://www.scotland.gov.uk/Publications/2005/12/1493902/39032

SCOTTISH NATURAL HERITAGE. 2006. *Guidance on Establishing and Managing Local Nature Conservation Site Systems in Scotland*. 22pp.

SCOTTISH WILDLIFE TRUST. [2002]. Scottish Wildlife Trust Policy: Geodiversity [online]. Last update on 11 March 2002 [cited 20 March 2006]. Available from http://www.swt.org.uk/Downloads/03_d_Geodiversity_info.pdf.

SEYMOUR, T, and GOVAN, F. 2004. *Assessment of the Wildflower Grassland Resource of the Lothians.* Report prepared by Lothians Farming and Wildlife Advisory Group for Scottish Natural Heritage.

STANLEY, M. 2001. Welcome to the 21st century. *Geodiversity Update.* No. 1 p. 1.

SYMONDS TRAVERS MORGAN. 1998. *Environmental Geology in Land Use Planning, Case Study No. 3: Industrial Heritage and Landform Replication in West Lothian.* Report for the Department of the Environment, Transport and the Regions.

SUTHERLAND, D G. 1984. The Quaternary deposits and landforms of Scotland and neighbouring shelves. *Quaternary Science Reviews*, Vol. 3, 157−254.

THOMPSON, A, HINE, P D, POOLE, J S, and GREIG, J R. (1998). *Environmental Geology in Land Use Planning: A Guide to Good Practice*. Report to the Department of the Environment, Transport and the Regions by Symonds Travers Morgan, East Grinstead (80pp)

TREWIN, N H, (editor) 2002. *The Geology of Scotland*. (London: The Geological Society.) ISBN 1 86239 126 2

USHER, M B. 2001. Earth Science and the natural heritage: a synthesis. 314−324 in *Earth science and the natural heritage: interactions and integrated management.* GORDON, J E, and LEYS, K F, (editors). (Edinburgh: The

Stationery Office.) ISBN 0 11 497283 4

VINCENT, P. 2004. What's in a name? Geotope or Geodiversity? *Earth Heritage,* Issue 23, 7.

WETHERELL, A. 2004. Linking geology and biodiversity. *Earth Heritage,* Issue 23, 20–21.

WEST LOTHIAN COUNCIL. 2005. West Lothian Local Biodiversity Action Plan: Planning for Biodiversity Action 2005 –2009.

WEST LOTHIAN COUNCIL. 2005. The Finalised West Lothian Local Plan 2005.

WILSON, R C L, DRURY, S A, and CHAPMAN, J L. 2000. *The Great Ice Age*. (London: Routledge.) ISBN 0 415 19841 0

WOODLEY-STEWART, C, and YOUNG, B. 2004. Geodiversity takes its rightful place. *Earth Heritage,* Issue 23, 10–11.

5 Glossary

Acid Describes igneous rocks rich in silica (SiO_2 more than 63%).

Adit Horizontal, or nearly horizontal, tunnel or mine entrance

Alkaline Describes igneous rocks that contain more sodium and/or potassium than is required to form feldspar and hence contain, or have the potential to contain (i.e. in the norm), other alkali-bearing minerals such as feldspathoids, alkali pyroxenes and alkali amphiboles.

Alluvial Environments, actions and products of rivers or streams

Amygdaloidal A texture in lava consisting of spheroidal or ellipsoidal cavities formed by gas bubbles and subsequently filled with secondary minerals such as calcite, quartz or zeolites.

Annabergite Hydrated Nickel Arsenate [Ni3(AsO4)2-8(H2O)]. A bright green mineral formed as a weathering product of nickel-containing minerals such as niccolite. The characteristic green colour is easily noticeable and was used to spot veins of nickel-bearing ore.

Anthracosaur A order of late Palaeozoic labyrinthodont amphibians.

Anticline An arch-shaped fold in rock in which the rock layers are upwardly convex. The oldest rock layers form the core of the fold, and outward from the core progressively younger rocks occur.

Argillaceous Detrital sedimentary rocks composed of very fine grain silt or clay-sized particles (<0.0625 mm), usually with a high content of clay minerals

Baryte Barium sulphate [$BaSO_4$]. A dense colourless to white mineral found in hydrothermal veins.

Basalt A dark-coloured, fine-grained, usually extrusive, igneous rock composed of minerals rich in iron and magnesium and with a relatively low silica content.

Basanite A dark-coloured, fine-grained, usually extrusive, igneous rock composed mainly of feldspathoid, olivine and plagioclase feldspar minerals.

Basement A term usually applied to any widespread association of folded igneous and metamorphic rocks which are often unconformably overlain by relatively underformed sedimentary rocks.

Basic Describes igneous rocks relatively rich in the 'bases' of early chemistry (MgO, FeO, CaO, Fe_2O_3); silica (SiO_2) is relatively low (nominally 45-52%).

Bedding A feature of sedimentary rocks, in which planar or near-planar surfaces known as bedding planes indicate successive depositional surfaces formed as the sediments were laid down.

Bedrock A term used to describe unweathered rock below soil or superficial deposits. Can also be exposed at the surface.

Biohermal Relates to a build-up of largely in-situ organisms that produce a reef or mound of organic origin.

Bioturbation The disruption of depositional sedimentary structures by organisms e.g. activities such as burrowing

Bivalve class of molluscs with paired oval or elongated shell valves joined by a hinge.

Blaes Scots mining term for dark blue (blae) mudstone or shale.

Brachiopod A phylum of solitary marine shelled invertebrates

Bravoite	A variety of pyrite, nickel-rich iron sulphide, steel grey in colour
Breccia	Coarse-grained clastic sedimentary rock consisting of angular fragments of pre-existing rocks
Brickclay	Mudstone used in the manufacture of structural clay products such as bricks, pavers, roofing tiles and clay pipes.
Brown Forest Soils	Free-draining, fertile soils with brownish subsoils where iron oxides created through weathering processes are bonded to silicate clays. They are found mainly in drier climate of the east and south of Scotland, and in sheltered Highland glens at lower elevations. Also known as Brown Earths.
Calcite	Calcium Carbonate [$CaCO_3$] a widely distributed mineral and a common constituent of sedimentary rocks, limestone in particular. Also occurs as stalactites and stalagmites and is often the primary constituent of marine shells.
Calcsilicate	A group of mineral whose bulk composition consists of calcium silicates
Caledonian	Refers to a major mountain-building (orogeny) event related to the closure of the Iapetus Ocean during the Late Palaeozoic Era (Cambrian, Ordovician and Silurian Periods). It affected Scotland, Ireland, Scotland, Scandinavia and Greenland.
Carboniferous	A geological period [354–290 Ma] preceded by the **Devonian** and followed by the Permian.
Chert	A dense, microcrystalline form of silica which occurs as nodules or beds within parts of the Carboniferous succession of rocks
Complex	A large-scale spatially related assemblage of igneous rock units possibly, but not necessarily, with complicated igneous and/or tectonic relationships and of various ages and diverse origins.
Concretion	Hard, compact mass, usually rounded, in a sedimentary rock, formed by precipitation of a cementing mineral around a nucleus during or after deposition.
Conglomerate	A sedimentary rock, a significant proportion of which is composed of rounded pebbles and boulders, greater than 2mm in diameter, set in a finer-grained groundmass.
Contact metamorphism	The recrystallisation of country rocks when intruded by hot igneous rocks. Also known as thermal metamorphism.
Clast	Particle of broken down rock, eroded and deposited in a new setting.
Clastic	Applies to the texture of rocks which are comprised of fragments of pre-existing rocks which have been weathered or eroded.
Clayband ironstone	A bedded impure iron-ore, the iron occurring as **siderite.**
Columnar jointing	The crudely polygonal system of vertical joints formed in response to cooling of bodies of intrusive igneous rocks such as sills and dykes.
Cross-bedding	Cross-stratification formed by the migration of dunes and sand waves on a sediment surface.
Cross-lamination	Cross-stratification formed by the migration of ripples on a sediment surface. Foresets less than 10 mm thick.
Cross-stratification	A family of primary sedimentary structures formed by the migration of slip-faces of ripples and dunes in granular sediments. Characterised by internally inclined layers (foresets) bounded by planar surfaces.
Dalradian	A Supergroup representing the youngest stratigraphic division of the Precambrian in Scotland and Ireland.
Desiccation	Or shrinkage cracks are polygonal cracks formed in a sediment as it dries out in

cracks	a terrestrial environment.
Devensian	The last glacial stage in Britain, lasting from around 70,000 BP (Before Present) to about 10,000 BP.
Devonian	A geological system [418–354 Ma], oldest of the Upper Palaeozoic erathem, preceded by the Silurian system and followed by the **Carboniferous**.
Dinantian	The Lower Carboniferous sub-system, [354–326 Ma] comprising the Viséan and the Tournaisian Series.
Dolerite	A dark coloured, medium grained igneous rock which contains the minerals plagioclase and pyroxene. Commonly found as **dykes** and **sills**.
Dolomite	Calcium magnesium carbonate, A sedimentary rock-forming mineral [$CaMg(CO_3)_2$].
Dolostone (Cementstone)	A sedimentary rock usually formed by the dolomitization (diagenetic conversion of calcium carbonate to calcium magnesium carbonate) of limestones.
Dyke	Discordant, sheet-like bodies of intrusive igneous rock in a vertical, or near-vertical orientation
Echinoid	Marine animals belonging to the class Echinoidea (part of the phylum Echinodermata). Fossil records show that they first appeared in the Ordovician and are extant today, with approximately 1000 living species.
Erythrite	Hydrated Cobalt Arsenate [Co3(AsO4)2-8(H2O)]. A bright red-purple mineral formed as a weathering product of cobalt-containing minerals such as cobaltite. The characteristic red-purple colour is easily noticeable and was used to spot veins of cobalt-bearing ore.
Eurypterid	Dominantly aquatic arthropods commonly having a pair of swimming and digging appendages and an anterior pair of food-gathering pincers, usually small, termed chelicerae. They first appeared in the early Ordovician but became extinct in the Permian. Also known as sea-scorpions they were typically 100 to 450 mm long but the largest known species reached 2.5 m.
Eustatic	World-wide changes in sea-level caused either by tectonic movement or growth or melting of glacial ice-sheets.
Evaporite	Sedimentary rock formed by the precipitation of salts from natural brines.
Extrusive	Refers to igneous rocks which have been extruded onto the Earth's surface, rather than being intruded beneath the surface (intrusive).
Facies	The characteristic features of a rock unit, including rock type, mineralogy, texture and structure, which together reflect a particular sedimentary, igneous or metamorphic environment and/or process.
Fault	A fracture in the Earth's crust across which the rocks have been displaced relative to each other.
Felsite	A general term used to denote light-coloured, fine-grained igneous rocks
Fireclay	Sedimentary mudstones that occur as seatearths underlying almost all coal seams. They represent fossil soils on which the coal-forming vegetation grew. The term was originally derived from their ability to resist heat. They are mainly used in the manfacture of high-quality facing bricks.
Fluvial	Referring to a river environment.
Fluviodeltaic	Refers to sediments deposited by fluvial processes in a deltaic environment.
Fluvioglacial	Refers to sediments deposited by flowing glacial **meltwater**.
Fluviolacustrine	Refers to sedimentation partly in lakes nd partly in rivers, or to deposits laid

	down under alternating or overlapping lacustrine and fluviatile environments.
Footwall	The fault block which lies below an inclined fault surface.
Gabbro	A dark-coloured, coarse-grained igneous rock consisting mainly of plagioclase feldspar and pyroxene. Is low in silica and may contain biotite, olivine and magnetite.
Galena	Lead Sulphide [PbS], a dense lead to silver grey mineral with a bluish tint. It may contain up to 1% Silver in place of lead and is the leading ore of Silver.
Gangue	Generally valueless mineral or rock which accompanies an ore
Hanging-wall	The fault block which lies above inclined fault surface.
Holocene	The youngest epoch of the Quaternary Period. Covers the last 10,000 years.
Hornfels	A fine-grained rock that has been partly or completely recrystallised by contact (thermal) metamorphism.
Gley	A poorly-draining soil that develops under periodic or permanent waterlogging, with a characteristic bluish-grey subsoil. The dominant soil types on the glacial tills of central Scotland.
Intrusive	Refers to igneous rocks which have been intruded into older rocks beneath the Earth's surface, rather than being extruded onto the surface.
Ironstone	Iron-rich sedimentary rock, the amount of iron found may permit the extraction of iron ore.
Lacustrine	Refers to a lake environment.
Lithodiversity	The diversity or range of lithology (rock type).
Lithology	The character of a rock expressed in terms of its mineral composition, structure, grain size and arrangement of its constituents.
Lode	Mineral vein or system of veins. Refers to productive veins only. Mostly commonly used in Cornwall.
Loxommatid	Large "amphibian" predator of the Late Carboniferous period.
Meltwater	Water produced by melting of snow or ice.
Metamorphism	The process of changing the mineralogy and structure of a rock as a result of the effects of heat and/or pressure.
Mineralisation	Conversion of organic tissues to an inorganic state as a result of decomposition by soil micro-organisms. The hydrothermal deposition of economically important metals in the formation of ore bodies.
Namurian	The lowermost series of the Silesian sub-system of the **Carboniferous** [326–316 Ma].
Niccolite	A former name for nickeline, a lead-grey, black or copper-coloured mineral consisting of Nickel Arsenide [NiAs]. The chief ore of Nickel.
Oil-Shale	Shale that contains organic substances that yield liquid hydrocarbons on distillation, but does not contain free oil.
Ostracod	A class of crustacean, typically about 1 mm in size, hinged into two calcareous valves. The fossil record indicates that they first appeared in the Cambrian and are still present today. They belong to the phylum Arthropoda.
Overfold	An overturned fold, in which the axial plane is inclined so that the fold limbs dip in the same direction.
Palaeoecology	The application of ecological concepts to the study of the relationship between ancient organisms and their environments.

Palaeosol A fossilised soil.

Petrography The study of the mineralogy, texture and systematic classification of rocks, especially under the microscope.

Picrite A term originally used to describe a variety of dolerite or basalt extremely rich in olivine and pyroxene. Chemically defined as a group name for rocks with SiO2 <47%, total alkalis <2% and MgO >18%.

Plug Solidified lava that fills the conduit of a volcano. It is usually more resistant to erosion than the material making up the surrounding cone, and may remain standing as a solitary pinnacle when the rest of the original structure has eroded away.

Podzol Podzol soils have distinct layers or horizons and are widespread throughout Scotland, generally associated with acid parent material and semi-natural heath or coarse grassland vegetation and coniferous woodland. They are characteristic of any topographic position where aerobic conditions prevail and water can percolate freely through the upper part of the profile. They are found at all elevations from sea level to the summit of the Cairngorms.

Pyroclastic Describes unconsolidated deposits (**tephra**) and rocks that form directly by explosive ejection from a volcano.

Pyroclastic breccia A rock comprising predominantly angular pyroclasts with an average size greater than 64 mm in diameter.

Sandstone dyke A sheet-like body on sand or sandstone cutting through a bedded sediment or sedimentary rock formed by the upwards injection of liquefied sand through a fissure, often as a result os seismic activity.

Seatclay A highly siliceous **seatearth.** It is also known as ganister.

Seatearth A bed of rock underlying a coal seam, representing a fossil soil that supported the vegetation from which the coal was formed.

Seatrock An alternative term for **seatearth.**

Sedimentology The study of sedimentary rocks and of the processes by which they were formed; the description, classification, origin, and interpretation of sediments.

Serpentine A green-coloured magnesium-rich phyllosilicate mineral often associated with ultrabasic igneous rocks. Serpentinite is a rock composed largely of serpentine.

Siderite Iron Carbonate, a yellowish-brown mineral [FeCO3], most often found in bedded sedimentary deposits with a biological component, such as shales, clays and coal. It is also found in metamorphosed sedimentary rocks as more massively crystalline material, as a gangue mineral in hydrothermal deposits, and in pegmatites.

Silesian The Upper Carboniferous sub-system, [326–299 Ma] comprising the Namurian and Westphalian Series.

Sill A tabular body of igneous rock, originally intruded as a sub-horizontal sheet and generally concordant with the bedding or foliation in the country rocks.

Silurian A geological system [433–418 Ma], youngest of the Lower Palaeozoic erathem, preceded by the Ordovician and followed by the **Devonian.**

Spherulitic A texture consisting of a spherical mass of acicular crystals, commonly feldspar, radiating from a central point; commonly found in glassy silicic volcanic rocks as a result of devitrification.

Stephanian The uppermost series of the Silesian sub-system of the **Carboniferous** [305–299 Ma].

Strata	Rocks that form layers or beds.
Stratabound	Mineral deposit or mineralisation confined to a particular stratigraphic unit
Stratigraphy	The definition and description of the stratified rocks of the Earth's crust.
Strike-slip	A term used to describe a **fault** on which the sense of movement is at right angles to the direction of inclination on the fault.
Subaerial	Located or occurring on or near the surface of the earth.
Syncline	A basin- or trough-shaped fold in rock in which rock layers are downwardly concave. The youngest rock layers form the core of the fold and outward from the core progressively older rocks occur.
Tephra	An unconsolidated accumulation of **pyroclast**s.
Teschenite	Generally dark-coloured, medium to coarse-grained igneous rock. It is undersaturated (with respect to silica).
Tetrapod	A vertebrate animal with four feet, legs, or leglike appendages.
Trace fossil	A biogenic sedimentary structure formed by behavioural activity of an organism, e.g. tracks, trails, burrows, and borings.
Tuff	A rock comprising **pyroclasts** with average grain size less than 2 mm.
Unconformity	A surface of contact between two groups of unconformable strata. Represents a break in the geological record where a combination of erosion and lack of deposition was taking place.
Vent	The opening at the earth's surface through which volcanic materials erupt or flow.
Vesicular	A texture in lava consisting of bubble-shaped cavities formed by expansion of trapped gases.
Viséan	The uppermost series of the Dinantian sub-system of the **Carboniferous** [342–326 Ma].
Volcaniclastic	Refers to **clastic** rocks or sediments composed mainly of particles of volcanic origin.
Westphalian	The middle series of the Silesian sub-system of the **Carboniferous** [316–305 Ma].
Xenolith	A rock fragment foreign to the igneous rock in which it occurs.

6 Acronyms

AGLV	Area of Great Landscape Value
AONB	Area of Outstanding Natural Beauty
AVHC	Almond Valley Heritage Centre
AWI	Ancient Woodland Inventory (SNH)
BAPs	Biodiversity Action Plans
BGS	British Geological Survey
B-SSSI	Site of Special Scientific Interest (Biological).
CERS	Community Environmental Renewal Scheme (Forward Scotland)
COSLA	Convention of Scottish Local Authorities
DiGMapGB	Digital Geological Map of Great Britain (BGS)
G-SSSI	Site of Special Scientific Interest (Geological)
GLN	Geology and Landscape North programme (BGS)
GCR	Geological Conservation Review (JNCC)
GIS	Geographic Information System
GPS	Global Positioning System
JNCC	Joint Nature Conservatrion Committee
LBAP	Local Biodiversity Action Plan.
LaBRIGS	Lothian and Borders RIGS Group
LBAP	Local Biodiversity Action Plan
Ma	Million years
RIGS	Regionally Important Geological and Geomorphological Sites
RTPI	Royal Town Planning Institute
ODPM	Office of the Deputy Prime Minister (Westminster)
PPS9	Planning Policy Statement 9
SEA	Strategic Environmental Assessment
SEPA	Scottish Environment Protection Agency
SPP	Scottish Planning Policy
SNH	Scottish Natural Heritage
SWT	Scottish Wildlife Trust
SSSIs	Sites of Special Scientific Interest
SNWI	Semi-Natural Woodland Inventory (SNH)
WLC	West Lothian Council
WLGSs	West Lothian Geodiversity Sites
WLGAP	West Lothian Geodiversity Action Plan
WLLP	West Lothian Local Plan