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Limestone Landscapes - a geodiversity audit and action plan for the Durham Magnesian Limestone Plateau

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The Magnesian Limestone at Marsden Bay

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Foreword

> *Along the coast of Durham from Shields to Hartlepool, the uppermost bed frequently consists of a species of breccia, the cement of which is a marl-like substance consisting chiefly of magnesian carbonate of lime, and with this breccia wide chasms or interruptions in the cliff are filled. The next strata are thin and slaty, but lower down the stratification becomes less distinct. The colour of this rock is then light hair brown, the texture crystalline and cellular, from which latter cause it strongly resists the stroke of the hammer. N J Winch – March 1814*

The unique and superbly exposed rocks known collectively as the Magnesian Limestone have been studied for more than 190 years and the names of some of the early workers - Geinitz, Murchison, Phillips, Sedgwick, and Sorby - would grace any geological hall of fame. Despite this formidable assault, and the efforts of a host of later workers, the Magnesian Limestone still retains many of its secrets. The connection between the distribution of the indigenous plants of Durham and the geological structure of the county was recognised and described by the naturalist John Winch in 1830. Even before this time the rocks of the Magnesian Limestone were being quarried for building and to burn for use as agricultural lime. The Romans quarried the Magnesian Limestone to build the Roman Arbeia Fort at South Shields.

This report is the published product of a study by the British Geological Survey (BGS), commissioned by Durham County Council on behalf of the Limestone Landscapes Partnership of North East England as a contribution to the establishment of a landscape-scale action plan for the management of the Magnesian Limestone Plateau.

A great deal has been done by individual districts, Durham Council and Natural England in the recognition and designation of sites with a geological interest. Indeed the region has been at the forefront of biodiversity and geological conservation in Britain. This study provides an excellent opportunity to review these achievements, but more importantly to make suggestions for the enhancement, and incorporation of geodiversity into the community in a manner appropriate for a new century. Where possible, sites should not be the preserve of just the scientist, but available for wider access in a responsible manner. In the 21st century it is recognised that access to the natural environment improves health and wellbeing and that local communities can obtain major social and economic benefit through good management of the natural environment in both rural and urban settings.

Today, rather than just preserving our geological sites in isolation, we wish to provide opportunities for communities to take ownership of the natural heritage on their doorstep as well as encouraging those from outside to understand and appreciate it. This study will have succeeded if it helps to engender enjoyment and local pride in the natural heritage and to spread knowledge about the world class geodiversity of the area and how it has influenced the landscape and people of the region.

Acknowledgements

The encouragement of Sue Mullinger of Durham County Council in the preparation of this report is gratefully acknowledged. The assistance provided by Mike Sutcliffe of Natural England in providing details of geological sites of special scientific interest and the information provided by Beth Andrews on RIGS sites within the area have greatly aided the study. Mrs Gillian Lawrence is thanked for her appreciation of the importance of visiting sites displaying geological interpretation whilst on holiday in South Africa.

Contents

Summary

This study of geodiversity has been carried out with the needs of the Limestone Landscapes Partnership in mind. It describes the most important features of geodiversity in the area and brings together details of existing geodioversity sites. It also discusses geodiversity interest at other nature sites, suggests links between them, provides pointers to the most important literature and ancillary information and aims to give inspiration for development and integration at all levels.

This study concludes that, for the most part, a selection should be made from those sites that already hold some form of nature or community designation, or are candidates for such designation. Such a selection should enable a very good representation of the world class geodiversity of the area to be conserved, presented, utilised and interpreted. It is felt that it would be most appropriate for a combination approach of mainly enhancing existing geological sites while developing some others where the geological interest is not the main reason for designation, for example the ‘places to visit’ featured in the MAGical Meadows booklet or other local nature reserves.

The report presents opportunities for development and interpretation of sites, for their integration, and for increased access by the local community and visitors, including people with disabilities.

The categorisation of sites in this study should be refined at the next stage of the process by incorporating information from complementary specialist reports and by discussion with stakeholder, professional and community organisations. The recommendations for the geodiversity action plan are intended to provide a stimulus to progress, but will, similarly, benefit from further consultation before implementation. It is essential that the final action plan is accepted and owned by those who will be responsible for its implementation.

1 Introduction

1.1 AIM

The principal aim of this study is to identify areas and means by which geodiversity can contribute to the vision of the Limestone Landscape Partnership: *"Working together in a landscape-scale Partnership to make a positive difference to quality of life and to the unique natural environment of the Magnesian Limestone area"*.

The Limestone Landscapes Partnership
Aims
A1 Champion and co-ordinate informed, participative and integrated action on the environment across a broad range of sectors.
A2 Deliver environment-led actions that achieve social and economic benefits.
A3 Work with communities connected to the natural area to help shape a landscape that reflects their need
Objectives
O1. Conserve and enhance the unique biodiversity, geo-diversity, landscape, heritage and cultural assets of the partnership area and strengthen and develop local character and distinctiveness.
O2. Improve access to countryside and natural green-space, and opportunities for healthy 'green exercise' that will improve mental, physical and social well-being.
O3. Raise awareness of the environment of the partnership area as an educational resource and a source of local pride, creating stronger links between urban and rural areas.
O4. Empower local people to participate in activities and decision-making on the environment.
O5. Improve, promote and use the environment as a stimulus for economic regeneration and sustainable growth.
O6. Support and promote activities that help to mitigate, or adapt to, the impacts of climate change.
O7. Support and complement the work of partners through linking and securing resources and expertise

1.2 SCOPE OF THE STUDY

- Geodiversity audit of main geological formations and features through desk top study of existing information
- Through existing data and field work: identification of a network of representative sites which encapsulate the essential features of the Durham Magnesian Limestone JCA's geology. To include or be additional to SSSIs and/or existing Local Sites
- Identification of interpretation opportunities and issues, particularly those that make links between geodiversity, landscape character, biodiversity and economic and cultural history.
- Prioritisation of sites according to interpretation, linkage and community use criteria
- A condition assessment of each site and management proposals.
- Suggestions for Action Points to be taken forward.
- Prepare a fully attributed digital file of sites compatible with ESRI GIS system.
- Photographs of key formations and features, and representative sites.

1.3 AREA OF STUDY

The Limestone Landscapes area broadly follows the boundaries of the Durham Magnesian Limestone Plateau (see Figure 1) (http://www.naturalengland.org.uk/ourwork/landscape/englands/character/areas/durham_magnesian_limestone_plateau.aspx). This covers just over 44,000 ha of south-east Tyne & Wear and East Durham and Hartlepool and is described by the Durham Magnesian limestone Natural area profile (http://www.english-nature.org.uk/science/natural/profiles/naProfile6.pdf.).

2 The Magnesian Limestone

2.1 COMPOSITION

The recognition, by the early 1800s, that some of the rocks exposed on the Durham Coast and the inland plateau contain magnesium led to the general use of the name 'Magnesian Limestone' to describe them, even though not all of the rocks contain magnesium nor are all limestones.

Limestone is one type of carbonate rock, a class of sedimentary rocks composed primarily of minerals that contain the carbonate ion, CO_3^{2-}, as the basic structural and compositional unit. The carbonates are among the most widely distributed minerals in the Earth's crust. In general terms a limestone is a rock composed predominantly of calcium carbonate ($CaCO_3$). Some limestones contain an appreciable quantity of magnesium, most commonly as the mineral dolomite ($CaMg(CO_3)_2$), and are known as *magnesian limestones.* The term 'dolomite' is applied to both the mineral dolomite and to a carbonate rock containing between 90 and 100% of this mineral. The strata that are exposed on the Durham coast and underlie the plateau consist of a variety of rock types; mainly carbonate rocks of different compositions including magnesian limestone and dolomite. The Magnesian Limestone is itself restricted to a narrow belt between Nottingham and Durham.

2.2 AGE

The rocks of the Durham Limestone Plateau were laid down during the Permian Period of geological history, which dates from about 299 to 251 million years ago. The Permian rocks of the plateau are underlain by coal-bearing rocks of Carboniferous age (310 my). Earth movements towards the end of the Carboniferous raised and tilted the land which was subsequently eroded for several million years before the deposition of the earliest Permian rocks, as desert sands.

Most of the Magnesian Limestone (above the Yellow Sands) was deposited in the late Permian. The superficial deposits that overlie the Magnesian Limestone date from the Quaternary Period, which commenced about two million years ago. Little is known with any certainty about the geological history of the area in the intervening time. Fissure fills in the Magnesian Limestone coastal cliffs at Warren House Gill, north of Easington, predate the Devensian glaciation and are the oldest Quaternary deposits in the area.

2.3 NAMING AND DIVISION

The naturalist John Winch used the term Magnesian Limestone to describe the rocks along the coast from 'Shield to Hartlepool' in his observations of the geology of Northumberland and Durham presented to the Geological Society in March 1814 (published 1816), although the name was probably in use before then. The eminent geologist Adam Sedgwick described the primary divisions of the Magnesian Limestone in a comprehensive scientific paper of 1829. The classifi-

cation of the rock sequence then evolved gradually as successive discoveries enabled later workers to refine the pioneer work. The Magnesian Limestone has traditionally been divided into Lower, Middle and Upper units. Although describing it within his Magnesian Limestone unit, Sedgwick recognised that the sand at the base might be more appropriately considered separately, as is now the case. However, the importance of this lowest unit, the Yellow Sand, in the development of the Limestone Plateau makes its inclusion essential in discussion of the Magnesian Limestone.

In order to accord with modern geological procedures, a new formalised system of names based on geographic locations was introduced in the 1980's and these have been used in this report. Table 1 indicates the relationship between these new names and those in earlier use. A geological map of the area and schematic cross section are illustrated in Figures 1 and 2.

Geological System	Previous Name	Current Name	Maximum thickness	English Zechstein Cycle
Upper Permian	Rotten Marl	Rotten Marl Formation	10m	EZ3
	Upper Magnesian Limestone	Seaham Formation	33 m	
		Roker Formation (including Concretionary Limestone)	200 m (116 m)	EZ2
	Middle Magnesian Limestone	Hartlepool Anhydrite	As a residue	EZ1
		Ford Formation (including the Reef)	116 m	
	Lower Magnesian Limestone	Raisby Formation	76 m	
	Marl Slate	Marl Slate Formation	6 m	
Lower Permian	Yellow Sands and breccias	Yellow Sands Formation	60 m?	

Table 1 The Classification of the Magnesian Limestone

3 Understanding the rocks

3.1 EVOLUTION OF THE ROCKS AND LANDSCAPE

Some 280 million years ago, at the beginning of the Permian Period, Britain as we know it today did not exist. Instead the area destined to become Britain lay within a large continent known as Pangea, situated in tropical latitudes very close to the equator.

During the early Permian, northern Europe was one of the world's great deserts. Major earth movements towards the end of Carboniferous times had created mountains across what became northern England. These widespread barren uplands were gradually worn down by Permian desert erosion and up to 500 metres of Carboniferous rocks were removed. The product of this prolonged phase of erosion was a mature, gently rolling plain, probably with, in present-day north-east England, a gentle eastward slope into the subsiding North Sea Basin. This plain became the Carboniferous-Permian unconformity, a surface of generally low relief on which the Permian Yellow Sands Formation was deposited. When the desert environments formed this part of England lay near the western margin of a major inland drainage basin, the floor of which was perhaps 250m below world sea level.

In the late Permian continental extension opened a seaway which flooded low-lying ground and formed inland drainage basins, the so-called Bakevillia and Zechstein seas, approximately in the areas now occupied by the Irish and North seas (Figure 3). The flooding could have taken as little as six years. With a sill or barrier remaining close to normal world sea level, the basin was particularly sensitive to relative sea-level changes and apparently became isolated from time to time when sea level fell. Similar to large enclosed seas of today, such as the Mediterranean, a tidal range of 1m or less was probable.

Straddling latitude 30° north during Late Permian times, the sea was subjected to high evaporation rates. As it was connected to open ocean to the north by a narrow shallow seaway, changes in global sea-levels affected the rates at which incoming sea-water could replace that lost by evaporation. The climate was hot and dry, possibly equivalent to that around the present Persian Gulf. During episodes of high global sea-level, recharge rates through the narrow sea-way were high, and so the salinity levels of the Zechstein Sea were normal and limestones were deposited in and around its margins. When global sea-levels fell, the amount of water flowing through the sea-way was significantly reduced, leading to elevated salinity levels and the formation of extensive evaporite deposits (particularly anhydrite (CaSO4) and halite (NaCl)). Repeated rise and fall of global sea-level resulted repetitive depositional cycles. For a long time, and in comparison with the German sequence, five cycles of carbonate to evaporite deposition were recognised, these are known as the Zechstein cycles. A more recent and plausible interpretation recognises seven sequence stratigraphical cycles with evaporite deposition related to low sea levels (lowstands) and carbonate deposition related to high sea levels (highstands).

No early Permian terrestrial sediments in north east England have provided evidence of contemporary life but it is hard to believe that the area was totally lifeless when other apparently equally inhospitable parts of Britain bear clear traces of a range of organisms including carnivores; an equally diverse range of specialized organisms probably inhabited the north-eastern desert.

3.2 YELLOW SANDS FORMATION

The Yellow Sands Formation consists mainly of weakly cemented, yellow fine- to medium-grained, well-sorted sands or sandstone of wind blown origin. Beautifully rounded and frosted

"millet seed" grains are abundant in most samples of the Yellow Sands. At outcrop the sands are typically bright yellow, due to a thin coating of limonite on many of the grains, although patches of white or light grey sand can also be seen in large sections. At depth, below the zone of oxidation, the sands are blue-grey and pyritic. The sands are normally incoherent and lack any cementing material other than limonite, but some beds, the so-called 'sand rock', contain a high proportion of carbonate. The uppermost part of the Yellow Sands, lying immediately below the Marl Slate Formation, is also characteristically cemented in this way. The name Yellow Sands was first given by Hutton in 1831 following pioneering work by Sedgwick. The western and southern edges of the Permian desert in which the sands were being deposited were fringed by rocky uplands. Breccias derived, from these uplands, and deposited at the same time as the Yellow Sands are present in the south of the area.

The Permian Yellow Sands crop out intermittently along the base of the Magnesian Limestone escarpment and dip to the east beneath the limestone. At outcrop the formation is clearly discontinuous and forms ridges of various heights. When they were deposited, the sands formed hills on the land surface and the crests of such hills have been visible in a number of exposures. The ridges, which probably represent accumulations of sand dunes, are typically between one to two kilometres wide with sand thicknesses of up to almost 70 metres and are separated by belts where the sands are thin or absent. The absence of suitable sub-surface information for much of the area makes it impossible to predict accurately where they occur, although it is generally accepted that they occur in west-south-west to east-north-east trending ridges which continue beneath the limestone for some distance. The exact nature of the dunes has been the subject of much discussion and is still a topic of research (Plate 1)

There is no independent evidence for the age of the Yellow Sands Formation, but it is generally considered to be late Early Permian (approximately 270 million years old)

3.3 MARL SLATE FORMATION

The Marl Slate Formation is a laminated, commonly bituminous, silty, argillaceous dolomite with an unusually high concentration of metallic minerals and a distinctive fish, and more rarely reptilian, fossil fauna. It represents a rapid marine transgression that occurred when the Zechstein Sea flooded the enclosed desert basin. At outcrop it is a dark yellowish orange or yellowish brown commonly fissile rock (splits easily along bedding), but where unweathered it is hard and compact, with alternating grey and black laminae. When freshly fractured, it smells of oil. It is locally interbedded with thin beds of dolomite and dolomitic limestone.

The well-established name Marl Slate was applied to the formation in the 19th century, although in strict geological terms the rock is neither a marl, nor a slate. The Marl Slate in places includes rounded sand grains and minerals such as sphalerite, galena and chalcopyrite. It has been suggested that some of the fish and other organic remains in the sequence may have been a source of the mineralisation that was taking place at the same time.

The Marl Slate is well known for its fauna of fossil fish. It has also yielded important fossil reptiles and plants. Permian fossil fish faunas are very limited in number and distribution world wide. Relatively well-preserved and locally numerous examples of fossil fish from the Kupferschiefer of Germany attracted attention early in the 19th century. Those in the Marl Slate of north-east England were discovered at about the same time and were described a little later. In the past well-preserved specimens were collected from localities such as the Ferryhill Gap and from quarries along the escarpment and there are internationally important collections of the fossils in numerous museums. The quarries south of Middridge have been the source of the best-preserved Permian plants found in England (Plates 2 and 3)

3.4 RAISBY FORMATION (FORMERLY LOWER MAGNESIAN LIMESTONE)

This lowest division of the Magnesian Limestone includes rocks which range in composition from yellow or cream dolomites to almost pure, grey limestones, though the latter are rare. Three main lithological units distinguished by colour, bedding thickness, texture and compositional variations can be recognized in many areas. The middle unit is the one most commonly seen; it is a sparingly fossiliferous hard rock with a characteristic mottling rarely found in other parts of the Magnesian Limestone. Lower units of the Raisby Formation are more regularly bedded and, on the whole, slightly coarser grained. Laminated argillaceous layers, commonly of brown clay, are present especially near the base of the sequence. Fossils are rare in the upper unit, but are locally common in the lowest unit. Calcite-lined cavities (or 'vugs') are characteristic of many sections and may represent the replacement of original evaporite minerals. The formation has only a narrow surface outcrop, which is mainly free of, or only thinly covered with, superficial deposits. It commonly forms an escarpment 30 to 60 metres high, but it extends beneath younger strata to the eastern edge of the county. The Raisby Formation is a major source of aggregate (Plate 4).

The Raisby Formation was deposited on a shelf sloping gently eastwards into the Zechstein Basin. During deposition of the limestone this slope was the cause of instability, possibly related to earthquakes, and at times there were minor submarine "avalanches" or 'slumping' of partly lithified sediment which moved downslope. The chaotic and often contorted rock structures produced by such slumping can be seen in the rocks of the Raisby Formation.

The type Section is in Raisby Quarries (now known as Coxhoe Quarry) Nr. Cornforth, County Durham.

At Thickley Quarry the lowest beds of the formation, which comprise thick-bedded dolomitic limestones, are overlain by fossiliferous limestone texturally similar to those at Raisby Hill Quarry. At Raisby this unit is 30 metres thick; at Thickley it is only 1 metre thick.

3.5 FORD FORMATION (FORMERLY MIDDLE MAGNESIAN LIMESTONE)

The Ford Formations displays a varied sequence of dolomites deposited in three distinct environments: shelf-edge reef that separates a broad belt of back-reef and lagoonal beds to the west from a belt of fore-reef talus aprons and off-reef beds to the east.

The barrier reef of the Ford Formation is perhaps the best known feature of the Durham Upper Permian. Most of the reef consists of massive unstratified rock which in places is at least 100m thick. It is composed predominantly of the skeletons of marine animals known as bryozoans along with many shells, some sea urchins and rare corals. Dolomites and dolomitic limestones of reef-facies crop out in a sinuous belt extending south-south-eastwards from Down Hill near Sunderland towards West Hartlepool. This has locally been much more resistant to erosion than adjacent bedded rocks and in places forms distinct topographic features such as Beacon Hill near Easington owing to the framework structure of the reef rocks being more resistant to erosion than the surrounding limestones and dolomites (Plate 5)

It is not always easy to distinguish where the Raisby Formation ends and the Ford Formation starts.

Rocks of the lagoonal type occupy most of the Ford Formation outcrop. They consist of a thick series of granular, oolitic and pisolitic carbonate rocks which are almost universally dolomitized. In most of these rocks the dolomite has recrystallised into platy crystals up to 5 mm across which give rise to a texture referred to as 'felted' and which is virtually confined to these lagoonal beds within the Ford Formation.

One of the largest exposures of late Permian reef-rocks in North-East England is at Hawthorn Quarry. An unusual algal-laminated dolomite, known as the Hesleden Dene Stromatolite Biostrome, overlies the top of the reef at Hawthorn Quarry. It has a boulder conglomerate at its

base. The biostrome is named from its occurrence further south in Hesleden Dene and it is also very well exposed at Blackhall rocks.

3.6 ROKER DOLOMITE FORMATION

The Roker Dolomite Formation includes the Concretionary Limestone, often considered as a separate unit in its own right. The two are best regarded as complementary and joint representatives of Zechstein Cycle 2 carbonates. They were formerly included as part of the Upper Magnesian Limestone along with what is now recognised as the Seaham Formation.

The Concretionary Limestone is about 100 m thick in the Sunderland area but thins southwards and dies out to the south of Seaham. It is by far the most varied carbonate formation of the English Zechstein sequence. Its best known feature is a range of calcite concretions which are spectacularly developed in the Sunderland area, most notably in the 'Cannon-ball Rock' and have been described as 'the most remarkable patterns in sedimentary rocks anywhere in the world'. Concretions are present at all levels but are abundant around Sunderland only at two levels, about 27 m and 55m above the base.

The lower beds are often so laterally variable that exact correlation of adjacent sections is difficult. The formation is composed mainly of thinly bedded granular dolomites of silt- to fine-sand grade, but the rock is locally recrystallised and in some places contains many concretions. When freshly broken these rocks usually smell strongly of oil. In all onshore areas the Concretionary Limestone has foundered and lower beds have suffered varying degrees of collapse brecciation due to the solution of the underlying Hartlepool Anhydrite.

Detailed correlation between exposures is difficult, the only exception being the widespread; 'Flexible Limestone' which is a thin relatively distinctive marker bed slightly below the middle of the formation. It is a thin laminated unit which locally can split into flexible paper-thin sheets. Plant debris is common within the Flexible Limestone and it has yielded fish remains at Fulwell and Hendon. The Concretionary Limestone is exposed in the cliffs from Trow Point to north of Seaham, and in quarries inland, most spectacularly at Fulwell. In coastal exposures the Concretionary Limestone falls into a lower group of beds containing abundant concretionary structures and an upper group in which such structures are generally absent (Plate 6)

Where the Concretionary Limestone is not developed, the Roker Formation consists of thin-bedded and flaggy cream finely granular dolomite and oolitic dolomite. It may in part be a shallow water equivalent of the Concretionary Limestone. It crops out mainly at the type locality, at Hartlepool and north of Seaham. Rocks of the Roker Formation also form a series of isolated outcrops between slipped masses of glacial deposits for about 410 metres on the north side of Dene Mouth [NZ457 408]. Inland it is exposed on the south side of Castle Eden Burn with limited exposures in Nesbitt Dene and Hardwick Dene.

3.7 SEAHAM RESIDUE

The Seaham Residue is interpreted as the insoluble remains of the Fordon Evaporites a mixture of salt (halite) and anhydrite with dolomite. At the type locality just north of Seaham Harbour it is a heterogeneous mass, up to 9 m thick, of angular blocks and fragments of limestone and dolomite in a clayey dolomite matrix. The residue is also exposed south of Blackhall Rocks.

3.8 SEAHAM FORMATION

Although itself highly variable, the Seaham Formation is the most uniform of the Late Permian carbonate units. It consists predominantly of thin-bedded limestone with some dolomite, but in places may resemble the Concretionary Limestone. Along with the Roker Dolomite Formation

and Concretionary Limestone, the Seaham Formation was once considered to be part of the Upper Magnesian Limestone sequence.

The formation carries a unique and distinctive diagnostic assemblage of alga and bivalves. Small tubular, stick-like remains of the probable alga *Calcinema permiana* are present in great abundance. The Seaham Formation is exposed mainly in coastal cliffs at Seaham, but is also patchily exposed inland in Seaham Dene. Its type exposure is in the sides of the dock at Seaham Harbour (Plate 7)

3.9 ROTTEN MARL

The Rotten Marl is a dull dark red-brown silty mudstone, which in borehole cores contains scattered halite crystals and a network of veins of fibrous halite and gypsum. It occurs *in situ* only south of the area and offshore. It was exposed with the filling of a breccia pipe, or fissure filling, at the top of the north wall in Seaham Dock, but has now been largely obscured.

3.10 QUATERNARY DEPOSITS

Quaternary deposits are sediments that were deposited during the Quaternary episode of earth history, between 2.5 million years ago and the present day. The Quaternary is divided into two periods: the Pleistocene Period dates from 2.5 million years ago until 10 000 years ago and the Holocene continues to the present day. For a long time these deposits were collectively referred to as ‘drift’, but are now more commonly referred to as ‘superficial deposits’ to separate them from the ‘bedrock’ which used to be termed ‘solid’.

Global cooling caused the Quaternary Period to be a time dominated by a series of ‘ice ages’ when the climate oscillated between colder (glacial) and warmer (interglacial) stages. Successive glaciations advanced across the landscape, sourced from the upland areas of Scotland, Wales, northern England and Scandinavia and formed extensive ice sheets that were over 1 km thick in places. Unfortunately, the nature of glaciations is that their imprint on the landscape is largely destroyed by any subsequent glacial advance, so most evidence for glacial advance in northern Britain dates from the most recent cold period, the Late Devensian, from about 25 000 to 10 000 years ago. The effects of persistent freeze-thaw action in ground which was often very deeply frozen, and the deposition of a variety of glacial sediments further modified any pre-existing landscape. The deposits of the Holocene Period reflect erosion and deposition in a varied succession of environments during much milder climatic conditions.

Quaternary deposits and their interpretation provide a wealth of information on the environments of the recent geological past. Information from glacial landforms and the nature and morphology of glacial deposits is essential to understanding these climatic conditions and may provide valuable insights into likely future environmental changes related to global warming.

Details of the Quaternary deposits are given in the geological survey memoirs for the area (Smith, 1994; Smith and Francis, 1967) and, more recently for the south of the area by Young (2008). The Quaternary Research Association Field Guide to the ‘Quaternary of North-east England’ (Bridgland et al., 1999) contains a wealth of useful and up-to-date information, including illustrations of key sections.

Glacial Deposits

There is very little evidence of the earlier part of the Quaternary in north-eastern England. The most probable reason for this is that the later glaciations reworked the material deposited during earlier glaciations and interglacial intervals. However, two sites on the Durham Coast provide evidence of the presence of Quaternary sediments that predate the last glaciation. Figure 4 illustrates the relationship of the glacial deposits found on the Durham coast.

Fissure fills in the Magnesian Limestone coastal cliffs represent the oldest known Quaternary deposits in the area, likely to have formed in the Lower and Middle Quaternary. The fissures contain a variety of boulders, fragments of rock and clay that have been forced in from above by later glaciations. A pre-Devensian till containing mollusc remains and Scandinavian erratics lies unconformably over the Magnesian Limestone bedrock at Warren House Gill about 2.5 km south of Shippersea Bay. Fossil material in some of the fissure fill from Warren House Gill and nearby Blackhall Colliery includes shells, peat, tree trunks, insects, rodent teeth and the vertebra of an elephant resembling *Mammuthus meridionalis*. Some of the fissures contain exotic rocks similar to those within the later Scandinavian Drift.

At Shippersea Bay the bevelled upper surface of the Magnesian Limestone represents the wave-cut platform on which rest the deposits of the **Easington Raised Beach** (Figure 5 and Plate 8)**.** The partly cemented sands and gravels are over 30m above the modern sea level and the deposit contains marine shells as well as pebbles bored by marine molluscs and worms. The remains of molluscan shells, which occur in the sands, indicate a temperate climate with sea surface temperatures 3–4 degrees above present temperatures. These raised beach deposits have been assigned to the Ipswichian Interglacial, indicating that the overlying boulder clays are Devensian in age. Erosion surfaces, perhaps related to post-glacial sea levels higher than the present day, and elevated by some uplift of the land, include a prominent platform up to about 0.8 kilometres wide, at about 30 metres above the present coastline between Marsden and Whitburn. This surface may be equivalent to that on which the Easington raised Beach lies further south.
The most widespread glacial deposit is ***Till (or boulder clay)*** which usually consists of a heterogeneous mixture of grey silty clay with rock fragments ranging in size from gravel and pebbles to boulders several till sequences are recognised:

Scandinavian Drift-*The Warren House Till* has been identified as a deposit that may have formed before the last glaciation. The deposit consists mainly of locally derived limestone but is distinctive because the erratics it contains have been matched with rocks that occur beneath the North Sea and in Scandinavia rather than with rocks present on the British mainland. The ice mass from which this till was deposited originated in Norway, crossed the North Sea and covered the coastal parts of the county, but it is unlikely that the ice travelled further inland. This glacial deposit, the oldest in the area, is found in the base of buried valleys and topographic lows, the clearest exposures of which are found on the coast at such localities as Warren House Gill.

The Lower till (The Durham Lower Boulder Clay) containing North British rocks including Lake District and Scottish rocks was deposited by the British ice sheet after the Scandinavian ice sheet retreated. It is possible that there is a complete climatic cycle between the deposition of the Scandinavian and British Drift deposits. It is generally a tough, grey or brown, sandy boulder clay, or ‘till’, in which occur scattered pebbles cobbles and boulders of a variety of rock types that originated outside the district. These exotic rock types, known as ‘glacial erratics’ mainly comprise fragments of grey limestone and dolerite (‘whinstone’) derived from the Pennines or south Northumberland, accompanied by scarcer and smaller fragments of a variety of rock types originating from south-west Scotland, the Cheviots and the Lake District. Many of the included boulders exhibit conspicuous scratches, or striations, resulting from the grinding of boulders against one another as they were transported by the ice

The ***Upper till*** (The Durham Upper Boulder Clay) is a red-brown stony clay that overlies both the Lower Till and the Scandinavian drift. The deposit is widespread and was deposited during the last glaciation.

In parts of the county a tripartite division in the Devensian sediments has been recognised. This consists of the Lower and Upper tills, separated by an intervening body of sand and gravel referred to as the Middle or Ryhope Sands. These deposits may have been deposited by meltwaters from the retreat of the western ice back to the Lake District and Southern Uplands. Other bodies of sand and gravel include more recent deposits overlying the upper till and locally a group of basal sands and gravels.

Various ice-contact slopes are found in the area of the Upper Till, especially between Sheraton and Hart, south of Heselden Dene (Smith and Francis, 1967, fig. 28). There is also a series of elongated or rounded ridges forming a moraine from Easington through Sheraton to Elwick.

The Pelaw Clay, which was referred to in older literature as the 'Upper Wear Clay' takes its name from the disused Pelaw Brick Pits [NZ310 625]. It typically consists of brown to purple silty clay with scattered stones. Generally between 1 and 2 metres thick, though locally over 4 metres thick, it mantles much of the north of the area, concealing other 'drift' and 'solid' formations. It has been interpreted as a product of re-working of previously deposited glacial sediments, possibly during periglacial conditions.

The **Durham Denes** are features of the landscape in the eastern part of the county. These west-east orientated steep-sided coastal valleys are incised through the cover of Quaternary Deposits into the Magnesian Limestone. The 'denes' are in part glacial meltwater channels, cut rapidly by streams flowing to the North Sea at the end of the Devensian glaciation. The distinct morphology of these channels in this coastal area is due to the rapidity of the erosion.

Holocene Deposits

Marine Beach Deposits are modern day accumulations of sand and shingle exposed between the high and low water marks. In addition to boulders and pebbles of Magnesian Limestone, a high proportion of the naturally occurring beach material appears to have been derived from the Quaternary deposits eroded from the cliffs. A variety of glacially transported rock types can be seen in most accumulations of beach shingle. Most prominent are boulders of Carboniferous limestones and sandstones, with smaller quantities of whin Sill dolerite, some Cheviot volcanic rocks and rocks derived from southern Scotland and the Lake District, including granites, volcanic rocks, slates and greywacke sandstones.

Storm beach deposits are accumulations of beach material built up by storms and high tides well above normal high tide level. Substantial deposits of colliery spoil at Dawdon Blast Beach and at Hawthorn Hive are, in effect, storm beach deposits, albeit composed of tipped material.

Submerged forest

Periods of reduced sea levels are recorded in the 'submerged forests' found locally around the British coastline. These typically comprise beds of peaty sediment with tree stumps in former growth position. One small example of such a submerged forest deposit is present at Whitburn. This is intermittently exposed, normally after storms have removed the overlying sand. Remains of a variety of tree species, including alder, birch, hazel and oak have been recorded, together with bones of deer and *Bos primagenius* (Smith, 1994). A significant exposure of peat beds with abundant wood remains is exposed in several places in the intertidal zone in Hartlepool Bay at the southern edge of the area.

Blown sand occurs as coastal dunes in the south of the area around Crimdon. The largest patches of Blown Sand are up to 2 metres thick. A small area of sand dunes, composed of wind-blown sand, lies adjacent to the coast at the mouth of the Tyne at South Shields. The dune system and

golf course roughs at Hart Warren supports many species characteristic of both northern and southern British dune floras.

By their very nature, as generally weak and unconsolidated materials, there are few permanent natural exposures of Quaternary deposits within the inland parts of the district. However, continuing marine erosion ensures that the coastal cliffs provide almost continuous, though inevitably changing, sections through parts of some of these deposits. These materials are typically found in the upper portions of the cliff sections, though their instability commonly results in parts of the Quaternary succession being partially obscured due to slipping of loose material or, in places, the development of significant vegetation cover.

In addition to numerous important exposures of Permian rocks and Quaternary deposits, the Durham coast includes a number of characteristic **coastal landforms**:

Sea cliffs extend almost continuously along the coastline. Typically the cliff profile reflects the geological deposits exposed. The 'solid' limestones of the Magnesian Limestone generally stand as vertical or near vertical cliffs. Overlying this, a more gently inclined profile marks the exposure of a variety of Quaternary deposits, mainly till and sands and gravels. The variable erosion of sections of the cliff has produced a series of bays and headlands

Sea stacks are residual masses of rather more resistant limestone created by the retreat of the cliff line. Good examples may be seen at Marsden Bay and Blackhall rocks.

Caves of varying sizes are present within the Magnesian Limestone at many places along the coast. They are readily developed by wave action where the limestone is highly fractured by collapse brecciation, or adjacent to joints.

Wave cut platforms are more or less flat areas of bare rock cut by marine erosion at beach level. Examples include the expanses of Magnesian Limestone exposed on the beach between Hawthorn Hive and Horden Dene.

4 The geodiversity of the Limestone Landscapes area

4.1 MAJOR FEATURES OF GEODIVERSITY IMPORTANCE WITHIN THE AREA

4.1.1. The rocks themselves:

- The spectacular and varied coastal cliffs in the east provide exposures of Permian-age marine rocks that are without parallel in Britain and most of Western Europe; they are unrivalled for research and teaching purposes.
- Natural sections, cuttings and quarries within the undulating limestone plateau include important rock, mineral and fossil sites, many of which are recognised as SSSIs. A number of the fossil localities are of international significance because they have yielded fossils that are the 'type' material for the scientific classification of a taxonomic group and some of the rock types display the most bizarre geologically interesting structures.

The Permian Magnesian Limestone sequence represents a highly significant chapter in the evolution of the British Isles. Within the study area, it can be seen at its finest localities in Britain justifying it as the type area for the Magnesian Limestone in Britain (Pettigrew, 1980). In addition to the Permian Magnesian Limestone sites, the area also contains sites representing other areas of earth science interest, notably palaeontology, geomorphology and the Quaternary.

The limestone is also of great interest for its range of Permian marine fauna associated with the Ford Formation, particularly within the remains of the Zechstein sub- marine reef which is considered to be unique in Britain. Key sites for marine fossils are Tunstall Hills, Humbledon Hill and particularly Middridge Quarry in the Marl Slate Formation, which is the most important locality in Britain for Permian fossil reptiles and plants. A number of the fossil localities are of international significance because they have yielded fossils that are the 'type' material for the scientific classification of a taxonomic group.

The spectacular and varied coastal cliffs between Trow Point (South Shields) and Sunderland along with the coastal cliffs at Seaham and Blackhall are mainly in limestones and dolomites in the upper part of the Permian marine sequence. They also furnish magnificent examples of the disruptive effects of evaporite dissolution (Plates 9 and 10)

4.1.2. The direct influence of geology in the shaping the broad landscape:

- The rocks form the foundation upon which the distinctive landscape of the area has been moulded by geological processes. This moulding was largely by glacial action at the beginning of the Quaternary Period from about two million years ago until about 11,500 my ago and, subsequently, by river and coastal processes.
- Durham County Council has undertaken a comprehensive landscape character assessment for that part of the Limestone Landscape area that lies within County Durham (http://www.durham.gov.uk/landscape/usp.nsf/pws/landscape+character+-+County+Character+Areas) showing that it can be divided into four broad landscape types:
    - In the north and to a lesser degree in the south where it merges with the eastern ridges of the Pennine fringe, the Limestone Escarpment is deeply divided by minor valleys giving rise to distinctive 'spur and vale' topography. In its central section it forms a more singular ridge (Plate 11)
    - East of the escarpment, on the Clay Plateau, the limestone is overlain by thick glacial drift and is rarely expressed at the surface.

- Towards the coast - roughly east of the A19 – the Magnesian Limestone crops out more frequently in the low rounded hills and steep-sided coastal denes of the Coastal Limestone Plateau.

- The Limestone Coast, with its cliffs and dunes, is defined inland generally by the coastal railway line.

The four broad landscape types are fundamentally associated with the underlying geology and can be extended across the entire area (see Figure 2). The low upland plateau of Magnesian Limestone falls eastwards to the sea and southwards to the Tees plain and defined in the west by a prominent escarpment. The soft Permian rocks that underlie the plateau are covered in most places by a thick mantle of glacial deposits but outcrop on the escarpment and coast. The escarpment is deeply divided in the north forming a spur and vale landscape which becomes less sharply defined in the south and merges with the low eastern ridges of the Pennine fringe. The topography of the plateau is gently undulating and is deeply incised in the east by coastal denes. The coastline is one of clay crested limestone cliffs, giving way in the south to low dunes, with a foreshore of sandy beaches and rock outcrops heavily despoiled in the north by tipping of coal wastes.

4.1.3. Links to biodiversity

- The chemical composition of the limestones and the nature of the thin soils that have formed upon them provide the unique substrate and conditions upon which a variety of specialised habitats can flourish. These include, but are not limited to, the important and well-documented rich and unique group of wildflowers and grasses known as magnesian limestone grassland.

Soils on limestone rock are very nutrient poor and slightly alkaline. As a result only certain plants can survive here. Two-thirds of the UK's remaining magnesian limestone grasslands are found in east Durham and Tyne and Wear. On the Durham Magnesian Limestone some of these limestone-loving plants are at the southern limit of their range and others at their northern limit. The most extensive associated areas of semi-natural grassland occur in south east Tyneside and County Durham, although even here quarrying and agricultural intensification has reduced the overall area with the result that good examples of Magnesian Limestone grassland, as at Pig Hill, tend to be small and fragmented.

The paramaritime Magnesian Limestone vegetation on the Durham Coast is unique in the mix of plant communities which it contains, and is very different from the other lowland areas of the Magnesian Limestone grassland found in County Durham.

The coastal cliffs and other features have particular flora and fauna associated with them due to their unique settings; this includes the Durham 'denes'. The Durham Coast between South Shields and Hart Warren is contains most of the paramaritime Magnesian Limestone vegetation in Britain, as well as a species-rich dune system, and supports nationally important numbers of wintering shore birds and breeding little terns which contribute to the internationally important populations of the north-east coast.

The heavy clay soils that cover much of the plateau support mixed, predominantly arable, farmland in an open rolling landscape of low hedges with few trees. Field patterns are fairly regular in places but more often fragmented by amalgamation into large arable fields. The shallow calcareous soils of the steeper escarpment slopes have a more pastoral emphasis and contain areas of older, more diverse, magnesian limestone grassland. It is almost certainly the abundance of magnesium within the rocks that accounts for the area's characteristic Magnesian Limestone Flora.

Tree cover is sparse and there is little woodland. Ancient semi-natural ash woodlands are found in the coastal denes and occasionally on escarpment spurs and valley sides together with areas of scrub. Cliffs, bays and headlands are rich in wildlife, although despoiled in places by former extensive dumping of colliery waste on beaches and foreshores. Accounts of the link between biodiversity and geodiversity can be found in Dunn (1980), the MAGical Meadows booklet (Durham wildlife Trust, 2007) and SSSI descriptions.

Until the arrival of humans on the magnesian limestone plateau, climatic change was probably the most important factor in determining the vegetation of the natural area. This is supported by evidence from pollen analysis taken from a number of sites that roughly correspond to the distribution of magnesian limestone. From the Mesolithic period onwards, people began to settle in the area and use the land for agricultural purposes. Management became the dominant influence on the vegetation as settlements grew and activities diversified.

As the area was largely covered with ice in the Devensian glaciation little is known about the vegetation prior to the Late Devensian. However, an area of peat, probably transported locally by ice, within the till at Hutton Henry has been dated to the Ipswichian interglacial (Bridgland et al., 1999). This highly compact peat contains a variety of pollen assemblages including those indicative of a pre-forest herbaceous fauna, forest with hornbeam, alder and holly, a period with bog peat and another dominated by heather and birch. Rapidly changing successional vegetation characterized the period of environmental transition and climatic amelioration from 15 000 to 10 000 BP, with a marked vegetation reversion to an open ground tundra herb flora in the cold interlude at the end of the period. In the temperate conditions of the Holocene various trees succeeded each other in the forests until a relatively stable mixture of elm, oak and hazel with birch and pine had established itself. Lime, near the northern limit of its range, became important the lowland limestone area around Bishop Middleham in the mid Holocene.

A lichen flora of natural outcrops, disused quarries and churchyards in the Magnesian Limestone has been described by Gilbert (1984).

4.1.4. The influence that the distribution of the rocks, both at and beneath the surface, has had on human activity and modification of the landscape.

The geological distinctness of the plateau has meant that developments have occurred at different times and followed different routes from its surroundings to the north and west, thus giving the area a uniqueness which persists today.

- The rocks and minerals worked, both at the surface and from beneath the ground, have influenced the development and character of towns and villages and the social history of the area. The escarpment and parts of the plateau have been affected by the quarrying of limestone. A number of older quarries that have naturally re-vegetated are managed as nature reserves.
- The rise and fall of the coal mining industry in the nineteenth and twentieth centuries has had probably the most profound influence on the recent landscape, settlement pattern and infrastructure of the area, although today much of the direct evidence of the industry can be hard to find.

There is historical evidence that the Magnesian Limestone was being quarried in earnest in Durham for lime burning in the mid to late 18th century. With the increasing use of lime for agricultural purposes in the early part of the 19th century a number of quarries in the Raisby Formation and some new ones, including the large Tuthill Quarry in the Ford Formation near Haswell, supplied burnt or ground lime. The rocks were used also for building purposes, and many of the early settlements along the Permian escarpment were built of dolomitic limestone and dolomite worked in numerous small and a few large quarries. Old agricultural villages are scattered thinly across the landscape. In the mid nineteenth century a number of additional quarries were opened in the Magnesian Limestone to provide the specialist needs brought about

by the industrial revolution - supplying flux for iron making, dolomite for refractory bricks and 'magnesia' for chemical processes. Today a number of large quarries continue to provide sand and aggregate for the construction industry and large active and disused quarries occupy prominent sites on the escarpment.

The Magnesian Limestone, by its presence, hindered early exploitation of the underlying coal seams, thereby leading to a dramatically different pattern of population and growth from that of the Tyne and Wear lowlands where the near surface coal seams could be more easily extracted. It was not until the end of the eighteenth century that improved pumping techniques permitted shafts to be sunk to depths of 200 metres, so that attempts could be made to prove coal beneath the Magnesian Limestone. The first successful sinking on the plateau was at Hetton Lyons colliery, south-east of Hetton village. The eight mile stretch of railway connecting the Hetton collieries with Sunderland over Warden Law was the longest in the world when it opened in 1822 (Moyes, 1972). Seaham Harbour, founded in 1828, provided an outlet for Lord Londonderry's colliery workings to the south of Sunderland. Improved technical skills in the sinking of shafts, largely developed in Durham, brought to the plateau a succession of new collieries that moved eastwards as it became necessary to dig deeper and deeper to reach unworked coals. The deep sinkings meant that shafts were expensive, limited in number, and individual collieries were large, employing many men. This tended to concentrate settlement, bringing to the area a group of large mining villages which contrast markedly with the smaller units of the older coalfield west of the escarpment (Roberts, in Dunn, 1980). The new mining villages infilled and expanded the older rural settlement pattern. Many were built on the site of older villages and some retain an older core. and in the substantial areas of derelict and recently claimed land in the urban fringe.

4.2 THREATS TO GEODIVERSITY

Threats to the geodiversity of the area include:

- Development or quarrying that obscures or removes landscape features and/or important geological sites.
- Coastal erosion and/or inappropriate coastal protection schemes.
- Progressive deterioration of rock exposures and infilling or inappropriate restoration of quarries.

Planning procedures today are designed to take account of environmental concerns. Providing planners are made aware of the issues then the indiscriminate destruction of important sites and features should not happen. When applications for new mineral extraction operations are made, the opportunity should be taken where possible to interpret, enhance and preserve the geodiversity.

Sections of coastline undergo continual change, exposed to extreme weather conditions, erosion of the cliffs and beach sediments, and deposition of sediments on the beach. The active processes taking place on the coast are an important feature of geodiversity. Coasts are dynamic and the forces of nature balanced so that substantial intervention may damage adjacent areas. As well as solid rocks, the coastal exposures reveal sections through features such as buried valleys, karst fissures in the magnesian limestones, sand and gravel deposits and the oldest glacial deposits in northeast England. In general, it should be accepted that coastal sections are temporary, data should be collected and recorded when opportunity arises. For many years colliery waste was dumped over the edges of the cliffs along large sections of the northeast coast. In some places colliery waste has obliterated valuable sections through the deposits that constitute the cliffs. The deposition of large volumes of waste material has altered the morphology of the beaches and halted the erosion of the cliffs. Although the sediment has begun to be eroded from the upper

parts of some cliffs the sediment has raised the level of the beaches to permanently cover the lower sections of cliffs unless substantial erosion by the sea commences.

Many of the cliff sections within county Durham contain unconsolidated Quaternary sediments in addition to, or instead of solid rock. In some localities the Quaternary deposits constitute the entire cliff as the bedrock level is below sea level giving rise to very different stability considerations (Plates 12 and 13).It has been estimated that until the beginning of the 20th century parts of the Durham coast were eroding at an average rates of between 2 and 3 metres per year. Progressive accumulation of large volumes of colliery waste, dumped onto the beaches, resulted in a marked reduction in this rate of coastal retreat. With the ending of tipping, and the clearing of much of the accumulated spoil from sections of the coast, erosion rates of between 0.3 to 0.6 metres per year have been predicted.

Many years of dumping of colliery spoil particularly from collieries in the Dawdon and Easington area led to huge and disfiguring accumulations of Coal Measures shale, sandstone, pyrite and some coal on the Durham beaches. Long-shore drift spread much of this material southwards along the coast. Through the 'Turning the Tide' project (http://www.turning-the-tide.org.uk/), much of this contamination has been removed and many of the county's beaches are now approaching their original composition. Significant concentrations of colliery spoil remain locally. High concentrations of pyrite in the beach sand and shingle remain in the Dawdon and Hawthorn areas.

Threats to quarries and natural sections arise from inappropriate development, vegetation enhancement, tree planting, instability and slumping of faces and sections, and in the case of disused quarries, landfill. The possibility of inappropriate recreational activities and wanton vandalism destroying sections also needs to be considered, especially in the vicinity of urban areas. The grassland at Tunstall Hills SSSI has been subjected to erosion by the use of motor bikes, rock faces at Tunstall Hills and Claxheugh rock have been defaced with graffiti and indiscriminate tipping of rubbish is quite common.

4.3 ENHANCEMENT OF SITES

In order to maintain the geological integrity at most sites it is necessary to have well exposed and easily accessible rock faces. Thus, it may be necessary to clear vegetation and in some cases to clean or re-excavate parts of sections. It is of course essential that landowners and where appropriate responsible bodies, such as Natural England, are involved at all stages. It is also vital that a trained geologist is involved. Additionally, the geological management of sites should be carefully considered in conjunction with any botanical, archaeological or other heritage needs especially when clearing vegetation or redistributing talus. 'Geological Conservation: a guide to good practice' (Prosser et al., 2006) is a good introduction to the principles involved. Careful consideration needs to be given to ensuring that the access to sites, and where possible, the content, is suitable for people with disabilities.

5 Geodiversity Site selection

5.1 EXISTING DESIGNATED SITES

The geology within the study area has been discussed and considered for over 200 years. It is presented in a wide variety of scientific, conservation and general publications that, coupled with local knowledge and recent geodiversity studies for parts of the area, provide a sound basis for this study. The major sources of information consulted are listed, with brief synopses, in Appendix 2.

Most important, there is a strong record of geological conservation within the area by local councils, Durham County Council and national bodies such as Natural England (mostly in its former guise of English Nature) and the Joint Nature Conservation Committee. In the 1980's, Sunderland Borough Council, in co-operation with the Nature Conservancy Council and the British Trust for Conservation Volunteers preserved eight key localities in the magnesian limestone reef, most of which are now listed as SSSIs. Durham County Council was the first local authority to produce a Geological Conservation Strategy, published in 1994. This lists 20 County Geological sites within the area which are locally significant in terms of earth science conservation (see Appendix 3). Local Sites have been designated for their geodiversity interest by local councils, The Durham Wildlife Trust and by RIGS (Regionally Important geological and Geomorphological Sites) groups (http://www.ukrigs.org.uk/html/ukrigs.php). The discovery and preservation of the Sunderland North Dock Tufa RIGS is cited as a case study of earth science conservation in an urban development (Fenwick and McLean in Bennet et al., 1996). The Tees Valley RIGS Group (http://tvrigs.org.uk/tees-valley-rigs-group) is active in the very south of the area, but there is currently (April 2009) no active RIGS presence further north. Reserves and sites of national and international importance have been approved by Natural England and European bodies. More comprehensive discussion of each of these types of site can be found in recent geodiversity publications for the area (Lawrence et al., 2003 and Young, 2008).

Very many such sites have been identified for biodiversity or geological conservation within the project area, although not necessarily in strict accord with the recent Defra Local Site Guidance (2006). There is also geodiversity interest in a number of the sites designated for a non-geological reason.

The scientifically most important sites are those identified in the Geological Conservation review. The Geological Conservation Review (GCR) was initiated by the Nature Conservancy Council in 1977 to identify, assess, document and eventually publish accounts of the most important parts of Great Britain's rich and varied geological heritage. GCR sites are those of national or international importance. Almost all the sites within the Limestone Landscapes area meet at least two of the main selection criteria, and some sites satisfy all the criteria for GCR sites (http://www.jncc.gov.uk/pdf/Chapter4.pdf.). Twenty-two GCR sites have been recognised in the study area (see Appendix 2) and subsequently designated as SSSIs. Seventeen of the sites are Marine Permian sites, representing two-thirds of all the GCR sites of this type nationally. Several of these are without parallel in the UK and Western Europe and are considered to be of international importance, i.e. Blackhall Rocks, Claxheugh Rock and Ford Quarry, Fulwell Hills Quarry and the coastal cliffs of Trow Point to Whitburn Steel (Smith, 1994). Many of the SSSIs in the area are type localities and lend their name to established stratigraphical nomenclature for the Upper Permian sequence. These include Ford Quarry (Ford Formation), Seaham Harbour (Seaham Formation) and Raisby Hill Quarry (Raisby Formation).

Coastal geomorphological processes and landforms are also well represented along the Tyne & Wear coastline from Trow Point to Whitburn Bay and sites important for demonstrating

Pleistocene and Quaternary deposits also occur further south along the coast at Warren House Gill and Shippersea Bay. Lastly, small sections of the underlying Carboniferous Coal Measures are exposed along the Wear River Bank at Sunderland. This section exhibits the best permanent exposure of the Carboniferous Permian interface in the region, as the Upper Carboniferous strata and the basal layer of the Permian sequence (Yellow Sands Formation) are represented together.

The sites are described in the following published GCR volumes:

No. 8 Marine Permian of England Smith, D.B.1995Huddart, D. and Glasser, N.F. (2007)

No 9 Palaeozoic Palaeobotany of Great Britain, Cleal, C.J. & Thomas, B.A., (1995),

No. 10 Fossil Fishes of Great Britain Dineley, D. & Metcalf, S., (1999)

No. 11 British Upper Carboniferous Stratigraphy, Cleal, C.J. & Thomas, B.A., (1996)

No. 16 Fossil Reptiles of Great Britain, Benton, M.J. & Spencer, P.S., (1995)

No. 25 Quaternary of Northern England, Huddart, D. and Glasser, N.F. (2007)

No. 28 Coastal Geomorphology of Great Britain May, V.J. and Hansom, J.D. (2003)

The site descriptions in these volumes are accompanied by an extensive bibliography.

Natural England also hold 'Geological site Documentation and management briefs' for each of the SSSIs which contain detailed information about the sites and were made available for consultation (listed in Appendix 2).

5.2 SELECTION OF SITES FOR LIMESTONE LANDSCAPES

It is not so much a question of finding sufficient sites, but more one of how to identify which of the multitude of sites are most appropriate for the task in hand. It goes without saying that the geodiversity at GCR sites and geological SSSIs is of great scientific importance; it does not, however, mean that they are all suitable for interpretation or development. They still remain an important part of the geodiversity of the region and need to be preserved, made available and perhaps better advertised to the geological community but existing conservation measures should already be in place for this. On the other hand, some GCR sites would be most appropriate for interpretation and development as part of Limestone landscapes.

The initial brief was for the identification of up to 25 sites which best represented the geodiversity of the area. However, in order to ensure continuity and connectivity with other aspects of the natural heritage and community usage, it was agreed at the first review meeting that it would be most appropriate to prepare a more comprehensive list of sites categorised by geodiversity quality. For example, two adjacent quarries might display the same geological feature, quarry one better than quarry two. But quarry two might display additional natural heritage features, already have community use and thus be a better option for developing geodiversity potential as part of a holistic scheme. Consequently, although some proposals are made for actions and management at sites, these must be considered as provisional until viewed in the wider context of the Limestone Landscapes Action Plan. Extensive discussion with community groups and interested parties will be needed to ensure that the best sites are selected with the prospect of medium to long term sustainability. Several of the sites recommended are SSSIs and is vital that Natural England are involved with any plans for these.

The selection of sites has been in part guided by the recent report "GeoValue: Valuing Geodiversity for the Community" (Scott et al 2007c; http://www.sustainableaggregates.com/docs/theme3/miro_ma_5_2_001a.pdf). This includes discussion of a number of criteria for site selection including those recommended by RIGS http://www.ukrigs.org.uk/html/ukrigs.php?page=downloads&menu=main) and the Geodiversity

profile handbook (Scott et al., 2007a; http://www.sustainableaggregates.com/docs/theme3/miro_ma_5_2_001b.pdf).

However, of overriding importance for the purpose of this study it is believed that the geodiversity at the location should:

- Be sufficiently clear /obvious/observable that, given appropriate interpretation or explanation, a non geologist will be able to recognize it.
- Have geodiversity features that are believed to be sufficiently robust to embrace community use of the areas.
- Be accessible and could link with Access to Nature
- Where possible link to other aspects of the environment and to other geodiversity sites.
- Be suitable for educational use at a variety of levels. Where possible links in with existing or proposed community initiative/space. It is hoped that nature-based voluntary and community organisations and locality-focused groups will be able to use the sites selected as a 'bridge' for wider community involvement.
- Have potential to engender local pride in the natural heritage.

This study concludes that, for the most part, a selection made from those sites (in some cases enclosing considerable areas) that already hold some form of nature or community designation, or are candidates for such designation, should enable a very good representation of the geodiversity to be conserved, presented and interpreted. It is felt that it would be most appropriate for a combination approach of mainly enhancing existing geological sites while developing some others where the geological interest is not the main reason for designation, for examples quarries featured in the MAGical Meadows project.

The locations selected include:

- Natural outcrops
- Coastal sections
- Disused Quarries
- Working quarries
- Sites with heritage/biodiversity/cultural links

The sites have been divided into three broad categories:

1. Those that have important and well-displayed geodiversity, generally have good access, would be appropriate for some form of interpretation and in many cases have links with other heritage features.

2. Those that have good geodiversity, often paralleling that in some of the sites in category 1, but probably are not as convenient or do not have such good heritage links. Consultation with communities and detailed consideration of other natural heritage or greenspace issues might promote some of these to category one. Most would be suitable for inclusion in themed trails or as viewpoints.

3. Sites that mostly have scientific importance, but are perhaps too specialised or have poor access for general use. Some could be incorporated in local trails or education initiatives.

Some sites, such as SSSIs, already have extensive descriptions available. Such information is not duplicated here, but supplemented where appropriate.

6 Opportunities for interpretation, involvement and enhancement

Well-planned earth science interpretation not only highlights the importance and relevance of geological interest, but also has enormous potential to contribute to, and enhance, the understanding of features and sites of parallel interest. It is recommended that in the first instance an 'Interpretive Master Plan' should be produced for the area's geodiversity. This should provide ideas and an approach for communicating the stories associated with each geological site in a way where "the whole" becomes greater than the "sum of its parts". The whole story should be coordinated and take people on a journey of discovery through Limestone Landscapes. To inspire wider interest in the relevance of the geological heritage of the area, natural, scenic, historical, cultural, archaeological and recreational qualities need also to be woven into the interpretive themes for each site as well as key messages and related stories.

Context, corridors and connectivity - Make people want to look a little further and show them how/where to do it. Museum to field and vice versa. Tie in with existing community initiatives

Much has been written about the geology of the area at a whole range of levels from the most complex geological description to the very broad. However, accessible information that enables a good understanding of the geodiversity to be reached by the non specialist is very hard to find. Even within sites noted for their geological importance the features of interest are commonly not conserved, displayed or interpreted to best effect for appreciation by the local or wider community (Plate 14)

A variety of methods of communication should be adopted. Getting to and examining sites and following trails could lend itself to modern techniques incorporating GPS, mp3 and podcasts. Instead of interpretation boards information could be delivered to mobile phones or ipods etc and linked with GPS. However, some people will prefer to use more traditional methods.

Business, health, education and heritage need to be signposted explicitly in any Partnership communication material so that the attention of these sectors is gained. Specific projects are needed to encourage the involvement of non specialists.

6.1 WORKING WITH ORGANISATIONS AND COMMUNITIES

There are already a few good examples of geodiversity in action within the area, but these are apparently happening in isolation. The following organisations should be consulted in addition to the partners and others already involved with Limestone Landscapes.

The **North East Geodiversity Forum** is a potential link with organisations and local geologists active and with an interest in the area.

The **National Trust** owns a part of the coast with dramatic geological exposure in the north of the area and has already put in place some interpretation, but there is considerable potential for further involvement with geodiversity along the lines of the Trust's geological policy (http://www.nationaltrust.org.uk/main/w-chl/w-countryside_environment/w-nature/w-nature-geology.htm)

- The Trust will care for the natural and cultural geological significance of all our properties.

• The Trust will inform conservation and manage change in the geological environment and its features through learning, identifying, recording, understanding and communicating its significance.

• The Trust will share the geological significance of our properties with members, visitors and stakeholders for all to appreciate and enjoy.

Durham University is active in scientific outreach in the North East and has a number of schemes that might be able to contribute to the geodiversity in the area (the current co-ordinator Dr. Paula Martin is an earth scientist)
(http://www.dur.ac.uk/science.outreach/outreachschemes/) .

Sunderland Museum has long been a proponent of the geology of the region It has recently (2008) purchased an important collection of Permian fossil fish.

Durham Wildlife Trust and the **Natural History Society of Northumbria** have contributed to the understanding and protection of geodiversity.

The **Tees Valley RIGS Group** is active in the southernmost part of the area and has designated RIGS sites, some of which are proposed for incorporation in Limestone Landscapes. The group should have a prominent role in any projects within their area of jurisdiction (http://tvrigs.org.uk/tees-valley-rigs-group).

The nascent **Northumbria RIGS Group** should be encouraged to participate.

A number of **community groups** are active in areas that are suitable for geodiversity development (e.g. Tunstall Hills Protection Group)

Durham Heritage Coast
(http://www.durhamheritagecoast.org/DHC/usp.nsf/pws/Durham+Heritage+Coast+-+Durham+Heritage+Coast+-+Welcome)

6.2 SUGGESTIONS FOR MAJOR THEMES THAT COULD BE DEVELOPED AND/OR INTERPRETED

Unusual Rock Types

There are some very unusual rocks types exposed in the area (e.g Cannon Ball Limestones, Spherulitic beds in the Concretionary Limestone; Collapsed Beds). These are unique to Britain, some possibly to the world (Plate 15). Interpretation could include:

- Creating a sensory rock trail with interpretation for visually impaired - the rocks of the area have possibly the widest textural variation of any in Britain and variations can be easily distinguished by touch. Such a trail could gain fame well outside the area and provide inspiration for similar initiatives in the UK. An example of a sensory trail in South Africa that includes rocks is shown in Plate 16.
- Creating trails with opportunities for design, photography and sketching of mineral and crystal development (with discouragement of collecting)
- A calendar of rock types
- What do we see – art work

The Upper Permian reef

The Zechstein reef of north-east England has long been known to geologists as one of the classic collecting grounds for Upper Permian marine faunas. Tertiary uplift has given the reef a gentle southerly tilt and consequently most of the main exposures of the reef base and core occur in the Sunderland area. Further south successively higher stratigraphical levels are exposed within the reef where they have not been removed by erosion. The reef has produced a rich and varied invertebrate fauna of international significance. Included are numerous brachiopod, bivalve, nautiloid and bryozoa species, together with rarer examples of echinoids and corals. Much of the shelly fauna was exhaustively collected and described in the nineteenth century. Today it is extremely difficult to distinguish fossils in the exposures. From its northerly outcrop at Down Hill, the reef can be traced southwards through the western suburbs of Sunderland into County Durham, where it is known to extend a short distance south-west of Hartlepool, a total distance of around 32km (Hollingworth and Pettigrew, 1988).

Development could include:

- Interpretation of reef localities
- Guides and explanations to identifying fossils
- Links to the fossil collection in Sunderland Museum
- Route linking reef outcrops
- Enhancement of Tunstall Hills, in conjunction with the Tunstall Hills Protection Group (http://www.tunstallhills.org.uk/index.html)
- Enhancement of Ford and Hawthorn quarry sections, perhaps involving selective re-excavation.

Fossils of the Marl slate

The Marl Slate Formation has yielded a wealth of extremely important vertebrate and invertebrate fossils for which it is internationally renowned. It is locally rich in well-preserved fish, especially species of *Palaeoniscus*. Fine examples have been recovered from several sites in the east of the county. Middridge Quarry, which has yielded bones of the Upper Permian reptiles *Protosaurus*, and *Adelosaurus* together with the amphibian *Leptosaurus*, is regarded as Great Britain's finest Upper Permian reptile locality. The site has also provided Britain's most diverse assemblage of Upper Permian plant fossils. Part of a skeleton of *Coelurosaurus*, a reptile believed to have been capable of gliding flight, and one of only a handful of such specimens known from Europe, was discovered in 1978 in the Marl Slate at Eppleton Quarry, Hetton-le-Hole. The interpretation of the Marl Slate could be enhanced by:

- Links with fossil collection in Sunderland Museum
- Encourage stockpiling of Marl Slate from active quarries
- Fossil trail
- Interpret and develop Middridge Quarry (Plate 17)

Building stone

Prior to about 1800 the rocks of the Magnesian Limestone were used mainly for building purposes, and most of the early settlements along the Permian escarpment were built of local stone. Many of the stone quarries were opened in the evenly bedded Lower Magnesian Limestone (Raisby Formation) which provided the most suitable building material. With the exception of reef-rock, which has been used on a small scale in buildings at Hawthorn, Easington, Peterlee and Hesleden, the dolomite of the Middle Magnesian Limestone is too soft and variable for building purposes, but the Upper Magnesian Limestone was formerly worked in large quarries at Hartlepool, and forms the substance of nearby churches, harbour works and private houses. Magnesian Limestone was quarried to build the Roman Fort at Arbeia, South

Shields. Good examples of building in a variety of styles with Magnesian Limestone can be seen in Whitburn (Plate 18).

- Identify and match the stone in buildings to those in quarries
- local community/school projects

Coal Mining

For a long time there was speculation and uncertainty as to whether coal lay below the Magnesian Limestone. Coal was first proved to exist here by the sinking of a pit at Haswell in 1811 but the first great deep pit in the region was sunk at Hetton in 1821. Sunk to a depth of over 1000ft, it became one of the most productive pits in the region as well as a focus for some of Stephenson's important locomotive developments. Monkwearmouth, 1700 ft in 1846 was the deepest coal mine in the country. The methods introduced to mine coal from deep beneath the limestone plateau at the beginning of the nineteenth century were taken up throughout Britain and indeed the world.

The first person to demonstrate that a steady light could be employed in coal mines without the danger of external explosion, was Dr. William Reid Clanny, of Sunderland. On May 20th, 1813, he announced his discovery at a meeting at the Royal Society of Arts in London, when he presented the Society with the first miner's 'Safety Lamp'. **A modification of this lamp** was used in Herrington Mill Pit**,** in 1815, making it the first colliery in which a safety lamp was used http://www.welshminerslamps.com). Items that can develop the mining aspects of the area include:

- Importance in history of coal mining
- Social history
- Personalities involved
- Interpretation and trails
- Community Pride in history

Some interpretation on coal mining is already in place e.g Seaham ‘3 Pits’ sculpture, Easington Shaft and Adventure through time leaflets, Information Board on Haswell Cycleway (Plates 19 and 20)

Coastal change

There is considearble potential for examination of historical records/photographs/illustrations to see how the coast has changed. Coastal change in the area reflects both natural processes and man’s influence, both negative and positive, with links to scientific exploration, social history and archaeological studies. BGS holds a a set of sketches of the Durham coast prepared by D B Smith in the 1950s, and pictures taken for the geologist Carruthers glacial undermelt theory. Significant archives of material must be available elsewhere.

Eminent geologists and naturalists of the Magnesian Limestone

The Magnesian Limestone has been studied for more than 190 years and the names of some of the early workers - Geinitz, Murchison, Phillips, Sedgwick and Sorby - would grace any geological hall of fame. More recently Trechmann and Smith have made great advances in the understanding of the rocks. A number of naturalists, such as John Winch studied both the rocks and the flora and fauna of the district. Trechmann wrote about geology and archaeology. Despite this formidable assault, and the efforts of a host of later workers, the Magnesian Limestone still retains many of its secrets.

- Research into the history of these workers, including biographies, paintings and photographs could prove an interesting link to social history.

Geodiversity and biodiversity

- Explaining the geodiversity interest at some existing biodiversity sites, such as nature reserves, would serve to provide added interest to those sites in the winter and when the nature interest is not at its height.
- Link sites with biodiversity interest to those with geodiversity interest and similar geology.
- Build on MAGical Meadows project

Quarrying

- Links to agriculture - With the increasing use of lime for agricultural purposes in the early part of the 19th century, a number of quarries in the Lower Magnesian Limestone and some new ones, including the large Tuthill Quarry near Haswell, in the Middle Magnesian Limestone (Ford Formation), supplied ground or burnt lime.
- Links to industry - quarries also supply crushed limestone and dolomite for use as building aggregate, building lime and road metal. Substantial amounts of dolomitic limestone were formerly employed in the chemical industry, particularly in the making of refractory products and as a flux in steel-making, though this use has declined markedly in recent years (http://www.thebgs.co.uk/mineralsuk/downloads/mpfdolomite.pdf).
- Research into social history and links with industrial archaeology, e.g 200 years of quarrying at Aycliffe http://www.aycliffehistory.org.uk/html/AycliffeQuarry.htm

Active Quarries

Active quarries (Plates 21 and 22) have high potential for local geodiversity involvement on a periodic and planned manner. Indeed some already encourage such activity on a controlled basis. Active quarries are listed in Appendix X. Recent examples of methodologies and procedures for recognising and managing geodiversity, particularly in association with quarry operators, are summarised in the publication “Creating environmental improvements through geodiversity” (Scott et al., 2008; http://www.sustainableaggregates.com/docs/revs/t3b_geodiversity.pdf)

- Quarry trail (see above)
- Permanent viewing area and interpretation
- Education (see below)
- Active quarries are usually keen to work with local communities on conservation and enhancement projects

Funding may be available through the Aggregates Levy Sustainability Fund

Walks and trails

Incorporate geodiversity in existing walks or cycle trails, combine with other heritage interests, prepare new geodiversity-centred trails

- Use Existing walks - link 2 or 3 nearby sites – eg grassland, archaeology and quarry via public footpaths. Students could make mp3 recordings at school (Plate 23)
- New geological trails, e.g. coastal trails such as those produced by Scottish RIGS groups http://www.scottishgeology.com/findoutmore/rigs_in_scotland/L&Binterpretive_lflts.html
- e.g.view of landscape from the jubilee walk http://county.durham.gov.uk/sites/dli/Pages/JubileeWalk.aspx
- Create new cycle trail (eg see North Pennines AONB ‘Wheels to the Wild’ cycle route that has been designed as a voyage of discovery taking in the fascinating landscapes and geology of the area (http://www.northpennines.org.uk/index.cfm?articleid=9246).
- Trail linking old collieries

- Durham coastal footpath: This long distance footpath traverses some fascinating geology and landscape, some of which are of world renown. An easy to follow guide to the features, which can be seen along the footpath, would greatly enhance understanding and enjoyment of this route.
- Quarrying trail – to demonstrate the past and present importance of stone, for buildings, roads and a host of constructional and industrial uses. The trail could incorporate landscapes affected by quarrying, buildings which incorporate interesting examples of stone, as well as pointing out characteristics easily discernible from publicly accessible footpaths, picnic sites etc. Operators of working quarries should be encouraged to participate in preparation of the trail, perhaps by facilitating access to workings on special occasions.
- Permian trail - The Permian rocks of the area are of international fame. They include coastal exposures of these famous limestones, celebrated outcrops of Permian desert sands and the fish-bearing Marl Slate. Not only are these fascinating rocks with a remarkable story to tell, they give rise to a highly distinctive landscape, including the fine Durham coastal cliffs, as well as a rich and beautiful assemblage of plants and associated fauna. The MAGical Meadows project and booklet demonstrate the interdependence of the geodiversity and other heritage features, but leave much scope for the explanation of the geological history.

Viewpoints

Identification of main viewpoints - eg Tunstall Hills, Beacon Hill, Views of escarpment, View towards Frenchman's Bay.

- Leaflets
- Interpretation Boards
- web-delivered information to ipod etc
- Trail linking best viewpoints

View of the Easington—Elwick Moraine	NZ 431364	Road from A19 to Hutton
	NZ 447382 and NZ460386	Road from Castle Eden to Blackhall Rocks
Tunstall Hills	NZ391 544	
Beacon Hill	NZ441 454	
Penshaw Monument	NZ335 545	

Quaternary geology/Geomorphology

Considerable scope exists for the explanation and interpretation of Quaternary features and landforms in the area.

Education

Many eductional opportunities exist at all levels including School/University/Community/U3A these can be enhanced by:

- RIGS educational project eg to explore coastal sites.
- Field guide at school level
- Comparing the past to the present:
  - Zechstein sea to North Sea
  - Fossils to current species. eg the Coelacanth was believed to be extinct until a fish was caught off South Africa in 1938 (http://www.pbs.org/wgbh/nova/fish/letters.html)
  - Yellow Sand -Ancient desert dunes to modern dunes (or coastal dunes) (plates 24 and 25)
- Quarry companies already have national educational programmes that could be utilised:
  - Tarmac welcomes school visits to most of its operational quarries and its Quarryville website (www.tarmac.co.uk/QUARRYVILLE/teachers/visits/) is an education resource for schools that supports key content areas of the National Curriculum, Key Stages 2 and 3. Use of the pupil activities will meet many of the aims of the curriculum, especially those related to Science and Geography. However, there are opportunities to incorporate other subjects, notably ICT and Citizenship.
  - Lafarge Aggregates & Concrete UK is committed to developing relationships with schools close to their sites. The company also supports national education initiatives such as Enterprise Week. Schools and other education groups are welcome to visit operational sites including hard rock and sand & gravel quarries, landfill and recycling centres and Readymix plants.
- Establish local children's geology club on the lines of North Pennines 'Rock Detectives' or the Geologists' Association 'Rockwatch' club for young people (http://www.rockwatch.org.uk/

7 Recommendations for geodiversity action plan

OBJECTIVE 1 Raising awareness of the area's geodiversity	1.Hold a series of presentations and workshops with *Limestones Landscapes* stakeholders, local businesses, community groups etc. to promote the contents of the geodiversity audit and action plan
	2.Establish a group of operators of working quarries and encourage them to consider controlled access to and protection of exposed geological features and to continue making available stockpiles of interesting waste material
	3. Prepare a master interpretive plan and undertake a comprehensive analysis of existing interpretation associated with sites and features of geodiversity interest.
OBJECTIVE 2 Conserving/Restoring	1. Undertake consultations to agree priority sites for enhancement and development
	2. Clearing and stabilising faces and improving access at up to 10 sites to conserve and enable access to good quality geological sections that represent the full spectrum of geodiversity in the area. A number of these are SSSIs and money might be available for match funding under the Natural England Face Lift programme. To include: Middridge Quarry (Marl Slate Formation - world famous fossil locality); Bishop Middleham/Trimdon Grange quarries (Raisby Formation); Tunstall Hills (Reef); Ford Quarry (Reef); Fulwell Hills Quarry (to include sensory rock trail – see below)
	3. Prepare a clear collecting policy and seek to identify a site (or sites) suitable for collecting by educational and recreational groups drawing on best practice.
OBJECTIVE 3 Access and Learning	1. Create a sensory rock trail with interpretation for visually impaired - the rocks of the area have possibly the widest textural variation of any in Britain and variations can be easily distinguished by touch. Initially within single quarry (e.g. Fulwell Quarry), and consider extending to additional locations.
	2. Open days at active quarries - incorporate opportunity to search for fossil fish from stockpiled Marl Slate.
	3. Investigate further links with quarry companies - e.g. establishing viewing area with interpretation could also feature biodiversity. Possible match funding from Aggregates Levy Sustainability Fund.
	4. Prepare ipod trails, web-based materials to encourage visitors. Include magnificent fossil material from the area some of which is held in local museums. (Preparation of ipod trail, other media materials, could be undertaken by local school, as a community event, in conjunction with Durham University, BGS etc.)

OBJECTIVE 4 Education	1. Prepare educational and explanatory materials at variety of levels - school, university, U3A.-Lifelong Learning. Could involve RIGS education officer nationally and Tees RIGS group
	2. Coastal trail/Quarry trail leaflets linked to GPS/mp3 etc.
	3. Series of talks from 'experts' comparing the past to what we can see in other parts of the world today, e.g. Sand dunes in UAE. Sabkhas in the Arabian Gulf. Investigate twinning with other areas/countries.
OBJECTIVE 5 Increasing Community Participation	1. Investigate and celebrate important local people associated with geodiversity in its widest sense
	2. Involvement of community group in cleaning up and explaining a site e.g. reef Limestone at Tunstall Hills.
	3. Event to celebrate the unusual rocks of the area - opportunities for art and photography - could coincide with the launch of the sensory trail
	4. Quarry open days
	5. Establish local children's geology club on the lines of North Pennines 'Rock Detectives' or Geologists' Association 'Rockwatch'.
	6. Link in with events at Sunderland (and other) museums
OBJECTIVE 6 Training and skills	1. Provide support and training for heritage bodies and the existing network and new volunteers e.g. National trust staff and volunteers, coastal rangers in understanding and explaining the world class geodiversity of the area. Durham wildlife Trust.
	2. Students on science outreach projects from Durham University (Dr Paula Martin, the programme co-coordinator is a member of the North-east geodiversity Forum) could work with schools.
OBJECTIVE 7 Seek additional funding	1. Investigate Aggregates Levy Sustainability Find (ALSF)
	2. Investigate Natural England 'Face-Lift' programme for SSSIs

Brief descriptions of principal geodiversity sites

The main geodiversity sites are illustrated here to give an indication of the variety of potential in the area. This should be viewed in conjunction with the more comprehensive list of categorised sites.

Information in some of the tables is incomplete and should be supplemented at the next stage of the study with information from complementary specialist reports and stakeholder and community groups.

Sites described:

Key to designations:
NNR - National Nature Reserve
SSSI - Site of special scientific interest
GCR - Geological Conservation Review site
CGS - County Durham Geological site
LNR - Local Nature Reserve
DWT - Durham Wildlife Trust Site
MAGical - locality identified for visiting in MAGical Meadows project

Fulwell & Carley Hill quarry							438200	559800
Disused Quarry Owned by	The quarry has long been justly famous for its bewildering array of bizarre calcite concretions. Unusual rock types are exposed in series of rock faces. Building stone connection. Some of the most dramatic textures are in fallen and loose blocks lying around the quarry. Opportunity for community involvement							
Proposed Action	Undertake detailed survey of current condition. Many of the sections are overgrown. Ensure most interesting examples are visible by cleaning and expososing as necessary . Prepare a 'sensory' trail with description and examples of the rock textures suitable for the visually disabled and with wheelchair access.							
Existing Designations	GCR	LNR						
Existing on site interpretation	None							
Major geodiversity interest	The disused quarries at Fulwell and Carley Hill are of national geological importance showing the greatest variety and most spectacular development of dolomites and dedolomites in the Late Permian Concretionary Limestone. The series of dolomites and concretionary limestones exposed in these quarries consist of thin-bedded to massive, grey and brown crystalline, finely laminated limestone with subordinate beds of unlaminated cream-coloured dolomite which were deposited during the second cycle of the English Zechstein. The laminated beds display a great variety of calcite concretions, with complex three-dimensional combinations of concentric, rhythmic bands and radial calcite crystals, on scales ranging from millimetres to more than 20 cm, some of which are associated with bedding and joint planes. The unlaminated, dolomitic beds generally contain fewer calcite concretions and these tend to be of a subspherical, so called "cannon-ball", type. Well preserved plant and fish remains have been found at several levels at Fulwell Quarry and fish remains are best known from, and most abundant in, a thin bed about five metres above the base of the Flexible Limestone.							
Biodiversity interest	Associated areas of semi- natural Magnesian Limestone grassland.							
Other heritage links	Building stone and industrial archaeology connections. Fulwell windmill was built with stone from the quarry (1808) Quarrying, largely for lime burning and building purposes, started before 1746 and ceased in 1957; much of the output was transported by wagonways to ships on the River Wear, 2 km to the south.							

Fulwell & Carley Hill quarry	438200	559800
Additional comment	Links by footpath to Fulwell Mill. Good viewpoints	






Date of photography	2008	

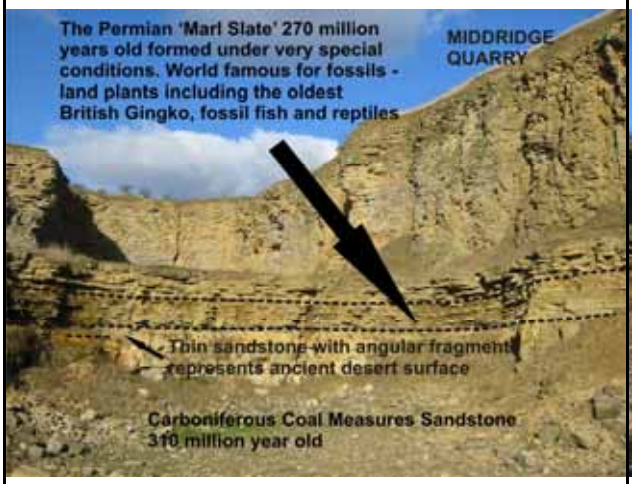
Tunstall Hills and Ryhope Cutting						439100	554600
Natural outcrop and quarry Tunstall Hills managed by Sunderland City Council	Tunstall Hills is a complex site of considerable geological and botanical interest in an urban setting to the south of Sunderland. Its geological interest centers upon numerous rock exposures of the Permian reef which occur on the Maiden Paps, in disused quarries and in cuttings above the reclaimed Ryhope railway line. It is a very good viewpoint.						
Proposed Action	The reef exposures were improved by Sunderland County Council, English Nature and community groups in the 1980s but are now largely degraded. With a very active Tunstall Hills Group today the time is ripe to revaluate, re-expose and interpret so that fossils can be seen again.						
Existing Designations	SSSI	GCR	LNR	MAGical			
Existing on site interpretation	Board describing nature reserve with brief information on geology.						
Major geodiversity interest	Tunstall Hills has been known for many years as one of the best areas for the study of the Middle Magnesian Limestone (Ford Formation) reef and its fossils. Numerous type specimens have been collected from the area and the outcrops display various reef facies not seen at other localities. Several of these are not dolomitised or have only been partially dolomitised. Undolomitised outcrops, particularly those in the reef-base coquina, have yielded a diverse and superbly preserved shelly fauna, including colour-banded gastropods, which are unknown from equivalent carbonate rocks deposited during the first cycle of the Zechstein in northwest Europe. The reef-base coquina also contains a vertebrate fauna.						
Biodiversity interest	The species-rich grassland which has developed on shallow soils overlying the Magnesian Limestone, is botanically important. A range of other habitats are also represented here, including scrub and woodland. Also good for butterflies.						
Other heritage links							
Additional comment							

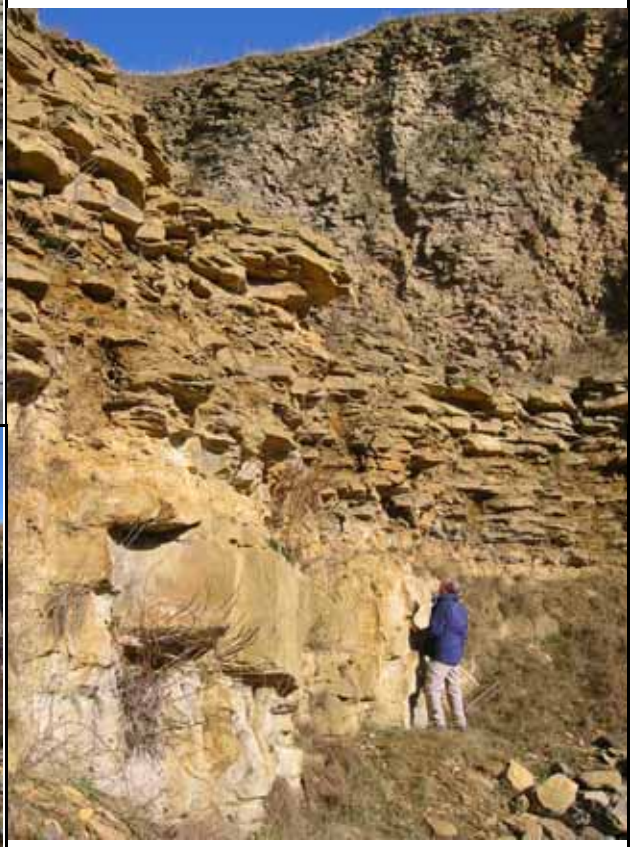
Tunstall Hills and Ryhope Cutting	439100	554600

Date of photography	2008

Middridge Quarry						425200	525200
Disused Quarry Ownership not known	One of the most significant geodiversity sites in the area. Exposes rocks from the basal unconformity and breccia with the overlying Marl Slate Formation up to Ford Formation; here the Marl Slate Formation is world famous for fossil vertebrates, fish and plants.						
Proposed Action	Prepare interpretation. Consider re-exposing unconformity. Would be a good site to feature on the importance of the area for fossils of international importance.						
Existing Designations	SSSI	GCR					
Existing on site interpretation	None						
Major geodiversity interest	Geological succession from Coal measures to Ford Formation exposed in the site. A key site with the richest and most diverse Permian flora in Britain. Its conifer dominated flora compares with the Kupferschiefer flora of Germany and Hungary. The assemblage at Middridge is of great interest for yielding the oldest British ginkgo. Middridge quarry is the best British Permian tetrapod locality. Three species of fossil reptile were collected from the vicinity in the last century: two species of Proterosaurus and a Lepidotosaurus. Finds of bone indicate the potential of the site.						
Biodiversity interest							
Other heritage links							
Additional comment	Displays a very good sequence of basal Permian breccia beds which differs somewhat from the sequence in Thickley Quarry 1 km to NNW. The basal muddy conglomerate bed (0.34m) passes upwards directly into the Marl Slate Formation.						

Middridge Quarry	425200	525200





Date of photography	2003	

Claxheugh Rock							436200	557400
Natural exposure Ownership - appears to be freely accessible.	Excellent accessible section to demonstrate the relationship of the Yellow Sands Formation with the overlying formations. This is one of only two significant exposures of the Yellow Sands Formation that is not associated with a working quarry or subject to tides.							
Proposed Action	Consider interpretation, include in geodiversity trail.							
Existing Designations	SSSI	GCR						
Existing on site interpretation	None							
Major geodiversity interest	The early Permian aeolian Yellow Sands Formation is developed at its thickest (about 58 m) beneath the rock and is overlain by the Marl Slate Formation and succeeding magnesian limestones of the Raisby and Ford formations. The reef facies of the Ford Formation forms the bulk of Claxheugh Rock. Together with the nearby Ford cutting and quarry they represent the type area of the Ford Formation. Exposures of Magnesian Limestone at Claxheugh Rock, Ford Limestone Quarry and the adjacent, disused railway cutting are of national geological importance whilst areas of associated and seminatural Magnesian Limestone grassland are also significant. The rock exposures here cut through marine limestones of the Magnesian Limestone and are significant in showing facies of the Raisby and Ford formations. These sections allow geologists to study a range of marine Permian carbonate environments, their facies and faunas, and in particular lateral variations in reef and backreef settings.							
Biodiversity interest								
Other heritage links								
Additional comment	Rock falls occur periodically from the top of the cliff. There is quite a lot of rubbish at the base of the slope and some graffiti on the sandstone faces. The other inland section, Old Quarrington is associated with a working quarry and could be subject to mineral operations in the medium term.							

Claxheugh Rock	436200	557400

Date of photography	2008	

Ford Quarry							436440	557300
Disused Quarry Public access	Only topmost part of quarry faces preserved, but makes these relatively safe for access. Has been a prime fossil locality in the past							
Proposed Action	Investigate possibility of establishing as a locality where fossils can be collected by supervised educational or recreational groups							
Existing Designations	SSSI	GCR						
Existing on site interpretation	None							
Major geodiversity interest	This is the type section of the Ford Formation in association with Claxheugh Rock. Good fossil locality. The sections have yielded a diverse fossil fauna of brachiopods, bivalves and abundant nautiloids							
Biodiversity interest	areas of associated and seminatural Magnesian Limestone grassland are also significant							
Other heritage links								
Additional comment								

Ford Quarry	436440	557300

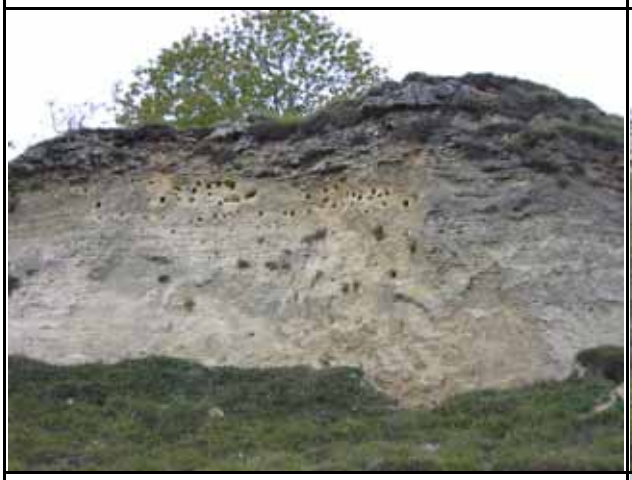
Date of photography		

Bishop Middleham Quarry	433260	532220
Disused Quarry Owned by DWT	Accessible quarry faces in Ford Formation. Good links between biodiversity and geodiversity.	
Proposed Action	Ensure adequate sections of faces are clear of vegetation to enable clear display of geology and improve access if necessary. Provide geological interpretation.	

Existing Designations	CGS	MAGical					

Existing on site interpretation	Biodiversity interest explained by signboard
Major geodiversity interest	A NNW-SSE elongate quarry in the backreef/lagoonal facies of the Ford Formation, excavated roughly along the lines of a complex of minor faults. A good sequence of oolitic dolomites can be examined in the East face of the Quarry, however elsewhere the outcrop is rather weathered. A sequence of beds that can be more easily examined is found in the NW corner.
Biodiversity interest	Limestone Grassland, Good butterfly site aided by warm microclimate
Other heritage links	
Additional comment	Section exposed is similar to Trimdon Grange Quarry. Active Quarry is working magnesian limestone on west side of road.

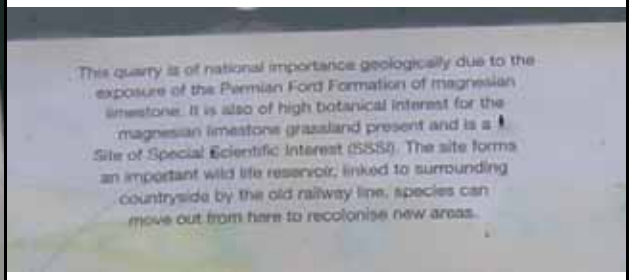
Bishop Middleham Quarry	433260	532220



Date of photography	2003

Trimdon Grange Quarry						436100	535300
Disused Quarry Owned by DWT	Good opportunity to link geodiversity with biodiversity. Details of the section are perhaps more suitable for the specialist but provides a good general example of the Ford Formation.						
Proposed Action	Ensure adequate sections of faces are clear of vegetation to enable clear display of geology and improve access if necessary. Provide geological interpretation.						
Existing Designations	SSSI	GCR	Durham Local Site.	MAGical	DWT		
Existing on site interpretation	Board mainly relating to biodiversity - mentions the important Ford Formation but with no explanation						
Major geodiversity interest	Backreef to lagoonal limestone of the Ford Formation. Part of nature reserve. The quarries at Trimdon display an excellent Middle Magnesian Limestone (Ford Formation) section and reveal features consistent with carbonate deposition in a shallow marine (back-reef) environment. Sediments include cross-bedded, oolitic grainstones,						
Biodiversity interest	Magnesian grassland						
Other heritage links							
Additional comment	The exposed section exposed is similar to Bishop Middleham Quarry.						

Trimdon Grange Quarry	436100	535300



Date of photography	2003

Wingate Quarry						437400	537500
Disused Quarry Managed by Durham County Council.	Quarry faces in Ford Formation. Faces generally in fairly poor condition. Has good biodiversity links.						
Proposed Action	Would need work to clean faces and make them accessible						
Existing Designations	LNR	MAGical					
Existing on site interpretation							
Major geodiversity interest	Large disused quarry. 24m of Ford Formation granular textured dolomitic limestones that show a felted recrystallisation texture commonly. Due to steepness of quarry faces it is difficult to examine the whole sequence and the locality is limited for teaching purposes. Sedimentary structures and ooliths are rare, but dedolomitisation adjacent to joints and faulting is of ineterest.						
Biodiversity interest	Has good bioiversity interest						
Other heritage links							
Additional comment							

Wingate Quarry	437400	537500

Date of photography	2003	

Marsden Old Quarry							439500	564500
Disused quarry Managed by South Tyneside Council	Good exposures of Concretionary Limestone and good links to biodiversity. Exposures are not as dramatic as Fulwell Quarry.							
Proposed Action	Clean faces where necessary and remove rubbish. See interpretive plan for the quarry prepared by B Young for South Tyneside Council							
Existing Designations	STLS	MAGical	LNR					
Existing on site interpretation	Interpretation board including illustration of the Permian sea							
Major geodiversity interest	Abandoned quarry faces display the Concretionary Limestone with some good features.							
Biodiversity interest	The abandoned quarry faces together with areas of limestone-rich quarry spoil offer fine habitats for the colonisation of a wide range of plant species unique to, or commonly closely associated with, the Magnesian Limestone. Range of limestone grassland types. A particularly fine demonstration of the intimate interdependence of bio- and geodiversity is provided by the area west of Marsden Old Quarry [NZ3940 6430] where stripping of vegetation and topsoil was carried out in an attempt to recreate and rejuvenate areas of Magnesian Limestone grassland. Not only has this proved very successful in enhancing biodiversity, but it has also greatly enhanced geodiversity by exposing significant features in the Concretionary Limestone Formation. Renowned location for migrant birds in the autumn.							
Other heritage links								
Additional comment								

Marsden Old Quarry	439500	564500

Date of photography	2008

Hepplewhites (Cold Knuckles) Quarry						432800	538000
Active Quarry Tarmac		Excellent section from Yellow Sands Formation to Ford Formation. Fossil fish have been found here recently. Links with Old Quarrington quarry.					
Proposed Action		Stockpile Marl Slate and maintain access for supervised parties. Consider open days. Possible viewing and interpretation point.					
Existing Designations	NONE						
Existing on site interpretation		None					
Major geodiversity interest		The basal unconformity is sometimes revealed. Very good and accessible section in Yellow Sands Formation. Faulting can be seen in west face. The Marl Slate Formation has yielded good specimens of fossil fish. Overlying beds of Raisby and Ford formations well displayed in higher parts of faces.					
Biodiversity interest							
Other heritage links							
Additional comment		Used by Open University for geology Summer School. Marl Slate Formation fish can be collected from weathered material. The quarry is working towards the old face at Old Quarrington Quarry - it is highly desirable that arrangements are made to keep a representative section of the complete sequence somewhere in the overall quarry.					

Hepplewhites (Cold Knuckles) Quarry	432800	538000

Date of photography	2003 and 2004	Fossil fish photo copyright G. Easterbrook

Crime Rigg Quarry					434400	541600
Active Quarry Owned by Sherburn Stone Co Ltd.	This working quarry displays probably the most important site in the Lower Permian Yellow Sands Formation, with overlying Marl Slate Formation and Raisby Formation.					
Proposed Action	Interpretation. Possible viewpoint to Yellow Sands Formation?					
Existing Designations	SSSI	GCR				
Existing on site interpretation	None					
Major geodiversity interest	A very thick exposure of Yellow Sands Formation displaying cross bedding. Cemented in upper beds, passing up through Marl Slate Raisby and Ford formations.(25/48m). The Marl Slate Formation is exposed at the top of a great thickness of Yellow Sands Formation in a similar situation to Quarrington. Well exposed basal and middle units of Raisby Formation in north of quarry. Large faces in the quarry show the complex, interdigitating cross-bedding typical of the Yellow Sand Formation.					
Biodiversity interest						
Other heritage links						
Additional comment	Quarry owner is well aware of, and sympathetic to, the geological importance of the site					

Crime Rigg Quarry	434400	541600






Date of photography	2003	

Thrislington Quarry						431200	533200
Working Quarry LaFarge Aggregates	The Marl Slate Formation at this site has yielded extensive amounts of typical fossil fauna and flora. It also probably possesses the largest amount of Marl Slate available for safe specimen collection at a single site.						
Proposed Action	Continue to stockpile Marl Slate and allow collection by supervised parties. Consider periodic open days.						
Existing Designations	CGS						
Existing on site interpretation	None						
Major geodiversity interest	Exposures from Yellow Sands Formation, through the Marl Slate Formation and the Raisby Formation to the Ford Formation lagoonal facies.						
Biodiversity interest	Thrislington Plantation SSSI has magnesian limestone grassland						
Other heritage links							
Additional comment	Could make good link with Thrislington Plantation grassland						

Thrislington Quarry	431200	533200

Rare fossil find at quarry

Date of photography	2004	

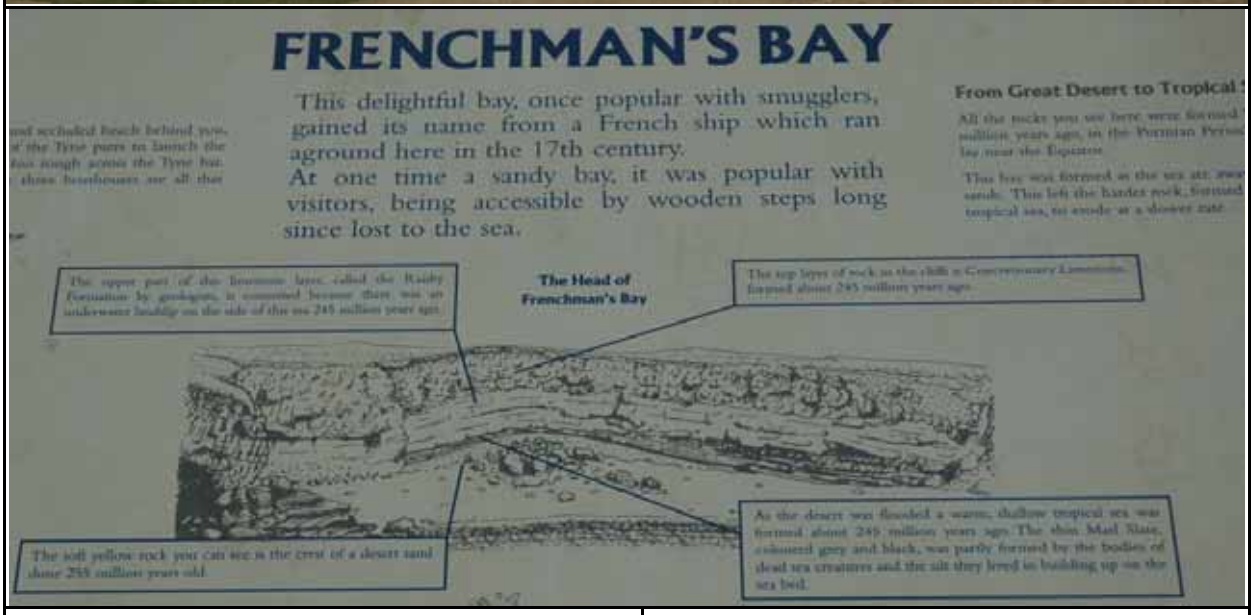
Trow Point to Frenchman's Bay						438400	566700
Coastal and cliff section and disused quarry Owned by National Trust	Trow Point clearly shows Concretionary Limestone Formation overlying slide beds in Raisby Formation. Section is readily accessible, except within two hours of high tide. Trow Quarry and faces adjacent to path show good variation in the Concretionary Limestone beds.						
Proposed Action	Work with National Trust to improve interpretation. Incorporate in Trail. Offer training to National Trust staff and voluntary wardens.						
Existing Designations	SSSI	GCR					
Existing on site interpretation	Description of use of Trow Quarry						
Major geodiversity interest	Bedded Raisby Formation, slide beds and overlying Concretionary Limestone Formation.						
Biodiversity interest							
Other heritage links	Stone from Trow Quarry used for building - including Roman Fort at Arbeia, South Shields.						
Additional comment	Very popular area for local walks.						

Trow Point to Frenchman's Bay	438400	566700

Date of photography	2008

Frenchman's Bay							438900	566100
Coast and cliff section Owned by National Trust	Only coastal section exposing Yellow Sands; good exposures of the Concretionary Limestone Formation. Superb views.							
Proposed Action	Incorporate in Trail. Offer training to National Trust staff and voluntary wardens.							
Existing Designations	SSSI	GCR						
Existing on site interpretation	Board describing the geology from viewpoint (NZ3921 6629)							
Major geodiversity interest	Yellow Sands Formation to Concretionary Limestone Formation well exposed in cliffs.							
Biodiversity interest								
Other heritage links								
Additional comment	This is some of the best geological interpretation in the area, but does not appear to form part of a co-ordinated set. Many people may not reach as far as this on their walks. GREAT CARE NEEDED WITH TIDES IF ATTEMPTING TO REACH SECTION FROM THE BEACH							

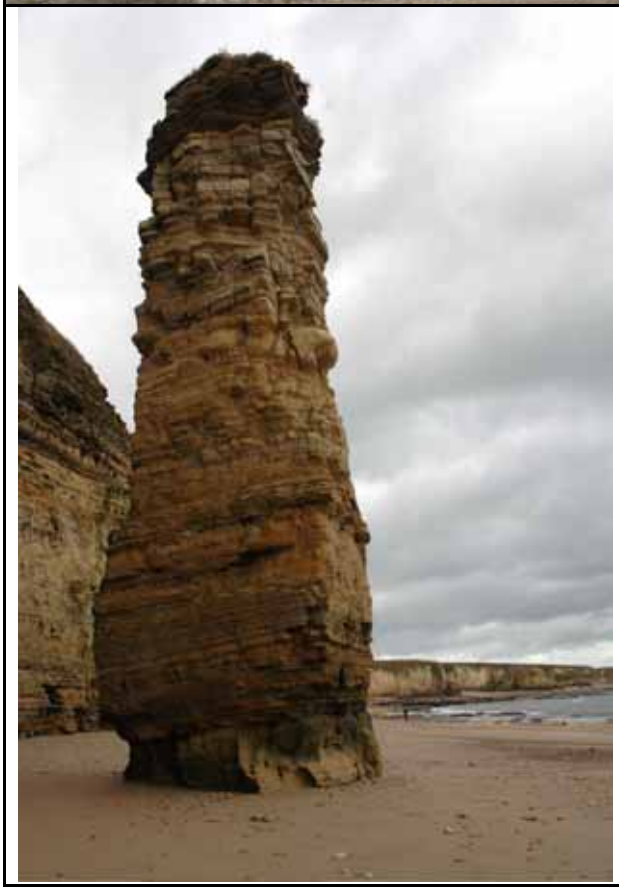
Frenchman's Bay	438900	566100



Date of photography	2008	

Marsden Bay						439950	564850
Coastal cliff and beach section.		Concretionary Limestone Formation magnificently displayed in cliffs with excellent examples of collapse breccia pipes (breccia gashes) Classic examples of coastal erosion including stacks, arches and wave-cut platforms. Extensive views from above.					
Public ownership?							
Proposed Action		Improve interpretation. Incorporate in trail. Training for voluntary wardens/rangers					
Existing Designations	SSSI	GCR					
Existing on site interpretation		None?					
Major geodiversity interest		Variety of features in Concretionary Limestone including excellent collapse breccia pipes. Coastal features.					
Biodiversity interest							
Other heritage links							
Additional comment		Access via steps or lift (when working). Refreshments available on beach.					

Marsden Bay	439950	564850



Date of photography	2003 and 2008	

Lizard Point & Mardsen Limekiln						441030	564240
Coastal cliff section National Trust?		Excellent viewpoint for coastal features and Concretionary Limestone Formation. Industrial archaeology links.					
Proposed Action		Incorporate in trail. Consider additional methods of interpretation.					
Existing Designations	SSSI	GCR					
Existing on site interpretation							
Major geodiversity interest		Good coastal features and cliff exposures.					
Biodiversity interest							
Other heritage links		Industrial and archaeological link with limekiln					
Additional comment		The Working Marsden Quarry is nearby.					

Lizard Point & Mardsen Limekiln	441030	564240

Date of photography	2003 and 2008	

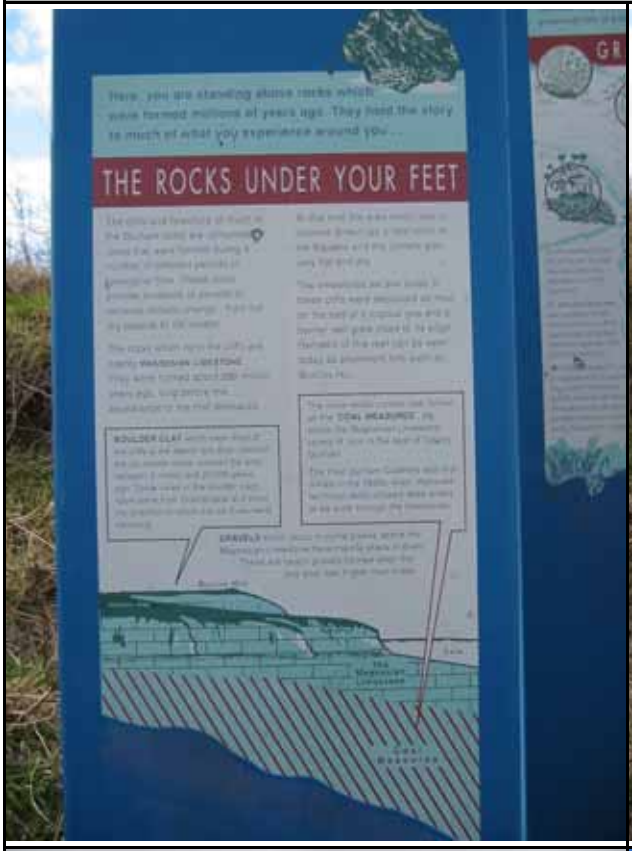
Seaham Harbour						443200	549700
Coastal and cliff section	The Seaham exposure provides a section ideally located next to the promenade which allows the outcrop to be examined with great ease. The coast to the north of Seaham Harbour provides by far the best surface exposures of both the Seaham Formation and the Seaham Residue, and is one of the best places in Britain for observing the effects of evaporite dissolution; it is also the best surface exposure of the highest beds of the Roker Dolomite Formation. The Seaham Formation here is unusual in its content of several thick units rich in calcite spherulites, some exceptionally large, and the Seaham Residue, the dissolution residue of the Cycle EZ2 (Fordon) evaporites, is at its thickest and most spectacular.						
Ownership?							
Proposed Action	Possible on site interpretation and training for rangers.						
Existing Designations	SSSI	GCR					
Existing on site interpretation	None						
Major geodiversity interest	This is an important locality for studies of Permian rocks, for it exposes the top of the Roker Formation (EZ2Ca), and Seaham Residue (EZ2E) and carbonates of the Seaham Formation (EZ3Ca). Collapse zones expose brown-red mudstones of the Roxby Formation, Type location for the Seaham Formation in which the full sequence between the Seaham residues and residues of the overlying Billingham Main Anhydrite can be seen. Uppermost beds of HRD and their contact with the Seaham Residues are best examined in the area around Feather Bed north of Seaham. Here the residue crops out for some distance and the top 10m of the dolomites can be examined in detail. Just below the residue, the HRD show a much harder form that is a consequence of dedolomitisation. Very good exposures of the upper beds of the Hartlepool and Roker Dolomite and particularly of overlying Seaham Residue. Exposure is best around Featherbed rocks where the residue horizon shows much contortion and variation in thickness (about 0.5m). The uppermost Seaham Formation is overlain by a small sequence of red and green mudstones revealed in part of the north wall of Seaham Harbour.						
Biodiversity interest							
Other heritage links							

Seaham Harbour	443200	549700
Additional comment	Coastal rangers often take people to these localities but feel they do not currently have information to explain the rocks. Good locality for parties as all three formations exposed.	

Date of photography	2008 and 2003 (bottom)	

Blackhall Rocks					446800	539500
Coastal cliffs and foreshore Owned by	Excellent exposures of three geological units: the Heselden Dene Stromatolite in the Ford Formation, the Roker Dolomite Formation and the Seaham Residue and Formation. Biodiversity interest. The exposure is very distinctive and is of great interest. When the tide is out the beach exposure is excellent and worthwhile visiting.					
Proposed Action						
Existing Designations	NNR	SSSI	GCR	LNR	MAGic	DWT
Existing on site interpretation	Information boards on cliff top describe 'The rocks under your feet' and 'Grassland life' a third board about stacks is now somewhat out-of-date since demolition of arch in 2004					
Major geodiversity interest	The coastal cliffs and shore platforms at Blackhalls Rocks constitute the largest and best exposure of the Hesleden Dene Stromatolitic Biostrome (?45m) together with the whole of the overlying cycle EZ2 Roker Dolomite Formation (?16m) and much of the Seaham Formation. The beds exposed at Blackhall Rocks reveal abundant stromatolitic and oolitic dolomites that are associated with brecciation, with a comglomerate containing shelly material exposed in the core of the anticlinal structure making up the section					
Biodiversity interest	Unusual seepage flushes from calcium-rich seepage waters where glacial deposits meet underlying bedrock. Large area of common rock rose centred on Blue House Gill.					
Other heritage links						
Additional comment	Can link to interpretation at Noses's Point.					

Blackhall Rocks	446800	539500



Date of photography	2004	

Appendix 1 Major sources of information consulted

Significant geological exposures in the Tyne to Tees area (Henderson and Lelliot, 1978). Between 1977 and 1978, the Durham County Conservation Trust undertook one of the first comprehensive surveys of geological sites to be undertaken by a County Trust. This identified and listed sites at which significant, or representative, exposures of named geological units or formations known within the county could be seen. The project aimed to provide the information necessary to further the effective conservation of geological sites, to facilitate monitoring of those sites and, where appropriate, to recommend sites for notification as SSSIs. For each of the sites identified, details including geological features exposed and condition of the site at the time of the field visit were recorded. In addition, each site was assigned a rating to reflect such factors as its geological merits, accessibility, and vulnerability.

The Magnesian Limestone of Durham County (Edited by T C Dunn, 1980)
Published by Durham County Conservation Trust this informative book provides probably the most comprehensive introduction to the Limestone Landscape available to the non specialist, although there have been considerable advances in understanding of the rocks and revision of the names applied to them since its publication. It includes an appendix of active and disused quarries in the Magnesian Limestone compiled by W Evans.

County Durham Geological Conservation Strategy 1994. Adopted by the Environment Committee this was devised to be a natural sequel to the Durham County Conservation Strategy. This involved a major review of the most significant sites representative of the county's geology and geomorphology. The work was undertaken with the advice and assistance of local geological experts who identified a network of candidate Durham County Geological Sites (DCGS). It may be seen as building upon, and updating, the principles that lay behind the 1978 report. The first County Geological Sites were approved by the Environmental Committee of the County Council in April 1993. Although these are non-statutory designations, the sites are recognised by the local planning authorities who consult the Wildlife Trust over proposals which may affect them. The County Durham Geological Conservation Strategy includes the following three non development plan policies:

The Geological Conservation Review (GCR)

The Geological Conservation Review (GCR) was initiated by the Nature Conservancy Council in 1977 to identify, assess, document and eventually publish accounts of the most important parts of Great Britain's rich and varied geological heritage. GCR sites are those of national or international importance which have either been notified as SSSIs or are being considered for such notification. Publication of descriptions of GCR sites is being undertaken in a series of 42 thematic volumes. Since 1991, publication of descriptions of GCR sites has been undertaken by the Joint Nature Conservation Committee on behalf of the three country agencies, English Nature, Scottish Natural Heritage, and the Countryside Council for Wales.

GCR volumes relevant to the area (these include extensive bibliographies):

No. 8 Marine Permian of England Smith, D.B. (1995)

No 9 Palaeozoic Palaeobotany of Great Britain, Cleal, C.J. & Thomas, B.A., (1995),

No. 10 Fossil Fishes of Great Britain Dineley, D. & Metcalf, S., (1999)

No. 11 British Upper Carboniferous Stratigraphy, Cleal, C.J. & Thomas, B.A., (1996)

No. 16 Fossil Reptiles of Great Britain, Benton, M.J. & Spencer, P.S., (1995)

No. 25 Quaternary of Northern England, Huddart, D. and Glasser, N.F. (2007)

No. 28 Coastal Geomorphology of Great Britain, May, V.J. and Hansom, J.D. (2003)

SSSI site descriptions (mainly prepared in the early 1990's) (provided by Mike Sutcliffe, Natural England) and *current web information*.

Published and unpublished guides to geological excursions, including Smith, 1995a and Bridgland et al. 1999. The latter, *The Quaternary of North-East England Field Guide* contains a wealth of useful and up-to-date information, including illustrations of key sections and a comprehensive introduction to modern understanding of the Quaternary of the area.

Durham County Council landscape study and strategy

The geodiversity of County Durham (Lawrence et al. 2003)

Part 1 defines and explains the relevance of geodiversity. The principal aim is given as reviewing the components of the county's geodiversity, and their relevance to other interests, including informing sustainable management, planning, conservation, and all aspects of Earth heritage. The influence of geology in County Durham is explained along with its link to biodiversity. A section on 'Conserving Earth science', as well as providing details of the areas with designated status (North Pennines AONB and Geopark, National Nature Reserves, SSSIs and RIGS / Durham County Geology Sites), reports that the word 'geology' can trace its origins back to the county.

Part 2 in three sections, is a detailed evaluation of the geodiversity under the headings 'The geological resource', 'The use of the resource', and 'Understanding the resource'.

Geodiversity of South Tyneside (B Young, 2008)

The Magic Meadows booklet

Zechstein Reef fossils and their palaeoecology (Hollingworth and Pettigrew, 1988).

The book contains a description of the reef in the Sunderland area and a 16 page field guide for the identification of common fossils found in the reef using photographs, line drawings and life mode reconstructions. Eight key localities are described.

JOHNSON, G.A.L. 1995. (editor). Robson's Geology of North East England. *Transactions of the Natural History Society of Northumbria,* Vol. 56, Part 5.

The Geological Survey memoirs for Sunderland and the district between Durham and West Hartlepool (Smith, 1994; Smith and Francis, 1967)

Appendix 2 GCR, SSSI, County Geology Sites and RIGS within the area

GEOLOGICAL CONSERVATION REVIEW (GCR) SITES

Code	Name	Block	Grid Ref	GCR Site Account
3016	Blackhalls Rocks	Marine Permian	NZ468395	Site Account
2086	ClaxheughRock, Claxheugh (Ford) Cutting and Ford Quarry	Marine Permian	NZ362574	Site Account
2985	Crime Rigg Quarry	Permian - Triassic	NZ344416	Not available
3017	Dawson`s Plantation Quarry, Penshaw	Marine Permian	NZ336546	Site Account
1966	Fulwell Hills Quarries	Marine Permian	NZ382598	Site Account
1963	Gilleylaw Plantation Quarry	Marine Permian	NZ375537	Site Account
1975	Hawthorn Quarry	Marine Permian	NZ435463	Site Account
2832	High Moorsley Quarry	Marine Permian	NZ334455	Site Account
1784	Humbledon Hill Quarry	Marine Permian	NZ382553	Site Account
1962	Hylton Castle	Marine Permian	NZ358589	Site Account
1944	Marsden Bay	Coastal Geomorphology of England	NZ400650	Site Account
2174	Middridge	Permian - Triassic Reptilia	NZ252252	Not available
302	Middridge Quarry	Palaeozoic Palaeobotany	NZ252252	Not available
2986	Raisby Quarries	Marine Permian	NZ346354	Site Account
1976	Seaham Harbour	Marine Permian	NZ430499	Site Account
2015	Shippersea Bay, Easington	Quaternary of North-East England	NZ443453	Not available
3019	Stony Cut, Cold Hesledon	Marine Permian	NZ417472	Site Account

2018	Thorpe Bulmer	Quaternary of North-East England	NZ453354	Not available
1968	Trimdon Grange Quarries	Marine Permian	NZ361353	Site Account
1977	Trow Point to Whitburn Bay	Marine Permian	NZ409612	Site Account
1969	Tunstall Hills and Ryhope Cutting	Marine Permian	NZ391546	Site Account
2010	Warren House Gill	Quaternary of North-East England	NZ436426	Not available
2393	Wear River Bank	Westphalian	NZ362579	Not available
1974	Yoden Village Quarry/Horden Quarry	Marine Permian	NZ436417	Not available

SITES OF SPECIAL SCIENTIFIC INTEREST FOR WHICH SITE DETAILS AND MANAGEMENT PLANS ARE HELD BY NATURAL ENGLAND

Each may contain more than one GCR site

Claxheugh Rockand Ford Limestone Quarry
CrimeRigg and Sherburn Quarries
Dawsons Plantation Quarry
Fulwelland Carley Hill Quarries
Gilleylaw Quarry
Hawthorn Quarry
High Moorsley
Humbledon Hill Quarry
Hylton Castle Cutting
Middridge Quarry
RaisbyHill Quarry
Seaham Harbour
Stony Cut, Cold Hesledon (ED) Durham
Trimdon Grange Quarry
Trow Point toWhitburn Steel
Tunstall Hills and Ryhope Cutting
Wear River Bank

DURHAM COUNTY GEOLOGY SITES

SITE NAME	SITE TYPE
Beacon Hill	Exposure/railway cutting
Bishop Middleham Quarry	Quarry
Castle Eden Dene	Exposures
Chilton Quarry	Abandoned quarry
Dene Holme	Exposure
Dropswell Farm	Feature Deposit Tufa mound
Easington Raised Beach	Exposure
Ferryhill Gap	Geomorphological
Hesleden Dene	Exposure
MIddridge Railway Cutting	Cutting
Old Town Quarry	Abandoned quarry
Old Quarrington Quarry	Abandoned quarry
Raisby Rail Cutting	Old railway cutting
Rough Furze Quarry	Disused dolomite quarry
Sheraton Kames	geomorphological
Shotton Valley East Side	Surface Build up
Thornley-Kelloe Meltwater Channels	Geomorphological
Thrislington Quarry	Active Quarry
Townfield Quarry, Easington	Disused Quarry
Easington Colliery Underground Tunnel	Disused tunnel;

RIGS

Houghton Hill, Cut And Scarp	NZ342504, NZ 343504, NZ 343504	The RIGS designation includes areas adjoining the SNCI site to the north, consisting of two thin strips on each side of the A690. This area cuts through the Permian Escarpment and displays interesting Stratigraphy, Lithology and Sedimentology.
North Dock Tufa	NZ 407585	The area contains a recently discovered geological tufa dome which represents the best example of such a structure within the area. The tufa is a calcified dome consisting of various materials which is growing from the North Dock harbour wall as a result of an unknown water source. The feature is created by calcified water in the same way that stalactites and stalagmites are formed.
Roker Cliffs And Parson's Rocks	NZ408597, NZ408592, NZ408599	This rocky shore is considered to be of great geological interest with its Magnesian Limestone cliffs and "Cannonball Limestone". The site is also of value to wading birds for feeding and roosting. The RIGS boundary extends approximately 0.3 km further south than the SNCI and includes the cliffs at the eastern entrance of Roker Park.
Ryhope Beach	NZ416542, NZ421519	The site is an area of sea cliffs with a wave cut platform that is largely obscured by coastal sand and extensive deposits of cobble and boulder. The cliffs exhibit several erosional features of interest as well as four different geological and geomorphological rock types.
Whelley Hill Quarry	NZ449340	Quarry face exposure of Magnesian limestone
Crimdon Dene	NZ471371	Deep gorge environment revealing exposures of Magnesian limestone. The gorge forms steep sides consisting of face of Magnesian limestone in a fluvial environment. Glacial erratics can be found in the stream bed.
Naisberry Quarry	NZ477333	Old quarry revealing various exposures of Magnesian limestone
Hartlepool Headlandf	NZ524344	Wave washed platform of Magnesian limestone. The exposure reveals examples of stack an pillar coastal features.

This list of RIGS is based on information provided at the time of the study - it is possible that other sites may have been proposed as RIGS.

Appendix 3 Working Quarries

Marsden Quarry	Owen Pugh Aggregates Ltd T: 0191 529 2441 http://www.owenpugh.com/Quarry.php	Whitburn, Sunderland Tyne and Wear SR6 7NG	Owen Pugh Aggregates Ltd acquired Marsden limestone quarry situated in Tyne & Wear in September 2000. The company provides limestone aggregates and agricultural lime to customer specific requirements, and also operates an inert waste landfill site as part of a long term quarry restoration scheme.
Bishop Middle-ham Quarry	W & M Thompson (Quarries) Ltd Tel: 01740 654128	Bishop Middleham, Ferryhill, County Durham DL17 9EB	
Aycliffe Quarry	John Wade Group http://www.johnwade.co.uk/map.html	Aycliffe Village, Darlington, Co.Durham DL5 6NB	
Crime Rigg Quarry	Sherburn Stone Co. Ltd.	Shadforth, Durham, County Durham, DH6 1LE	
Thrisling-ton Quarry	LaFarge Aggregates www.lafargeaggregates.co.uk	West Cornforth Ferryhill County Durham DL17 9EY	

Coxhoe Quarry	Tarmac 0191 377 0611		
Hepple-white (Cold Knuckes) Quarry	Tarmac 0191 377 9546		

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

BENNETT, M.R., DOYLE, P., LARWOOD, J.G. & PROSSER, C.D. 1996. *geology on your Doorstep - The role of urban geology in earth heritage conservation.* THE Geological Society:London. ISBN 1 897799 54 3.

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Figures

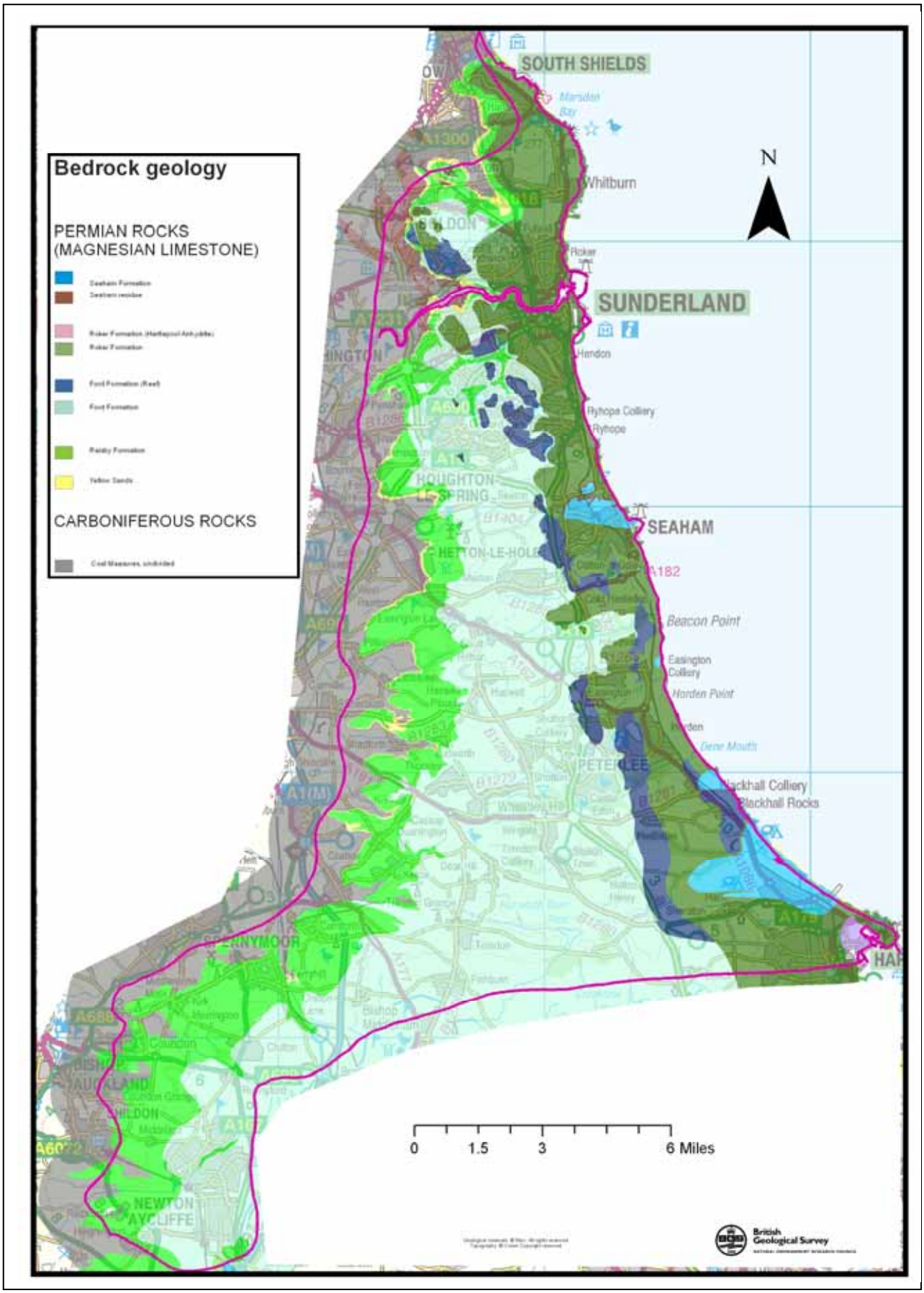

Figure 1 Geological map of the area showing bedrock

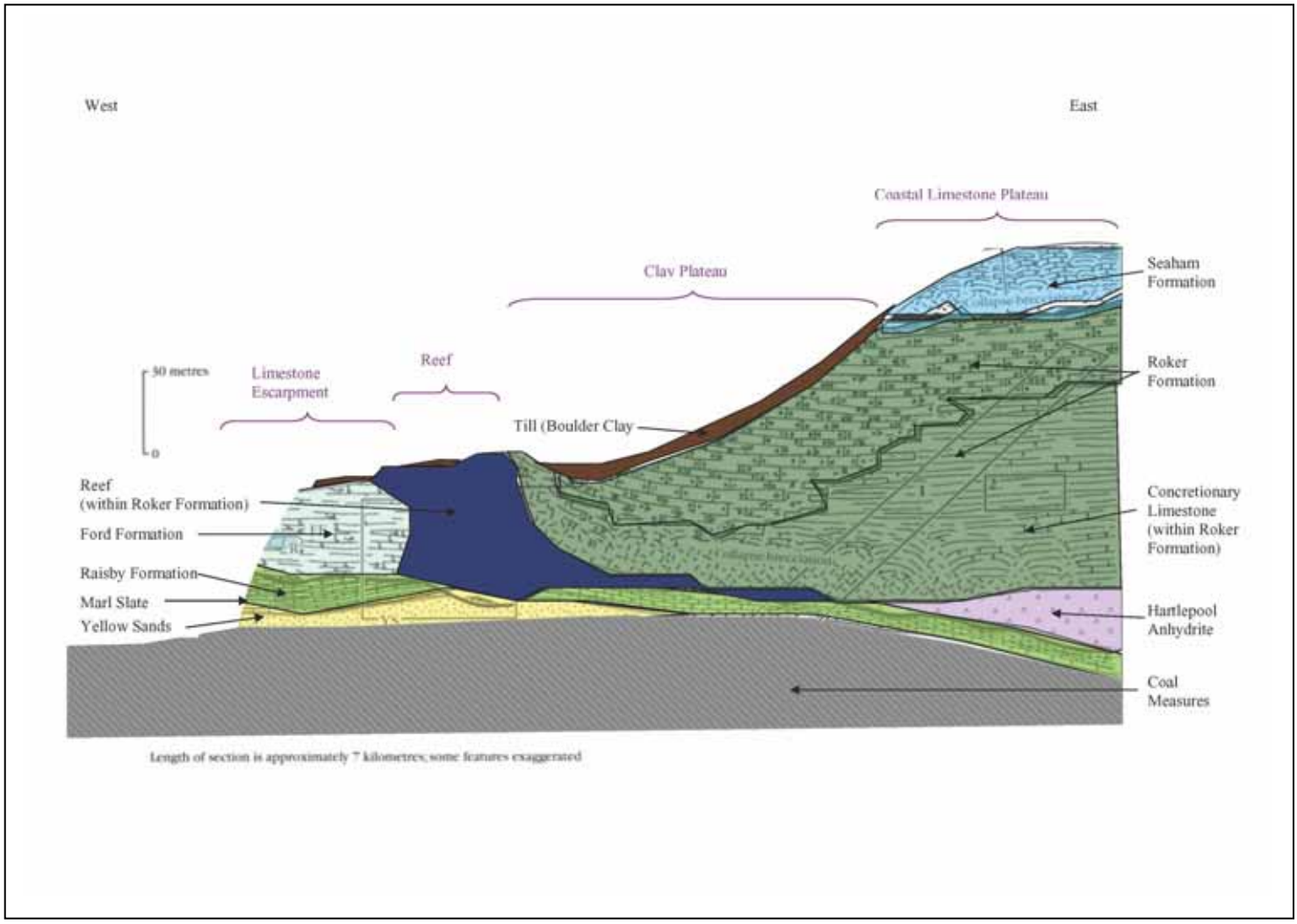

Figure 2 Schematic diagram to show general relationship of geological units (adapted from Smith 1994)

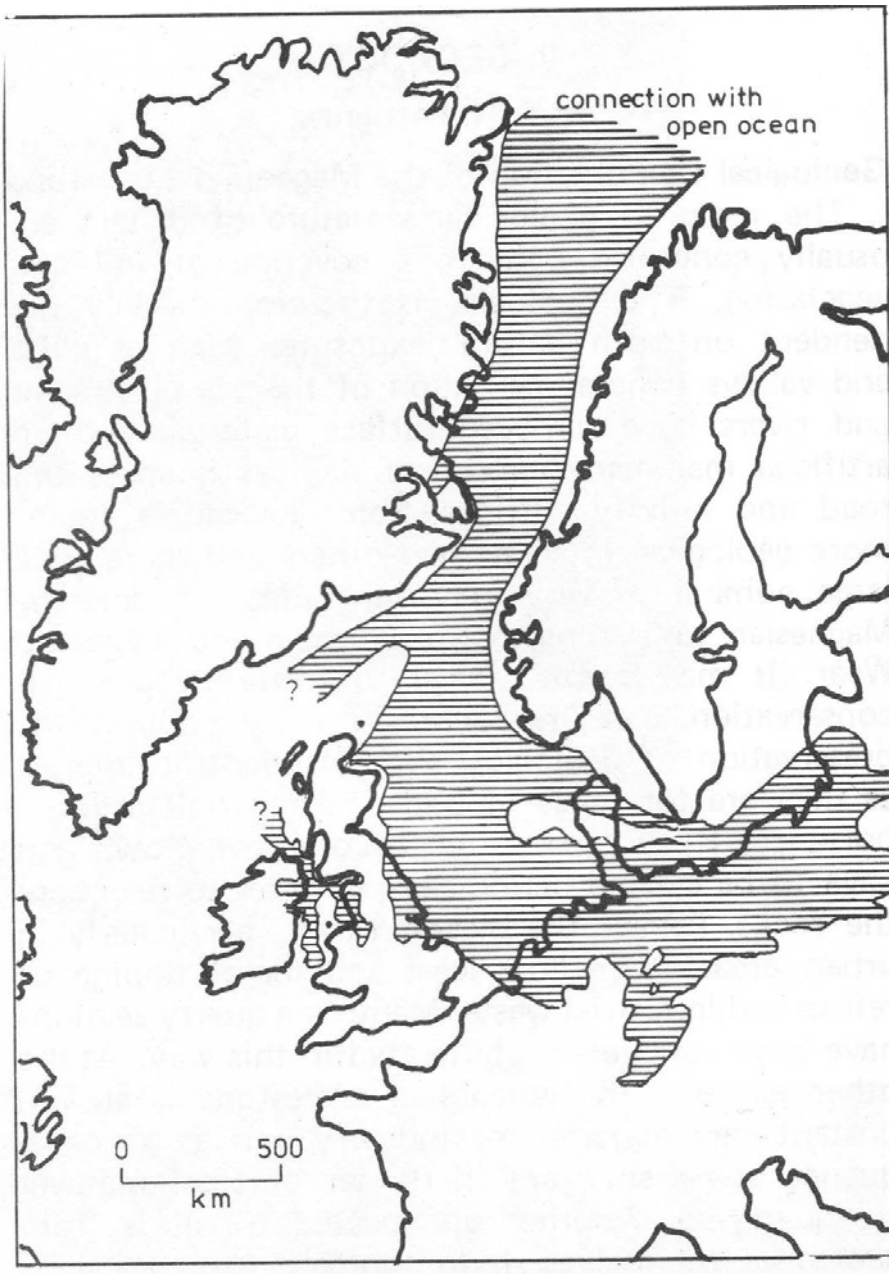

Figure 3 Map showing the position of Zechstein Sea in relation to present day geography (adapted from Pettigrew,1980)

Greenland is shown in its inferred position before continental drift

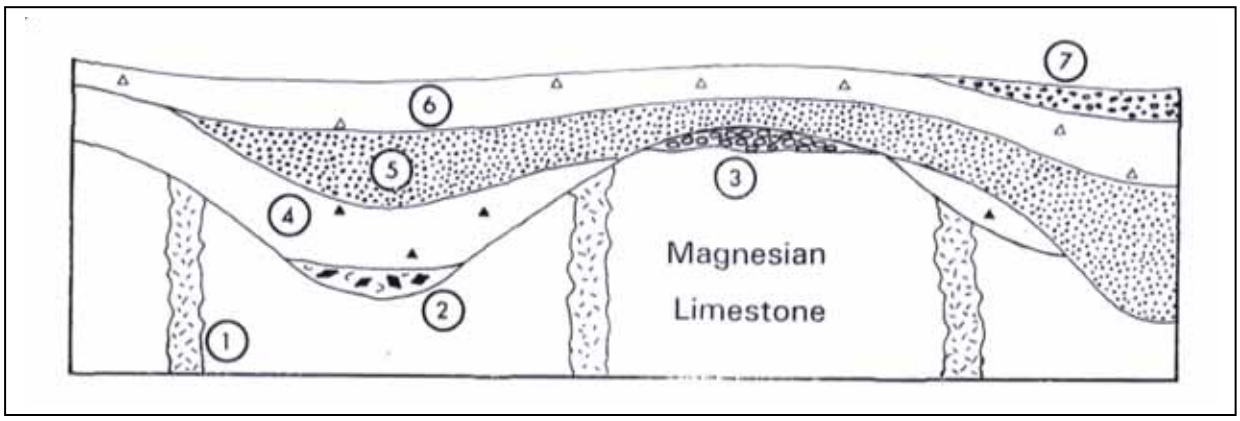

Figure 4 Idealized section through the Quaternary sequence exposed on the Durham coast (after Bridgland et al., 1999)

1 Fissure infills; 2 Scandinavian Drift; 3. Easington Raised Beach; 4. Lower Till; 5. Middle Sands and Gravels; 6. Upper Till; 7. Upper Gravels.

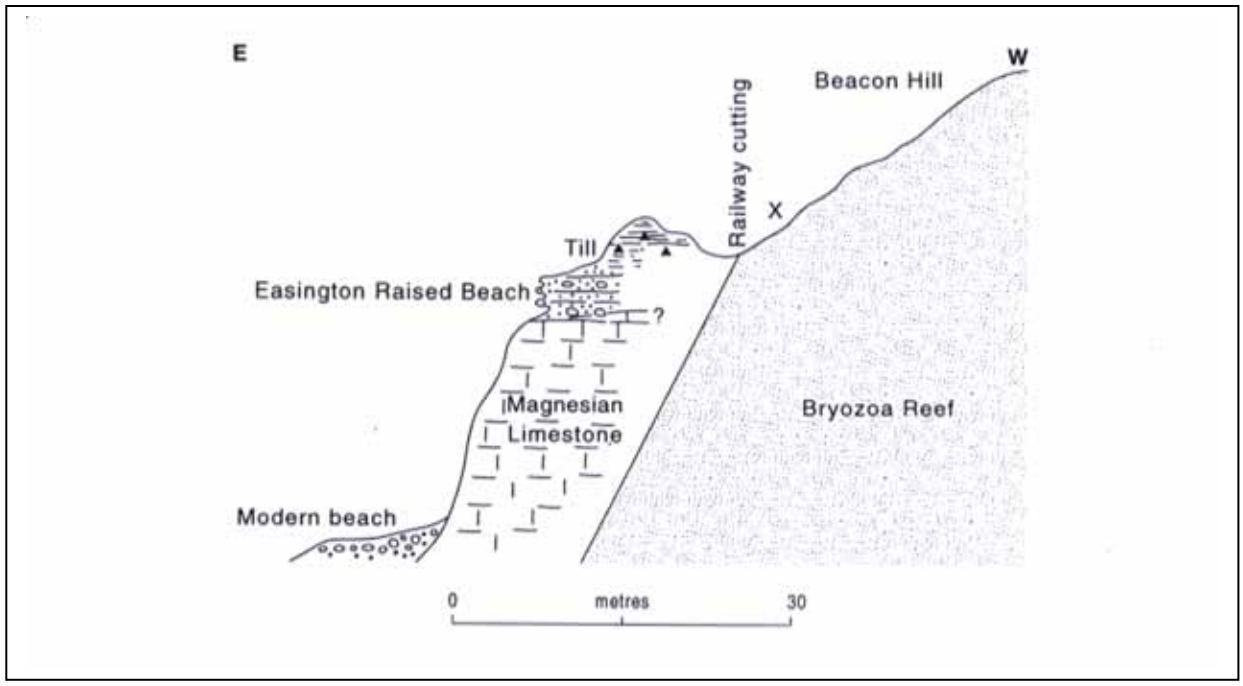

Figure 5 Schematic section of coast showing Easington Raised Beach (after Bridgland et al., 1999)

Plates

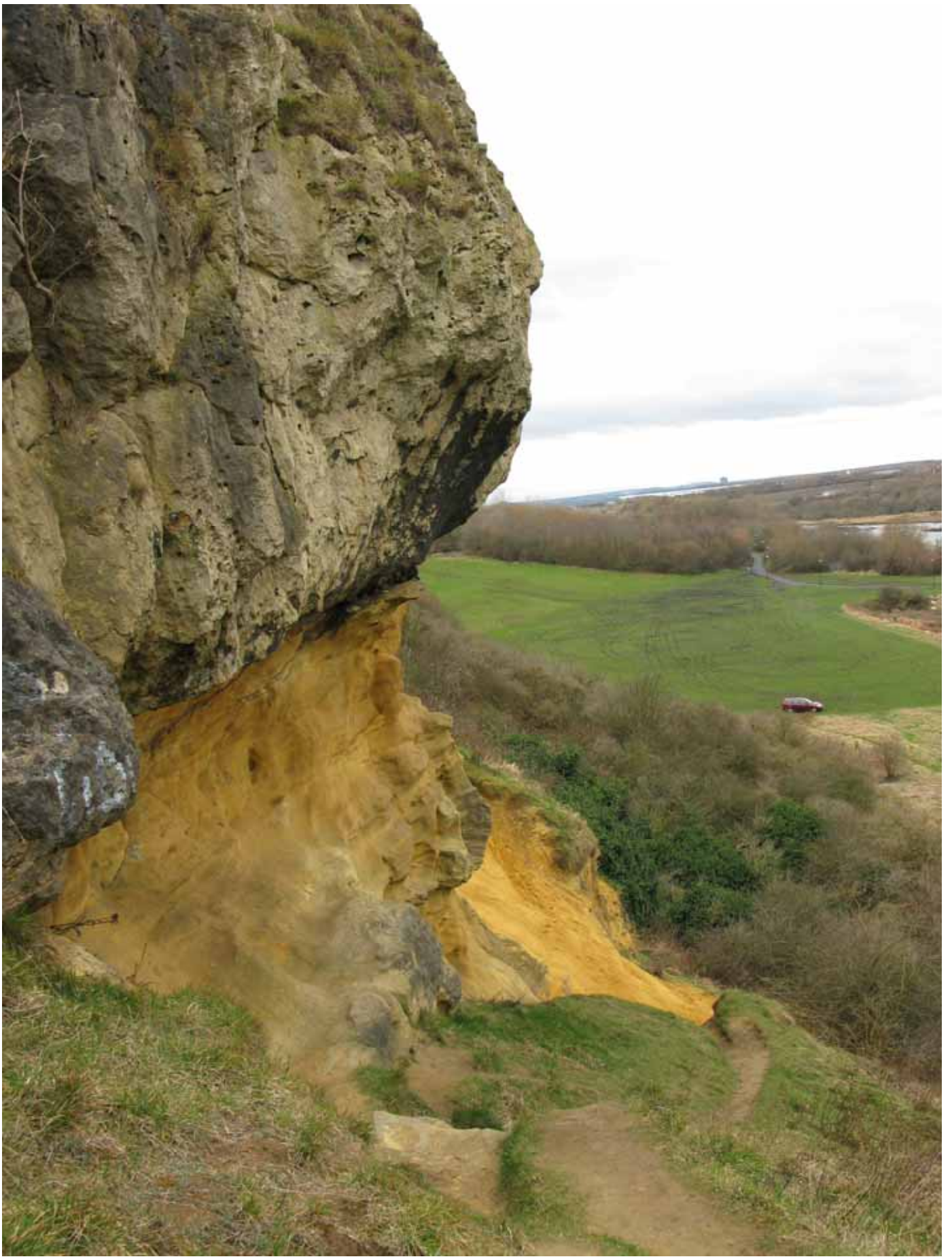

Plate 1 Yellow Sands beneath the Ford Formation Reef at Claxheugh Rock, Sunderland

Plate 2Searching for fossil fish in the Marl Slate at Hepplewhites (Cold Knuckles) Quarry

Plate 3 Palaeoniscid fish from the Marl Slate Formation at Quarrington, found in 2006 (photo © G. Easterbrook, may be used freely, with acknowledgement, in 'not for profit' publications)

Plate 4 Dolomitic limestone of the Raisby Formation at Aycliffe Quarry

Plate 5 Ford Formation Reef Limestone at Tunstall Hill

Plate 6 The Concretionary Limestone overlying slide debris in the Ford Formation at Trow Point

Plate 7 The Seaham Formation at Seaham Harbour

Plate 8 The Easington Raised Beach at Shippersea Bay

Plate 9 Coastal stacks in the Roker Dolomite Formation seen from Lizard Point

Plate 10 Collapse breccia in the cliffs at Marsden Bay

Plate 11 The Escarpment seen from the south-west

Plate 12 Till (Boulder Clay) slippage in the cliffs north of Seaham (November 2008)

Plate 13 Wire mesh protection of the cliffs near the steps at Marsden Bay. The nature of the rocks can still be seen through the stabilisation measures (February 2009).

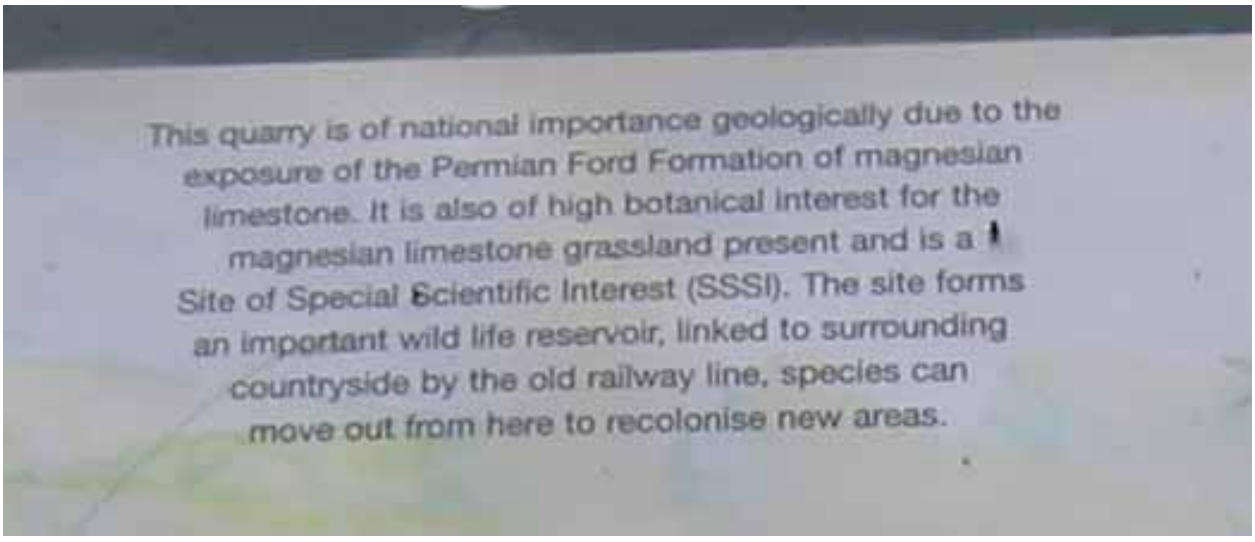

Plate 14 Information Board at Trimdon Grange Quarry – note mention of the importance of the Ford Formation (detail), but no further explanation of why it is geologically important

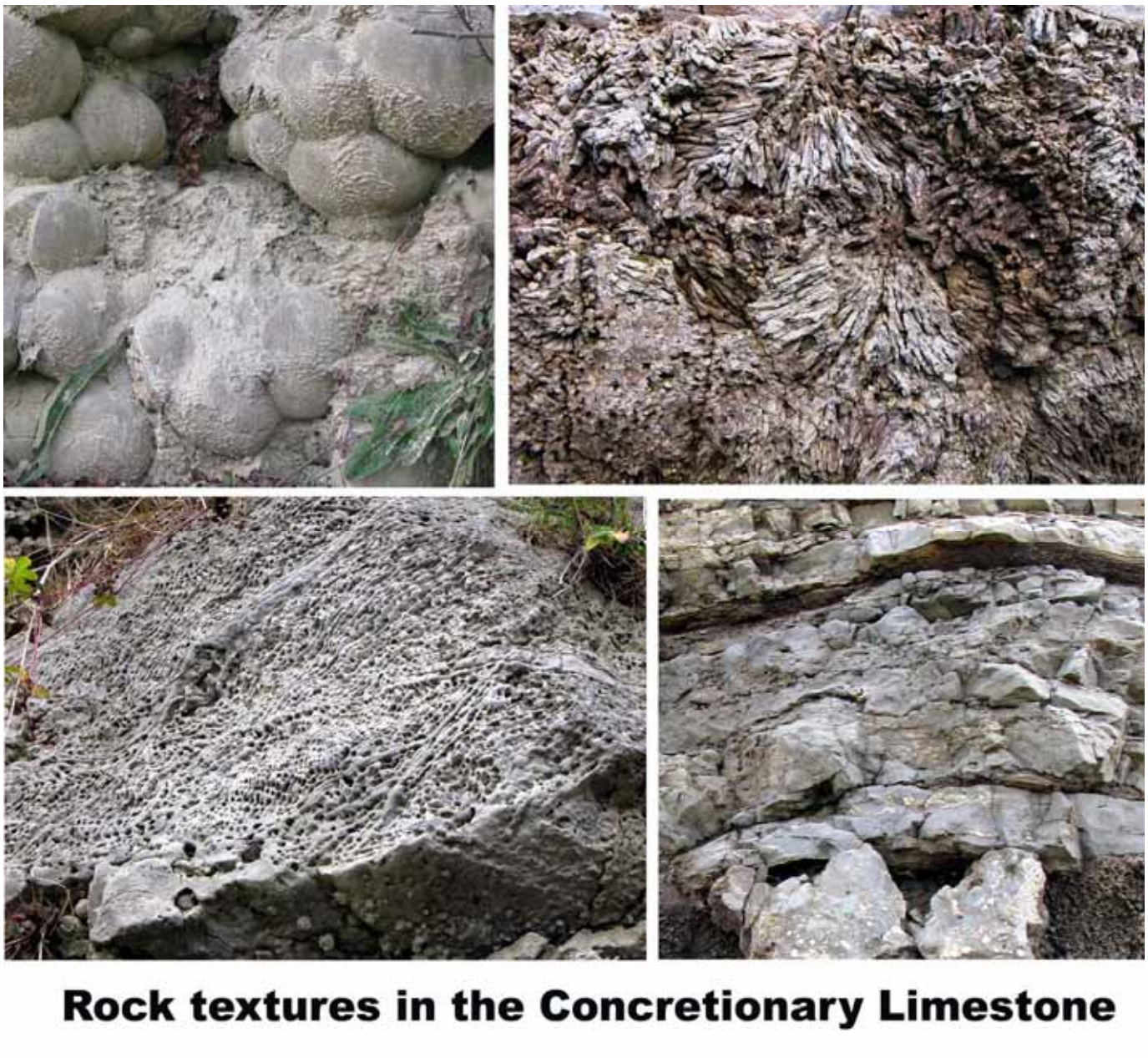

Plate 15 Rock textures exposed in Fulwell Quarry and surroundings

Plate 16 Example of wheelchair accessible trail incorporating description of rocks suitable for the visually handicapped. Karoo Botanic Garden, South Africa

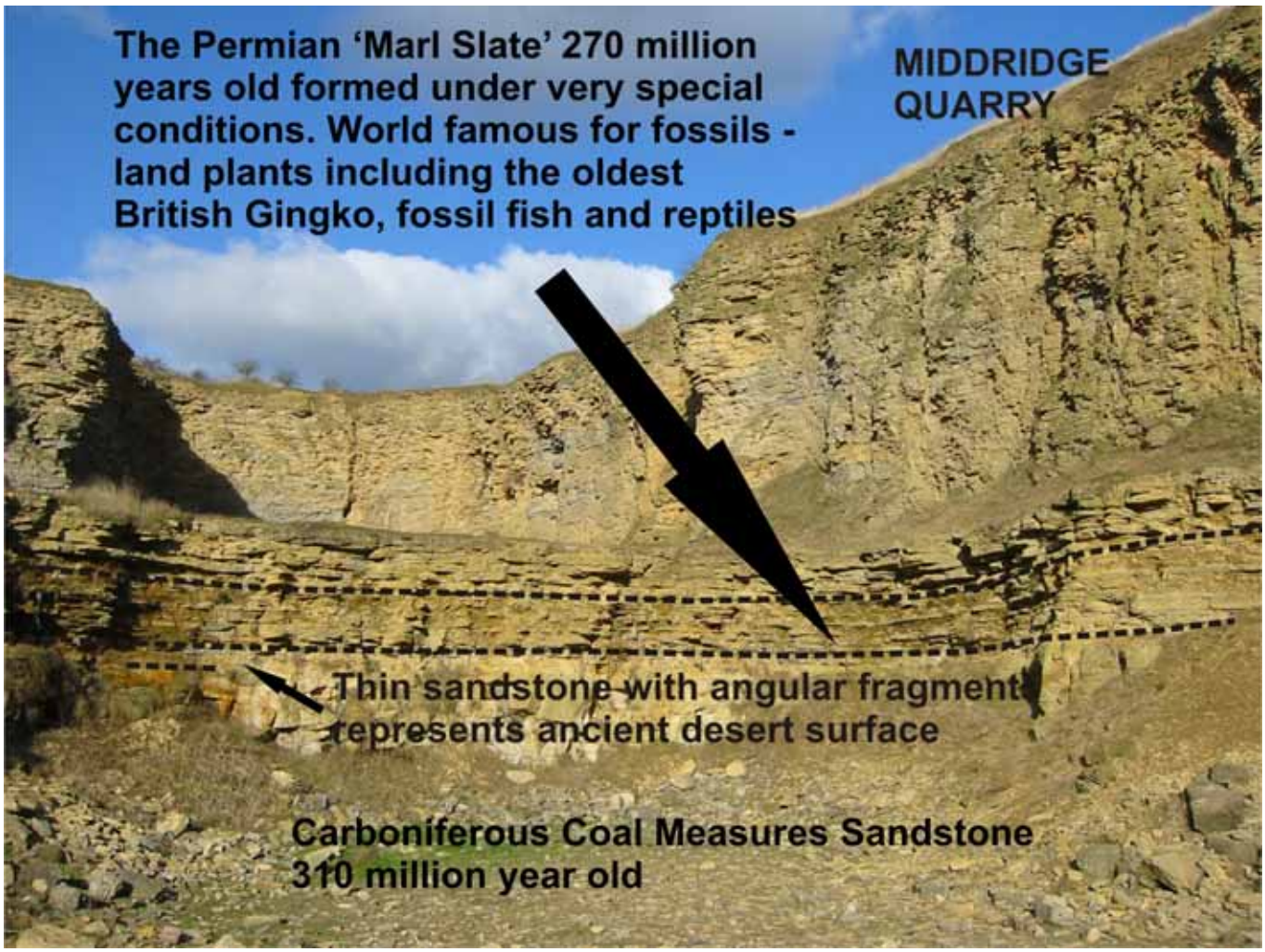

Plate 17 Schematic interpretation of rock exposed in Middridge Quarry

Plate 18 Use of magnesian limestone as building stone in Whitburn

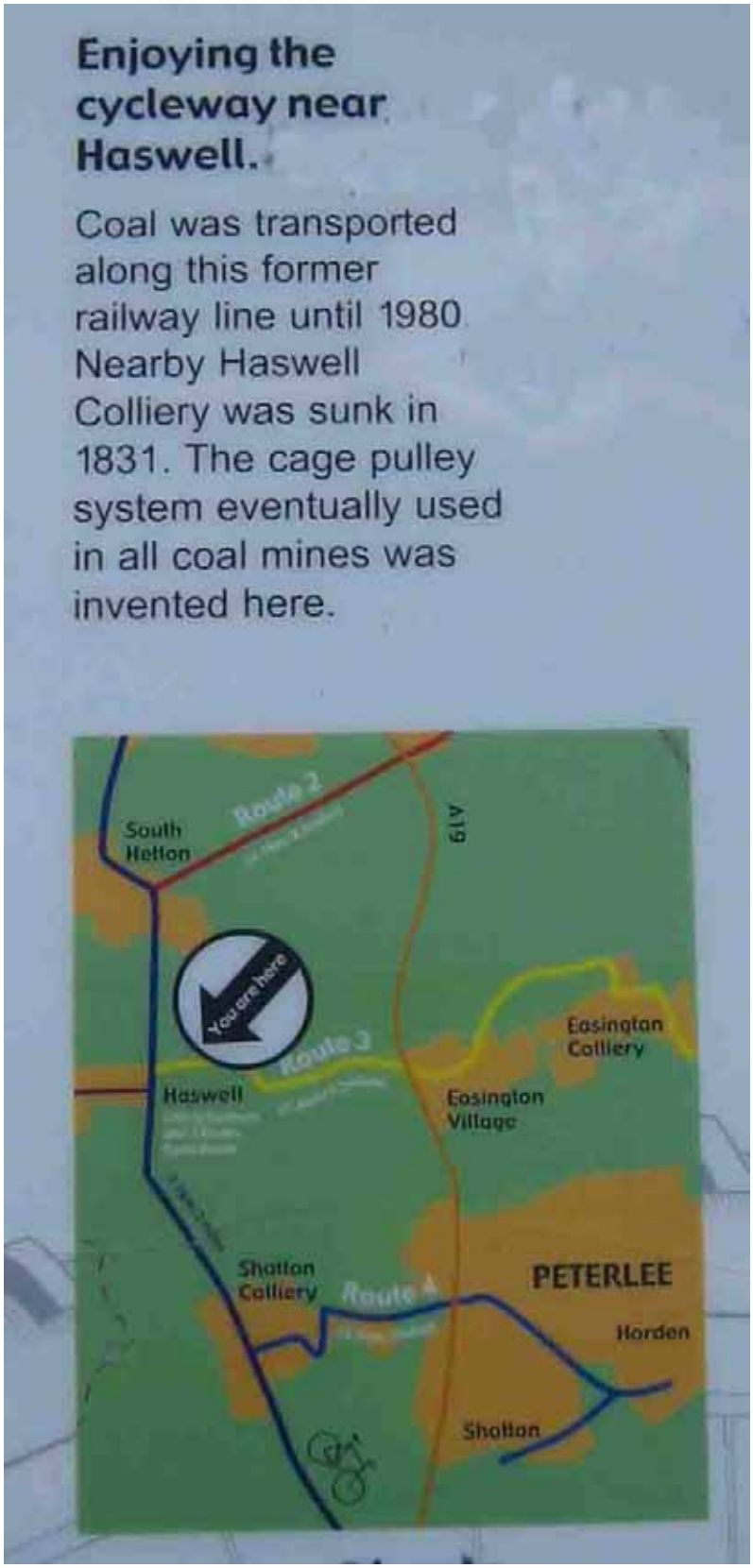

Plate 19 Display board on cycleway near Haswell

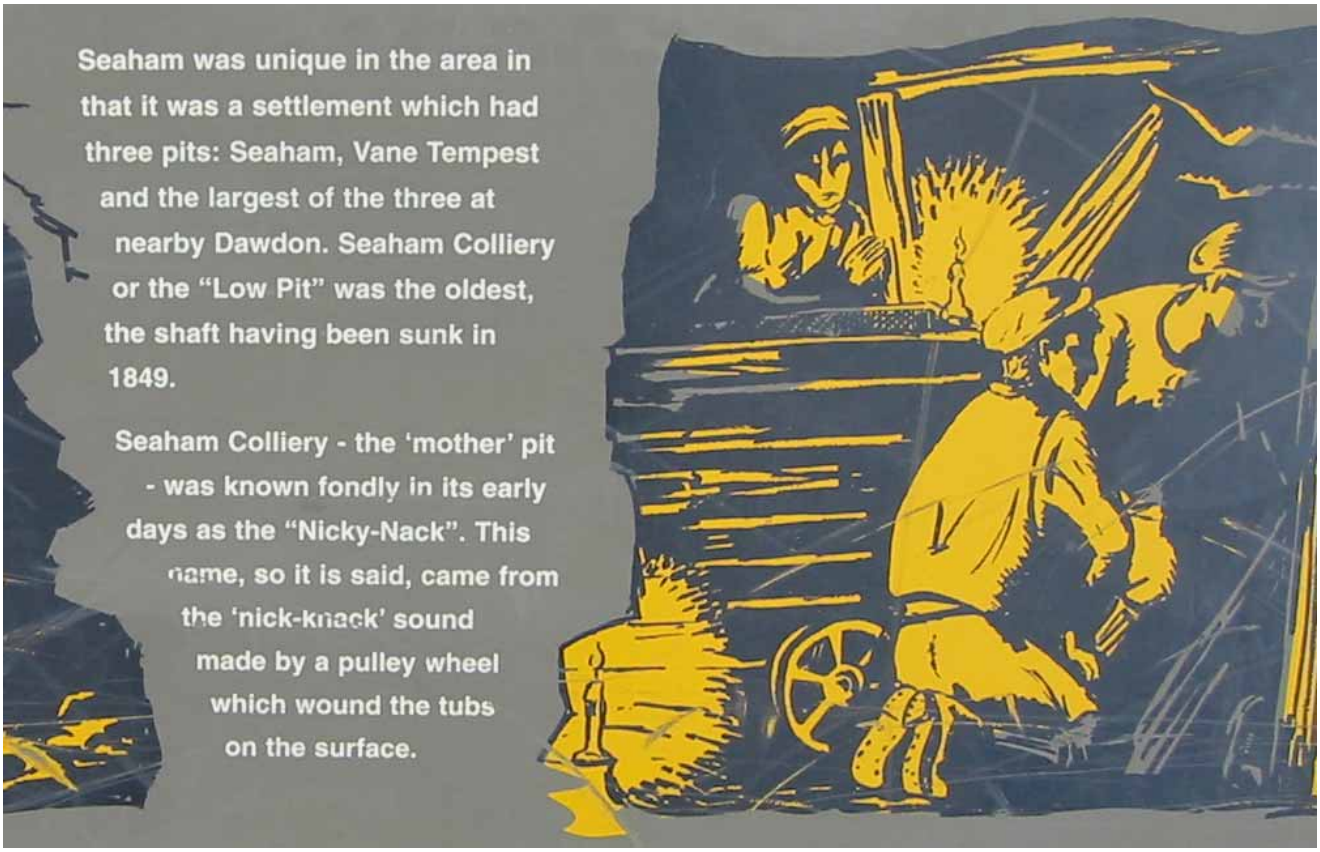

Plate 20 The Seaham 3 Pits sculpture and a detail from the panel

Plate 21 Magnesian Limestone (Raisby Formation) overlying the Marl Slate Formation (the grey layer) above the Yellow Sands Formation in the working Hepplewhites Quarry.

Rare fossil find at quarry

A 12-year-old girl discovered a rare fossil at Thrislington Quarry during a special fossil hunt organised for the wildlife explorers' club of the Royal Society for the Protection of Birds.

Stephanie Gomersall hammered apart a large piece of slate at Lafarge Aggregates' Thrislington Quarry, near Ferryhill, and found the imprint of a fish called '*Coelacanthus*' which is about 250 million years old.

She showed it to the organiser of the fossil hunt, Steve McLean, curator of the Hancock Museum, Newcastle, whose suspicion that it was a rare specimen was later confirmed by the Natural History Museum in London.

Stephanie, of Ponteland, Northumberland, was searching the last pieces of stone when she made her discovery... "I was quite amazed as it's the first time I've looked for fossils".

Her father Richard, who works in the advertising department of the Newcastle Journal newspaper, had co-ordinated the fossil hunt for the RSPB Wildlife Explorers' Club. Stephanie has donated the fossil to the Hancock Museum which is putting it on display.

Steve McLean said: "*Coelacanthus* is a rare fossil. We only have a few in the collections at the Hancock Museum. It is a very interesting type of fossil because it was thought that fish of this type were extinct until a modern coelacanth was caught by a fishing boat off the coast of South Africa in 1938. They are still being caught today.

"It's great to find this fossil specimen in Durham and I thank Lafarge Aggregates for hosting the fossil hunt in their quarry".

Quarry manager Graeme Parkin said: "Lafarge's partnership with the museum means we can organise these fossil hunts from time to time".

The Hancock Museum is also putting on display another specimen found at Thrislington Quarry. Shotfirer Keith Farley was preparing some slate for a visit of school pupils and discovered what is commonly called a shark's head fossil but in fact is the imprint of a fish called *Janassa* which was ray like and fed on the bottom of the sea.

"It is quite a rare find and although this specimen is somewhat mangled we can see evidence of the skin and the mouth and teeth of the fish", added Steve.

- The fossil find follows the recent unearthing of a 40,000-year-old skeleton of a woolly rhino at another Lafarge quarry in Staffordshire.

12-year-old Stephanie Gomersall and Steve McLean, Curator of the Hancock Museum, with the rare fossil

Plate 22 Fossil found by a young person during RSPB organized visit to the working Thrislington Quarry in 2003

Plate 23 ‘Walking Works Wonders’ board south of Lizard point

Plate 24 Cross-bedding in Permian Yellow Sands Formation at Crime Rigg Quarry

Plate 25 Modern desert dunes in the United Arab Emirates