Arnside & Silverdale
Area of Outstanding Natural Beauty






# Landscape Monitoring Project -
# Geology Audit and Assessment

Final Report, January 2019

Cuesta

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# 1. Introduction

*The Arnside and Silverdale Area of Outstanding Natural Beauty (AONB) is an intricate, close-knit landscape that has been shaped, primarily, by its geology and by the range of natural, 'geomorphological' processes which have acted upon it over many millions of years. Whilst the modern landscape also reflects a range of human influences, those have occurred over a much shorter timescale – the last several thousand years at most – and have served only to modify the mosaic of details created by nature itself.*

*In recognition of the very evident link, in this area, between landscape, geology and geomorphological processes, this geological audit was commissioned as a starting point for monitoring the role which geological factors have in relation to the primary purpose of the AONB (i.e. to conserve and enhance the natural beauty of the area) and in relation to the area's Management Plans, which identify the specific actions needed to achieve that purpose over successive five-year periods (2014 - 19 and 2019 - 24).*

## *Geodiversity*

In this context, it is not just the geology (i.e. the characteristics of the rocks, sediments and geological structures) which is important; it is also the '***geodiversity***' (i.e. the sheer variety of geological features, including the fossils, minerals, natural processes, landforms and soils – as well as the rocks – which underlie and determine the physical character of the landscape and the natural environment). It is the geological equivalent of 'biodiversity', which covers the variety of living things, and is a key aspect of geological conservation.

Arguably, the rocks themselves (almost entirely limestone in this area) are quite limited in their variety – at least to the casual observer – but the detailed evidence which they provide regarding past environments, and the intricate variety of structures, features and landforms which have been created over time through the action of natural processes upon these rocks, is quite astonishing for such a small geographical area. Much of this is reflected in the wealth of environmental designations relating directly or indirectly to geology that are present within the AONB (as illustrated in **Map 1**), and in the very lively ongoing interest in several aspects of the area's geology that is evident in both local geological societies and Universities.

**Map 1** attempts to illustrate this variety by combining information on the distribution of different bedrock formations exposed at the surface (or beneath thin soil cover); with the distribution of younger 'superficial' deposits such as glacial sediments, peat deposits[1], saltmarsh and tidal flats; selected geomorphological features (landforms); and the distribution of designations which relate primarily (or at least partially) to the geology.

The geological linework is taken from the latest available 1:50,000 scale digital mapping of the area (Kirkby Lonsdale Sheet, EW049), published by the British Geological Survey (BGS). Landforms are derived in part from the BGS map, and from BRITICE outputs, but supplemented (in the case of drumlins and eskers) by additional geomorphological mapping from topographic maps and aerial photographs, by the authors.

The designations, as listed on **Map 1**, include the **National Nature Reserve** (NNR) at Gait Barrows; three geological **Sites of Special Scientific Interest** (SSSIs); one additional SSSI (Leighton Moss) which, though primarily designated for its biological interest is also an important part of the area's geological history; two **Local Nature Reserves** (LNRs) and several **Local Geological Sites** (LGSs), proposed by the local geo-conservation groups (Cumbria Geo-Conservation and Geo-Lancashire) and designated by the respective County Councils. **Map 2** (part A) shows the Local Geological Sites within both Cumbria and Lancashire without the details of other designations.

Also shown on **Maps 1 and 2** are numerous, nationally-designated **Limestone Pavement Orders** (LPOs), many of which are recognised as being among the best examples of lowland limestone pavement in the world. Five of the LPOs form part of the 'Morecambe Bay Pavements' **Special Area of Conservation** (SAC) – a European Designation. Morecambe Bay itself is a separate SAC which is also designated (along with Leighton Moss) as a European **Special Protection Area** (SPA)

[1] With regard to the mapping of superficial deposits, taken from the latest available BGS digital mapping, it should be noted that the peat deposits, in particular, are rather generalised, by comparison with the far more detailed work carried out by University researchers – particularly at Hawes Water – see page 38 for details of that site.

and International **Ramsar** Site. To avoid over-complication, the SAC, SPA and Ramsar boundaries within the AONB are shown separately, along with other (biological), SSSIs, on **Map 3**.

Overall, the AONB is remarkable for the extent and variety of its designated features: 48% of its 75 $km^2$ is designated under European Directives for its habitat, species or bird interest (SACs and SPAs) and 54% of the area (including the European sites and others) is covered by SSSIs. Whilst features and designations comparable to most of those shown on Maps 1 to 3 can also be found elsewhere, including within areas directly adjacent to the AONB, what sets the AONB apart more than anything is the close proximity of the diverse features within this area and the way in which they combine to produce such a fascinating ***landscape mosaic***, underpinned by a distinctive ***geological jigsaw***.

Key elements of this mosaic are the limestone hills, open and wooded limestone pavements, limestone scarps and slacks (including 'The Trough' close to Trowbarrow Quarry), the limestone quarries themselves, locally complex geological structures, low coastal cliffs, shingle bays, saltmarshes, tidal flats, former and current lakes, former areas of lowland raised bogs, residual peat bogs and reedbeds, and the shapely rounded low hills known as '*drumlins*' which are associated with former ice sheets and glaciers.

Several aspects of the geological puzzle are the subject of ongoing research, exploration and/or promotion for education by academic geologists and geographers at northern universities including Liverpool, Lancaster, Leeds and Manchester, and by a good number of local, very dedicated amateur and retired professional geologists. Such interest helps to underpin the importance of local geology to the purpose of the AONB and its ongoing Management Plan.

## *The Purpose of this Study*

The aim of the project was to carry out a detailed geology audit across the AONB and to undertake research into the geological evolution of the area to enable a robust evidence base of the geodiversity of the AONB to be established for monitoring delivery of the current AONB Management Plan, for monitoring landscape change and for preparation of the next AONB Management Plan.

The project was also required to provide a local landscape monitoring evidence base and to inform an ecosystems approach to AONB management activity, helping to ensure the landscape is resilient to change and continues to deliver multiple benefits for people.

In order to achieve these aims, the project had the following, more specific objectives:

- Undertake an audit of the AONB's geological resource compiling maps, data, information on key sites and features, photographs and other relevant evidence.
- Present a geological story of the AONB in plain English.
- Describe in detail the Geological Framework of the AONB, identifying what is distinctive and unique.
- Assess how the geology and current active geomorphological processes influence and contribute to the area's natural beauty, landscape and seascape character, biodiversity, built environment, industrial heritage/economy and culture.

- Assess how the geodiversity of the AONB is a natural capital asset, provides ecosystem services and contributes to landscape resilience.
- Identify conservation issues/risks/vulnerabilities.
- Present guidelines for conserving and managing the area's geodiversity.
- Make recommendations for further work.

The evidence base provided by this project will form a baseline for future monitoring of the AONB's many different geodiversity assets and their ongoing contributions to the quality and character of the area. Such monitoring will not only assist in the delivery of the existing Management Plan, it will also inform the development of the next Plan and will contribute to Natural England's wider objectives in monitoring landscape change and monitoring environmental outcomes in protected landscapes.

## *Structure of the Report*

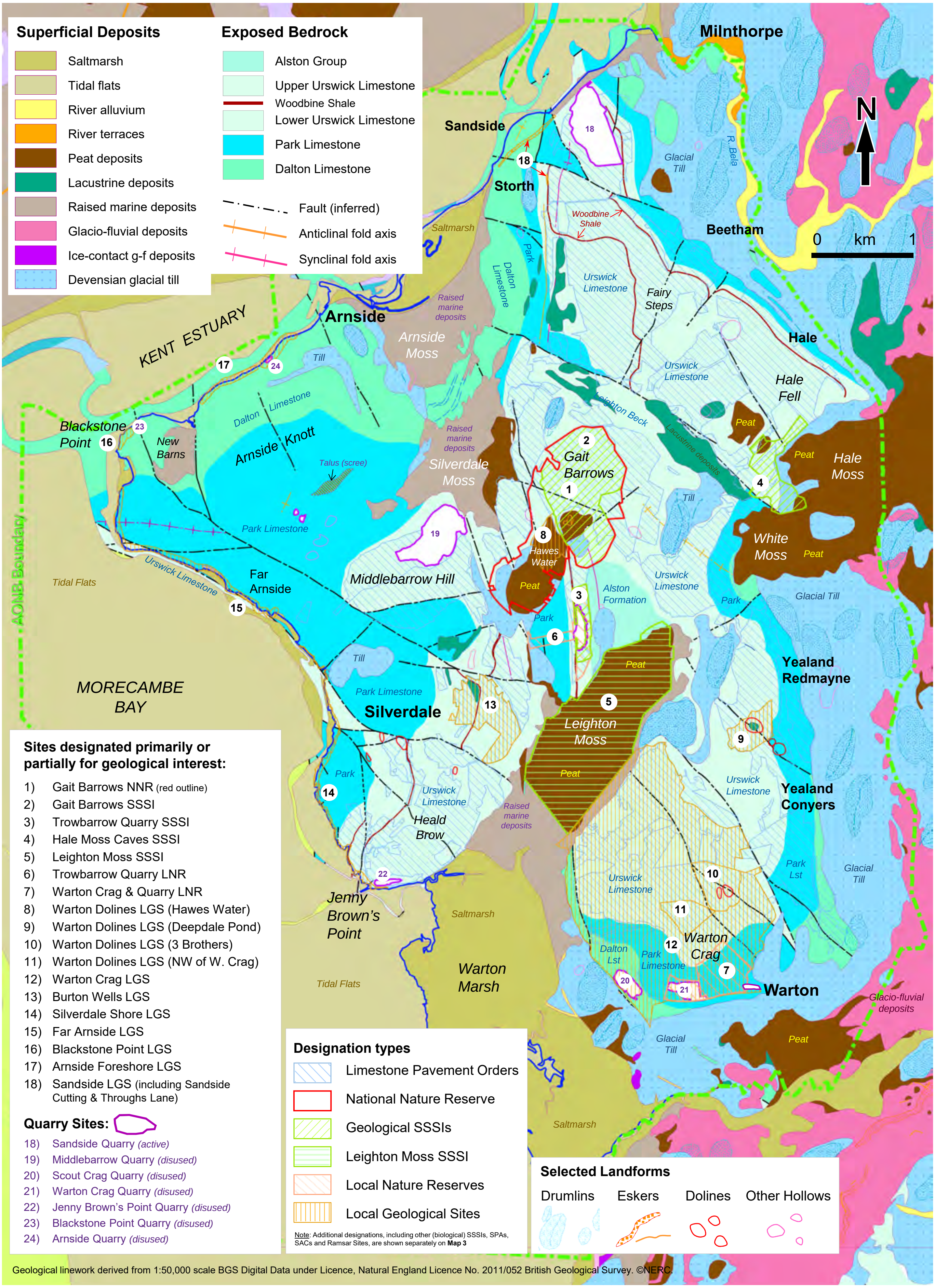
Chapter 2 of this report explains the chronological sequence of geological periods and events – including the influence of human activity in recent times – which have led to the formation of the present-day landscape of the AONB. It is deliberately written in a non-technical style which enables the geological 'story' to be followed by those with an interest in the origins of the landscape but without necessarily having any prior geological knowledge. A slightly abbreviated version of Chapter 2 is also available separately as a free-standing publication, with the aim of explaining the local geological 'story' to non-specialists.

Chapter 3 then provides a more in-depth analysis of each of the geological formations and deposits which are encountered within the AONB. These are again listed in chronological order, but the focus is on the geological characteristics of the strata, rather than their origin, together with an assessment, in each case, of their influence on natural beauty, landscape and seascape character, soils and biodiversity; their economic and recreational use, including built heritage; and the conservation of their geodiversity interests.

Chapter 4 provides an assessment of the 'Ecosystem Services' provided by each of the geological strata, sediment types and ongoing geomorphological processes noted in Chapter 3, as a means of understanding their contribution towards the special qualities of the AONB and its resilience to climate change. Building upon that understanding, Chapter 5 then sets out geodiversity conservation guidelines for the AONB as a whole. These take account of the geodiversity audit completed in developing both the Geological Framework and the ecosystems services assessment. The recommendations are set out in relation to the six guiding themes of the UK Geodiversity Action Plan (GAP), thereby providing a first consideration of some of the steps that have already been taken and those that could be completed in developing a Local GAP for the AONB itself.

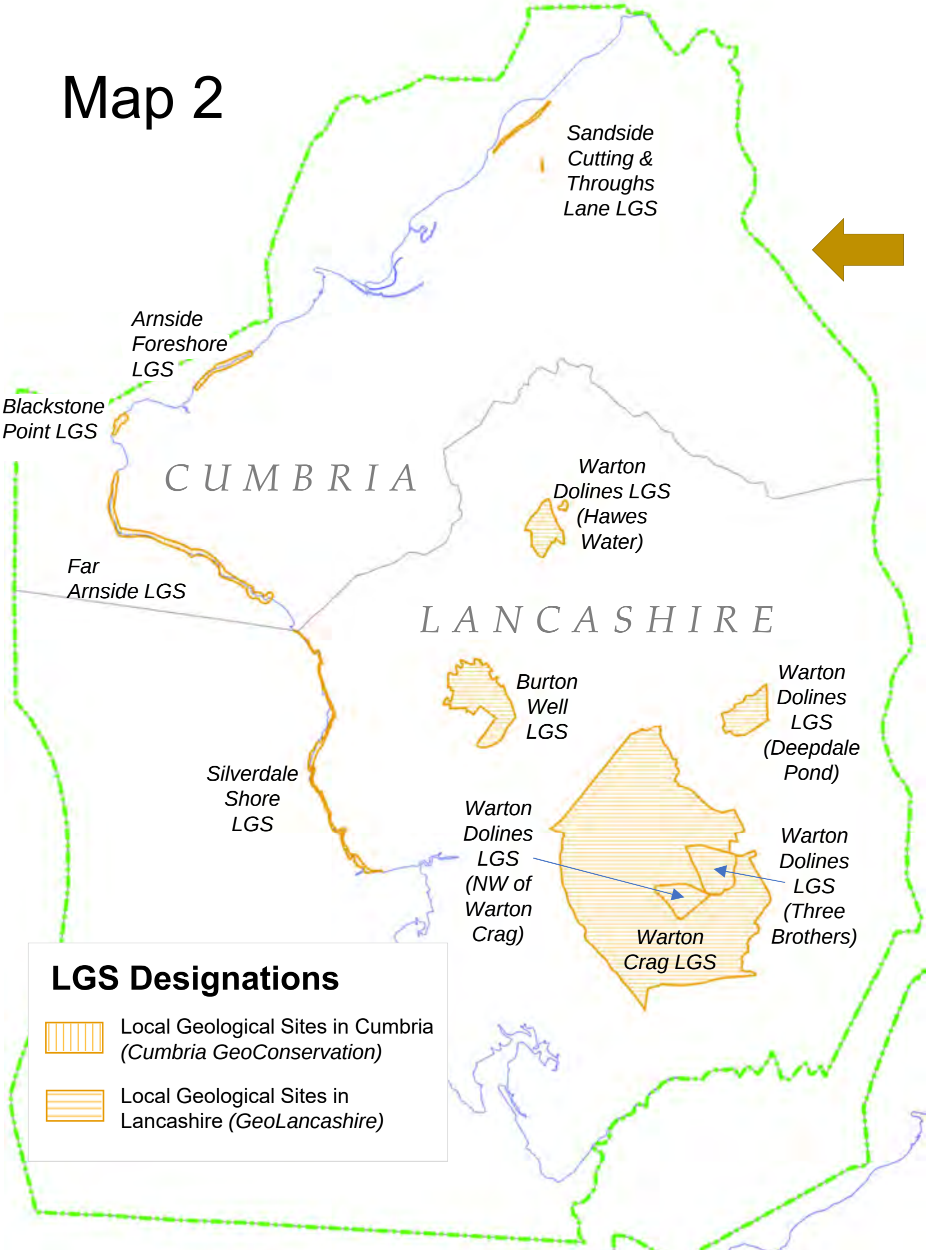
Chapter 6 then provides draft recommendations for a number of other topics including the identification of key Indicators for monitoring future landscape change; opportunities for supporting future Landscape Resilience; and recommendations for further research, including the maintenance of active links with academics, professionals and enthusiastic amateur geologists.

# Map 1 – Geodiversity

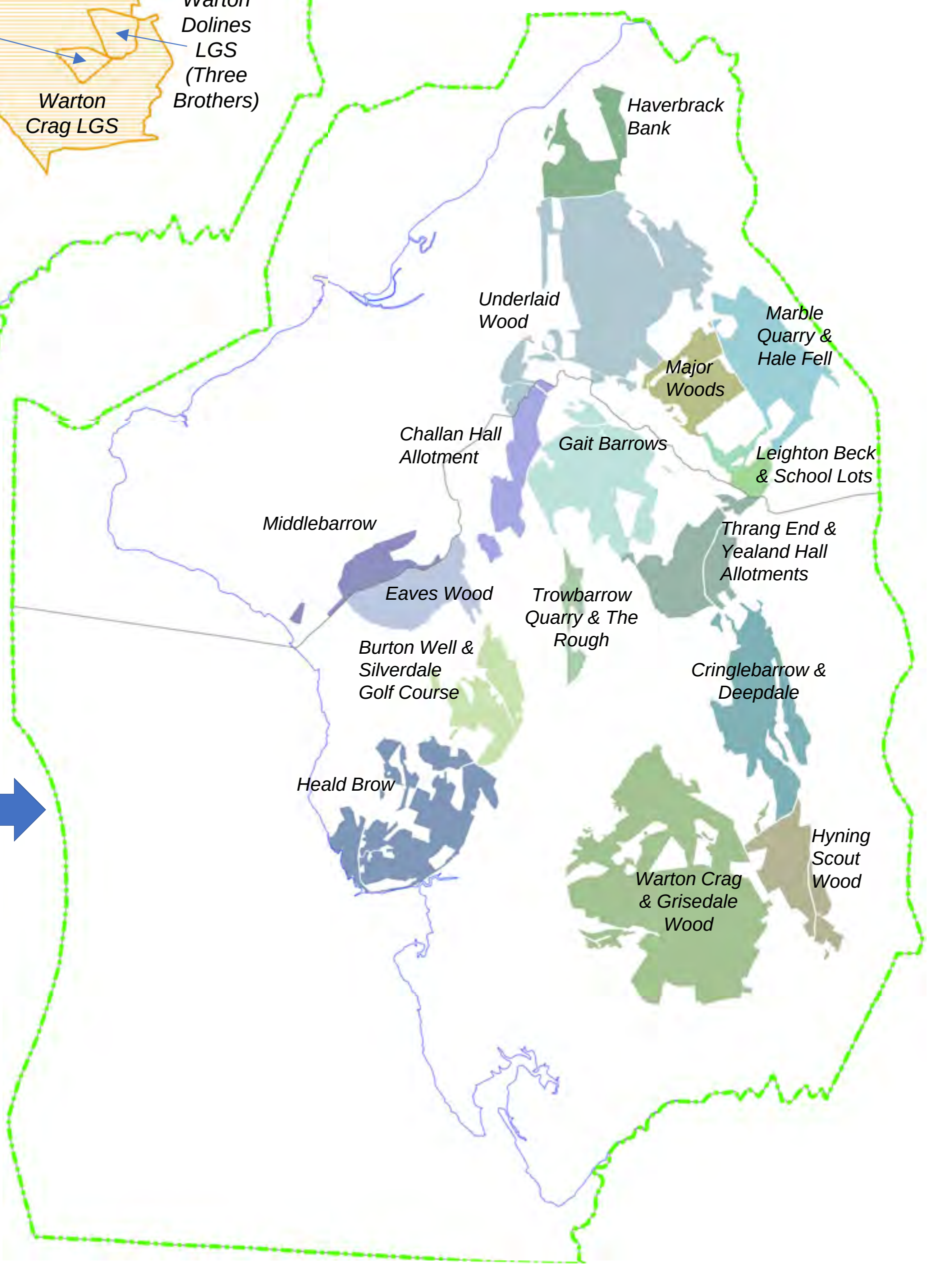


# Map 2

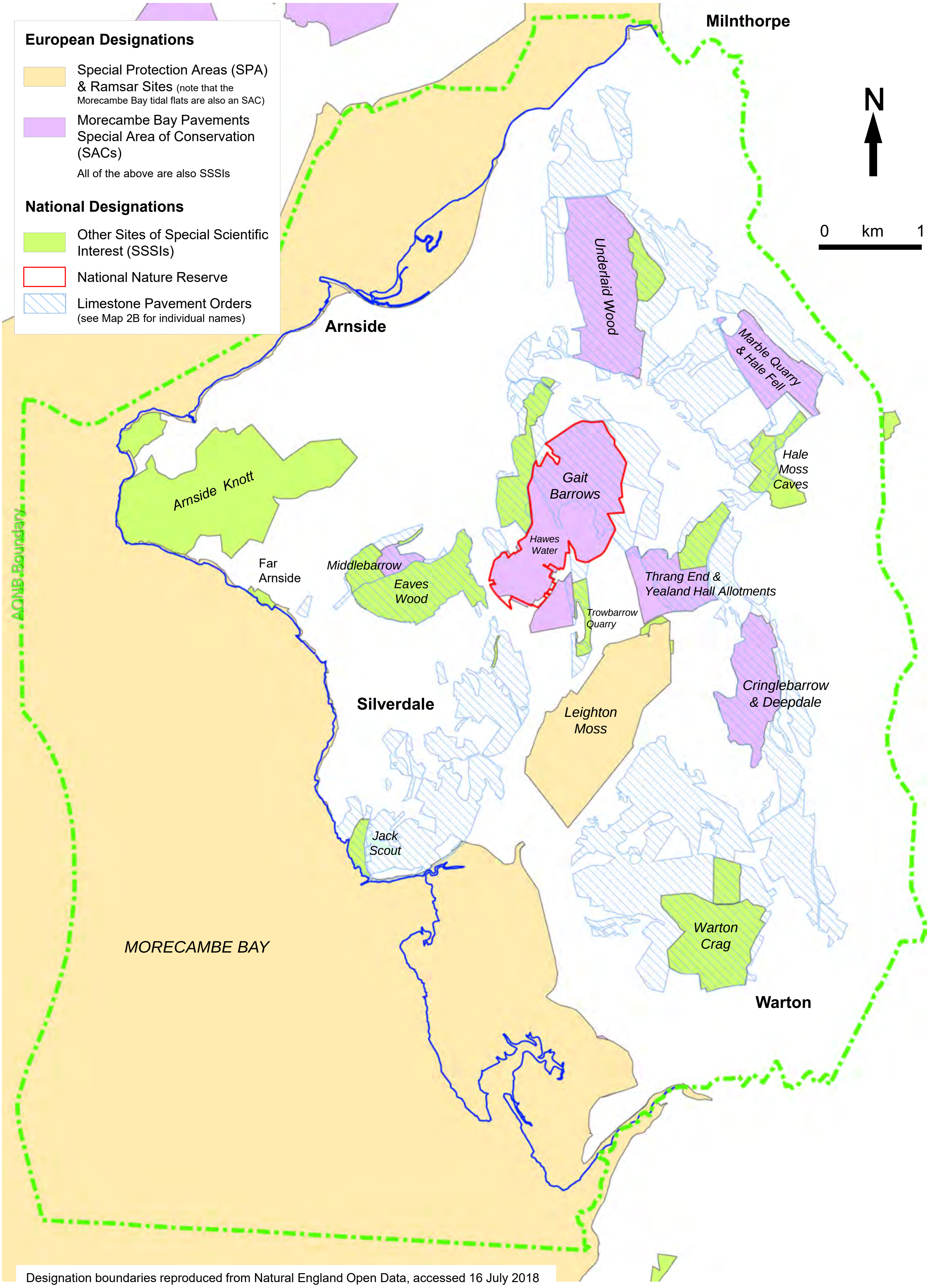
## (A) Details of Local Geological Sites within the AONB




## (B) Details of Limestone Pavement Orders within the AONB



# Map 3 – European & National Designations




Designation boundaries reproduced from Natural England Open Data, accessed 16 July 2018

# 2. The Geological 'Story' of the AONB

*The highly varied landscape of the Arnside & Silverdale Area of Outstanding Natural Beauty owes its origin to nearly half a billion years of geological history and evolution. Understanding how the various rocks within the area were formed, and how they have since been sculptured by ice, wind, rain and rivers, provides a fascinating insight into the nature of the area and the reasons behind its intricate variety.*

*The underlying geology, topography and diversity are reflected in the wide range of special ('priority') habitats which have developed in this area over the last 10,000 years or more, and which now contribute further to its natural heritage. In more recent times, generations of farming, tourism, built development and other land uses have also left their mark on the landscape, but in many cases, even these reflect the underlying geology and landforms of the area.*

*The following account is intended to enable this 'story' of geological evolution to be followed by those with an interest in the form and origins of the landscape but not necessarily with any prior geological knowledge or formal training in the subject. It is based, as far as possible, on the latest available scientific evidence, and on the authors' own field observations, but it deliberately avoids excessively detailed explanations. It seeks to explain things, as far as possible, in 'Plain English'. There are, however, a small number of geological terms which are difficult to avoid and very useful to understand. The main ones are explained briefly on the following page, and others are explained as and when they are first used, in the text.*

## *Geo-Jargon - A few essential terms explained*

**Geology** is simply the scientific study of the Earth. It encompasses the study of all ***rocks***, ***superficial deposits***, ***minerals*** and ***fossils***, including how they were formed, how old they are, and what evidence they provide about the conditions which prevailed in a particular area at the time of their formation.

**Rocks** are the solid materials which make up the surface of the Earth and much of its internal structure. They include ***igneous rocks*** (formed by the solidification of molten material either deep inside the Earth or, in the case of '*volcanic*' rocks, ejected at the surface through volcanoes and fissures); ***sedimentary rocks*** (formed either by the erosion of older rocks, and the subsequent deposition of the eroded material into new layers, or by the accumulation of shells and other organic remains, usually in water); and ***metamorphic rocks*** (those which have been changed from their original form, either by high temperatures and/or pressures within the Earth's crust).

**Superficial deposits** are sediments which have been deposited on the surface of the Earth, generally within the last 2 million years, and which have not yet become hardened into rocks. They are clearly distinguished, on geological maps, from the underlying bedrock.

**Minerals** are the inorganic constituents of rocks and sediments, occurring as individual crystals (in the case of igneous and metamorphic rocks) or eroded grains of sand etc. (in sedimentary rocks). Individual minerals are distinct chemical compounds, such as Calcium Carbonate (or Calcite, the main constituent of limestone), or Silicon Dioxide (Silica, the main constituent of most sandstones). Rocks may comprise just one or (usually) more than one type of mineral.

**Fossils** are the preserved traces or remains of animals and other organisms which formerly inhabited the Earth. In most cases, it is only the shells or skeletons which are preserved, often as a result of the recrystallisation or even replacement of the original minerals that were present within the structures.

**Geomorphology** literally means the scientific study of the shape of the Earth's surface features (landforms), and of the natural ***geomorphological*** processes which have been responsible for their formation. These include the processes of weathering, erosion, sediment transportation and deposition. They may involve rivers, glaciers, landslides, rockfalls, mudflows, tidal currents and wind, along with mechanical effects of temperature variations and the chemical dissolution or precipitation of minerals in water.

**Groundwater** is any water contained within, or flowing through, rocks or superficial deposits beneath the surface of the Earth.

**Karst**, and '***karstic***' are more specialised geomorphological terms which have particular relevance to areas, such as the Arnside & Silverdale AONB, where soluble rocks, such as limestone, are exposed at the surface. They relate to the special landforms and processes which are associated with the natural dissolution of these rocks by slightly acidic rainfall and percolating groundwater. Further details of these terms and associated features are given on pages 29 and 30 below.

## *The Geological Timescale*

In order to understand the geological 'story' of the area, it is important to know something about the timescales involved, and the names which geologists have given to each successive part of the sequence. The names are not all that important but are often used to describe the age of particular rocks or features, so it is useful to know how these names tie-in with the overall timescale, expressed in years before the present day. It should be noted that the various divisions shown do not represent equal time intervals and that not all sub-Periods and Ages are shown – only those which have relevance to this area. Further details of selected geological 'events' and of the various 'strata' (layers of rock, or sediment) mentioned in the right-hand column will be explained as the story unfolds.

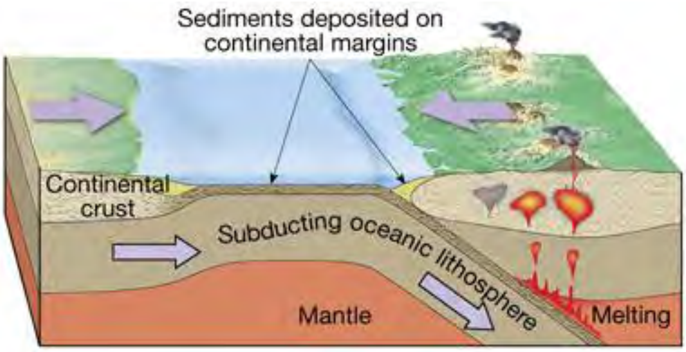
| *Start* (Years Before Present) | *End* | *Period* | *Sub-Period* | *Age (& selected events)* | *Strata* within the AONB |
|---|---|---|---|---|---|
| *2,750* | *ongoing* | ***Quaternary*** | *Holocene* | *Sub-Atlantic* | ***Tidal flats, alluvium, saltmarsh, soils, +*** *increasing human influence* |
| *5,950* | *2,750* | | | *Sub-Boreal* | |
| *8,200* | *5,950* | | | *Atlantic* — *Flandrian marine transgression* | ***Raised marine clays, marl, lacustrine clays, peat, raised bog, soils*** |
| *10,500* | *8,200* | | | *Boreal* | |
| *11,700* | *10,500* | | | *Pre-Boreal* | ***Marl, lacustrine clays*** |
| *12,600* | *11,700* | | *Pleistocene* | *Late Devensian* | ***Screes, loess*** |
| *14,700* | *12,600* | | | *Late Devensian, Windermere interstadial* | ***Marl, lacustrine clays, peat, soils*** |
| *29,000* | *14,700* | | | *Late Devensian, Dimlington Stadial (Last Glaciation)* | ***Glacial till, glacio-fluvial sediments, screes, loess*** |
| *2.58 million* | *29,000* | | | *Earlier glaciations and interglacials* | *No undisturbed deposits remain* |
| *65.5 million* | *2.58 million* | ***Tertiary*** *(= Neogene & Palaeogene)* | | *Alpine Orogeny* | *No deposits remain* |
| *145.5 million* | *65.5 million* | ***Cretaceous*** | | | |
| *200 million* | *145.5 million* | ***Jurassic*** | | | |
| *251 million* | *200 million* | ***Triassic*** | | *Mineralisation* | ***Haematite ore*** |
| *299 million* | *251 million* | ***Permian*** | | *Variscan Orogeny* | *No deposits remain* |
| *326 million* | *299 million* | ***Carboniferous*** | *Silesian* | | ***Millstone Grit Pendle Grit*** |
| *331 million* | *326 million* | | *Dinantian* | *Brigantian* | ***Alston Formation*** |
| *335 million* | *331 million* | | | *Asbian* | ***Urswick Limestone Fm.*** |
| *339 million* | *335 million* | | | *Holkerian* | ***Park Limestone Fm.*** |
| *343 million* | *339 million* | | | *Arundian* | ***Dalton Formation & Red Hill Lst. Fm.*** |
| *347 million* | *343 million* | | | *Chadian* | ***Martin Limestone*** |
| *359 million* | *347 million* | | | *Courceyan* | *No deposition?* |
| *416 million* | *359 million* | ***Devonian*** | | *Caledonian Orogeny* | ***Shap Granite*** |
| *444 million* | *416 million* | ***Silurian*** | | | ***Kirkby Moor Formation Bannisdale Formation*** |
| *488 million* | *444 million* | ***Ordovician*** | | | ***Borrowdale Volcanics*** |
| *4.56 billion* | *488 million* | ***Cambrian & Pre-Cambrian*** | | | *No surviving evidence* |

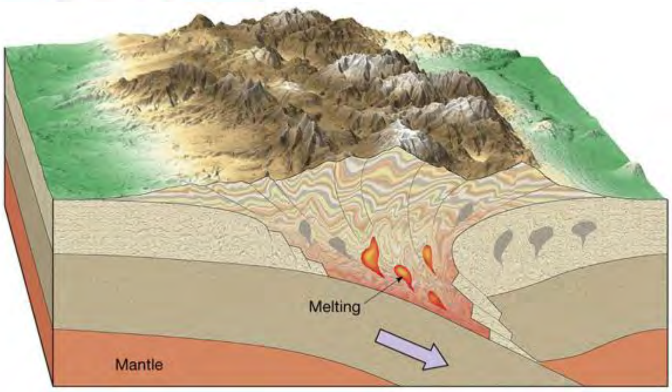
## *Before the Rocks were Made*

Long before the present-day landscape began to take shape, and before even the rocks from which it is sculptured (as shown on **Map 1**, above and **Map 4** on page 22 below) had been formed, the Arnside – Silverdale area would have been largely a barren semi-arid upland landscape. This was during the "**Devonian**" period of Earth history, some 359 to 416 million years ago. Much of northern England and southern Scotland were emergent (above sea level) at this time - remnants of a large land-mass from which sediments were eroded to form the 'Old Red Sandstones' deposited elsewhere. No direct evidence of this period remains within the AONB, but it was on this Devonian landscape that the more recent rocks that we see today were laid down.

To fully understand the origins of the Arnside - Silverdale area, however, we need to go back much further in time. In geology, the spans of time involved are enormous – almost beyond comprehension – and are measured in hundreds of millions of years. The origins of this area can be traced back more than 400 million years. The Stratigraphic Table on the previous page summarises the overall sequence of geological periods since the Earth itself was formed, more than 4.5 billion years ago, showing the names of individual periods, strata and events which are mentioned below.

Prior to, and during the early part of the Devonian period, the upland landscape had been created towards the end of a complex episode of mountain-building known as the "**Caledonian Orogeny**". At the beginning of this sequence, during the "**Ordovician**" Period, gradual movements within the Earth's crust had resulted in two former continents moving towards each other, as illustrated in the first diagram below. What is now Scotland formed part of one continent, and what is now the north of England formed part of the other. In between lay the former 'Iapetus' ocean.



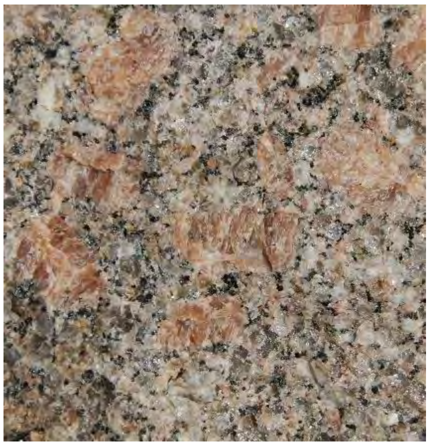



Stages in the collision of continents, leading to the creation of volcanoes and fold mountains[2]

As the continents moved towards each other, over an interval of more than 160 million years, the rocks beneath the ocean were pushed down ('subducted') below what is now the Lake District. This caused partial melting of the rocks at depth and large bodies of molten rock (known as '*magma*') gradually rose up into the overlying crust. This, combined with the intense compression and buckling of rocks on the southern continent created a vast mountain range - much higher than the present-day hills. Volcanic eruptions above the rising magma chamber resulted in the formation of a wide range of volcanic rocks at the surface within the central part of the Lake District. These are known collectively as the ***Borrowdale Volcanics***. None of the eruptions extended as far south as the Arnside area but some of the resulting rocks can be seen in the form of '**erratics**' – boulders and smaller rock fragments eroded from the Lake District and carried south by glaciers during more recent ice ages.

As the Lake District volcanism began to subside, during the "**Silurian**" period, the whole area fell below sea level and marine sediments known as '*Greywackes*' (ranging from mudstones and siltstones to coarse sandstones) began to accumulate on the continental shelf. Tilted and buckled during the later stages of the Caledonian orogeny, the resulting rocks probably remain at depth within the AONB but lie buried beneath more recent strata. Some of them, including the ***Bannisdale Formation*** slates and ***Kirkby Moor Formation*** sandstones occur at the surface only in the far north of the area, beneath the present-day Kent Estuary (see **Map 4**, on page 22 below), and so are not accessible for inspection. As with the Borrowdale Volcanics, however, they also occur as glacial erratics, deposited by glaciers on top of more recent strata. The same is true of the ***Shap Granite*** – a very distinctive, coarse-grained igneous rock which was intruded into the eastern side of the Lake District during the Devonian period, at the end of the Caledonian Orogeny.

Erratic boulder of Silurian greywacke on the Arnside foreshore, with distinctive lichens, quite unlike those found on the Carboniferous rocks



Detail of Shap Granite showing large, interlocking crystal structure

## *Shallow Seas and Advancing Deltas – the Carboniferous Period*

*As the old Caledonian land mass was eroded down during the Devonian period, and as global sea levels began to rise, the scene was set for the onset of the "**Carboniferous**" Period (so-called because of the extensive coal deposits which formed in much of northern England – and elsewhere – during the latter part of this period). Previously*

[2] Diagrams obtained freely from internet source here, accessed 17 July 2018.

*emergent land within the AONB area became submerged beneath warm, tropical seas, allowing the deposition of shallow marine sediments across the area. This 'marine transgression' began about 347 million years ago during the Early Carboniferous.*

The sediments laid down beneath the seas were '*carbonates*' – made up almost entirely of Calcium carbonate shell fragments, corals and other marine organisms which lived within the shallow seas. As they became compressed by the weight of other sediments laid down above them, these deposits were gradually transformed into the limestone rock that we see today. Sedimentation beneath the sea continued for a period of approximately 21 million years, interrupted periodically by episodes of emergence at times when sea levels fell. At such times, the depositional surfaces would have been exposed to atmospheric weathering. This, in turn, gave rise to the formation of incipient '*karstic*' surfaces, as the limestone began to be dissolved by rainwater. Old surfaces and features of this type, which were subsequently buried by younger sediments, are generally referred to as '*palaeokarst*'.

Whilst emergent, the limestone surfaces were also subject to the formation of soils and vegetation, now preserved as thin '*palaeosols*' (fossil soil horizons) between some of the beds. Some, at least, of the palaeosols contain bentonite – a type of clay which is a characteristic weathering product of fine-grained volcanic ash, produced from contemporaneous volcanic activity which was taking place further north in the Lake District and southern Scotland.

The sequence of Carboniferous Limestone deposits and subtle differences in their depositional environments are briefly outlined below. Their outcrop distribution within the AONB, based on the latest available digital mapping from the British Geological Survey (BGS) is shown on **Map 4**, on page 22, below. More detailed information on their characteristic features is given in the Geological Framework (Chapter 3).

## *The Carboniferous Limestone Sequence*

*The oldest parts of the Carboniferous Limestone sequence within the AONB are the **Martin Limestone Formation** (from the Chadian Age of the Dinantian sub-period – see Stratigraphic Table, above) and the succeeding **Red Hill Limestone Formation**, from the first part of the Arundian Age. Neither of these is seen at outcrop within the area; they occur near the surface only beneath mudflats within the Kent Estuary and beneath superficial saltmarsh and raised marine deposits in the adjoining coastal lowland of Arnside Moss. The Martin Limestone is made up of fairly pure carbonate deposits, laid down within tropical beach, tidal flat and lagoon environments. The Red Hill Limestone is also a shallow water sediment deposited within a high energy reef environment.*

*The **Dalton Formation**, which follows, was laid down during the latter part of the Arundian Age and represents a rapid change of environment to deeper water conditions within a subsiding depositional basin. Unlike the preceding high-energy, shallow-water conditions, most of the Dalton Formation sediments were laid down within relatively still water, probably at depths of more than 100m. This enabled fine-grained mud to settle out of suspension as well as the deposition of carbonate sediment. The formation therefore comprises relatively dark-coloured, well-bedded muddy limestones, often with thin beds of calcareous shale, representing periods of mud deposition. The formation crops out along much of the AONB's northern coast and is particularly well- displayed along the foreshore and low cliffs between Arnside promenade and Blackstone Point, where many examples of the formation's distinctive fossils can be seen.*

Typical outcrop of the Dalton Beds within the Arnside Foreshore Local Geological Site, showing alternation of limestones and shales.

*The succeeding **Park Limestone Formation** was laid down during the Holkerian Age and marks a return to relatively shallow water carbonate sedimentation, with deposition taking place around the 'wave base' in something like 10 to 30m of water. It thus comprises mostly cream or pale grey limestones, typically composed of carbonate sands, often in a matrix of carbonate mud. In contrast to the Dalton Formation, bedding within the Park Limestone is often indistinct. This is partly due to continuous sedimentation, partly due to the relative absence of shales in between the individual limestone beds, and partly to 'bioturbation' of the sediments by marine organisms. Irregular, blocky jointing is common within some of the beds, giving outcrops a more rubbly appearance than either the Dalton or Urswick limestones. These characteristics lend themselves to the formation of 'scree' slopes, made up of angular, broken rock fragments, below outcrops such as those on Arnside Knott.*

Typical outcrop of the Park Limestone within the Far Arnside Local Geological Site, showing characteristic blocky jointing and lack of clear bedding.

*The **Urswick Limestone Formation**, laid down during the Asbian Age, rests on a palaeo-karstic surface developed on top of the Park Limestone at a time when the area was above sea level. This, and several other similar surfaces within the formation have been interpreted as being a consequence of sea level changes linked to periods of glaciation – mostly within the southern hemisphere. These cyclic changes in water depth were superimposed on longer cycles of alternating crustal subsidence and stability to produce a much wider range of depositional environments than seen in any of the earlier formations.*

*During periods of emergence, the whole of the AONB area would have been flat, low-lying land with soil cover (now preserved as palaeosols on some of the palaeo-karstic surfaces) and extensive vegetation – including (at times at least) quite substantial trees.*

*As illustrated in the photographs below and on the following pages, sections though the Urswick Limestone are exposed within Holme Park Quarry (another of Cumbria GeoConservation's Local Geological Sites, just outside the AONB), which can be seen from a public viewing platform; at the top of high faces at both Middlebarrow and Sandside Quarries, which again can only be viewed from a distance; and also at the more accessible disused Trowbarrow Quarry where the beds are tilted into a vertical position.*

Section through a palaeo-karstic surface within the Urswick Limestone at Holme Park Quarry (just outside the AONB), showing the irregular surface topography and bentonite clay staining derived from the palaeosol developed on the karstic surface before the renewal of carbonate deposition. A sense of scale is given by the vertical lines, which are spaced a few metres apart. These are drill holes used to create this stable 'pre-split' face as a permanent feature within the quarry, forming one of Cumbria GeoConservation's Local Geological Sites.

The lower part of the Urswick limestone overlying darker-coloured Park Limestone beds in Middlebarrow Quarry. The darkest band seen towards the base of the Park Formation is a bed of dolomitised limestone.

Vertical beds of Urswick Limestone exposed in the Trowbarrow Quarry SSSI.

*Far more accessible are the numerous horizontal or gently-dipping limestone pavements which are found extensively within the AONB and which are almost entirely developed on Urswick Formation outcrops. These are described in more detail on pages 29 and 30 and in the section beginning on page 71 of the Geological Framework in Chapter 3.*

*The* ***Woodbine Shale****, a 4- to 8- metre-thick dark grey bed representing either a period of deeper water sedimentation and/or a temporary influx of muddier sediment, lies 30m above the base of the formation, close to the faunal boundary between the Upper Urswick Formation and the Lower Urswick Formation. This is most clearly seen in the exposure at the Holme Park Quarry LGS (pictured below left). Within the AONB, the shale is not easily seen, but differential weathering of the relatively soft shale generally produces a distinctive notch in the surface topography, marking its position between harder beds of limestone. This is best seen at Throughs Lane LGS at Storth and at 'The Trough' at Silverdale (pictured below right), where the strata (and therefore the notch) are vertical.*

*The* ***Alston Formation*** *– previously known as the 'Gleaston Group', and often referred to as such in local literature – forms the highest part of the Carboniferous Limestone sequence within the AONB and marks a change to quite different depositional conditions, during the uppermost (Brigantian) Age of the Dinantian sub-period. It comprises a highly variable unit of shales, mudstones, sandstones and limestones, deposited in varying depths of water, and it marks a transition towards the deltaic sequences of the Millstone Grit which followed (see below).*

The Woodbine Shale exposed between beds of Urswick Limestone at Holme Park Quarry

'The Trough' at Trowbarrow – the eroded outcrop of vertically-bedded Woodbine Shale

As the carbonate sediments increased in thickness and became compressed and consolidated over millions of years ,they were transformed into Carboniferous Limestone rock. As part of this process, after the sediments had been deposited and buried, some parts of the limestone were affected by the process of '*dolomitisation*': partial replacement of the original calcium carbonate by a slightly different mineral - magnesium carbonate.

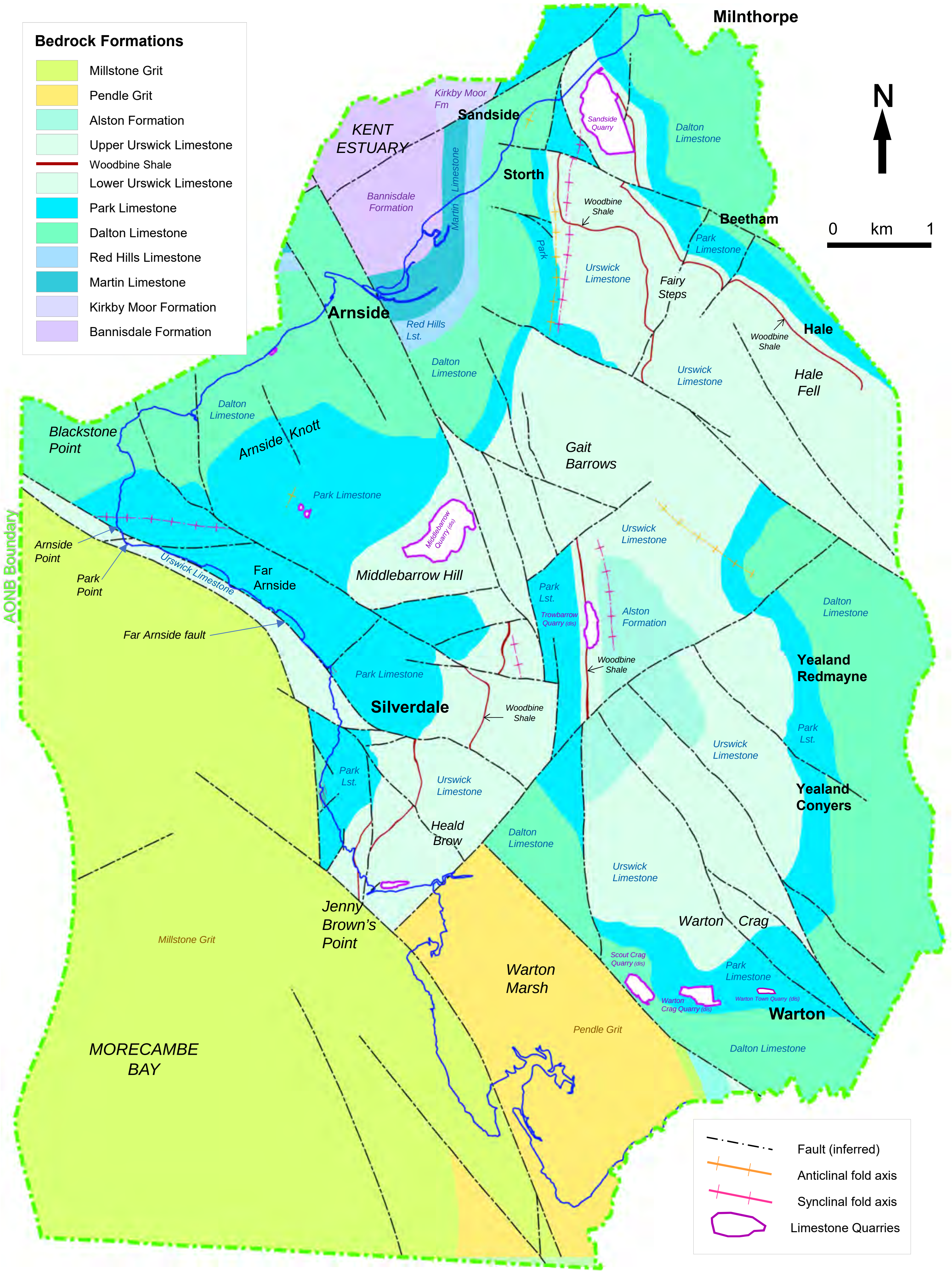
Fossils preserved within the limestone, including many different types of corals, brachiopods, and gastropods, such as those shown in the photographs below, have been used by geologists (notably Garwood 1912) to subdivide the sequence into distinctive faunal zones. These are now recognised as separate geological formations which can be traced throughout the AONB and beyond, as mapped by the British Geological Survey (**Map 4**).

Fossils of a colonial rugose coral (*Siphonodendron (formerly Lithostrotion) martini*) within the Park Limestone Formation exposed in the Far Arnside LGS shoreline.

Fossils of gastropods and small, solitary corals within the Dalton Formation exposed at Blackstone Point in the Far Arnside LGS.

At the start of the succeeding "**Silesian**" sub-period, deltas of fluvial sediment, brought down by large river systems from ancient uplands to the north and east, built out over the infilled limestone basins, laying down coarsening-upward sequences of sandstones and shales known as the ***Millstone Grit***. These sediments would have been thinner in this area than in the nearby subsiding basin of the Bowland Trough, and virtually all traces of them have been removed by subsequent erosion. ***Pendle Grit*** sandstones, from the lowest part of the sequence, are preserved beneath Warton Marsh, but are not exposed at the surface. Slightly younger mudstones, sandstones and siltstones, from higher in the Millstone Grit sequence, are similarly preserved further west, beneath the outer part of Warton Marsh and the tidal flats of Morecambe Bay.

# Map 4 – Bedrock Geology




Geological linework derived from 1:50,000 scale BGS Digital Data under Licence, Natural England Licence No. 2011/052 British Geological Survey. ©NERC.

The latter part of the Silesian sub-period, which elsewhere in the UK was associated with the deposition of Late Carboniferous *'coal measures'*, is not represented within the AONB – either because strata of that period were never deposited in this area or (more probably) because of substantial subsequent erosion. Erosion is the more likely explanation because, at the end of the Carboniferous period, substantial upheavals of the Earth's crust took place in what is now northern England, including uplift of the entire Pennine depositional basin (as it had been, until this time) along a north-south axis; doming of the Lake District area; and the formation of numerous smaller-scale folds and faults (large cracks within the Earth's crust with displacement of strata on either side).

As with any episode of tectonic uplift, the immediate and lasting consequence of steepening the terrain would have been increased rates of '*denudation*' – intense down-wearing of the land surface through the action of weathering, hillslope processes and rivers, and the removal (over immensely long periods of time) of previously-formed strata.

## *Cracking the Crust – the Variscan Orogeny*

*The upheavals at this time were part of what is known as the "**Variscan**" or "**Hercynian**" Orogeny. Both are equivalent terms, originating in different parts of Europe, for the period of mountain-building which resulted from the collision of various small tectonic plates, including land that is now southern England, SW Ireland and Brittany with 'Laurentia' (comprising what is now North America, Greenland, Northern Ireland and Scotland).*

Whilst most of the folding and faulting during this period was seen in south-west England and South Wales, with structures reflecting the generally north-south compression of the rocks, in northern England different orientations prevailed because of the interaction of those forces with pre-existing structures within the underlying rocks, including large stable blocks of higher ground, subsiding basins and major faults originating in the earlier Caledonian Orogeny.

Within the AONB, the effects are seen in a variety of '*normal*' faults, indicative of lateral pulling-apart of the Earth's crust, together with localised thrust faults and folding of the rocks, both indicative of compression, at different times. The various structures are orientated predominantly NW-SE and occasionally NE-SW or N-S, as shown on **Map 4**. They are well-displayed on the coast between Far Arnside and Blackstone Point and examples of both folds and faults are shown in the photographs below.

Broad synclinal fold in the Park Limestone Formation at Arnside Point

Normal fault within the Park Limestone Formation at Arnside Point showing downward displacement to the left.

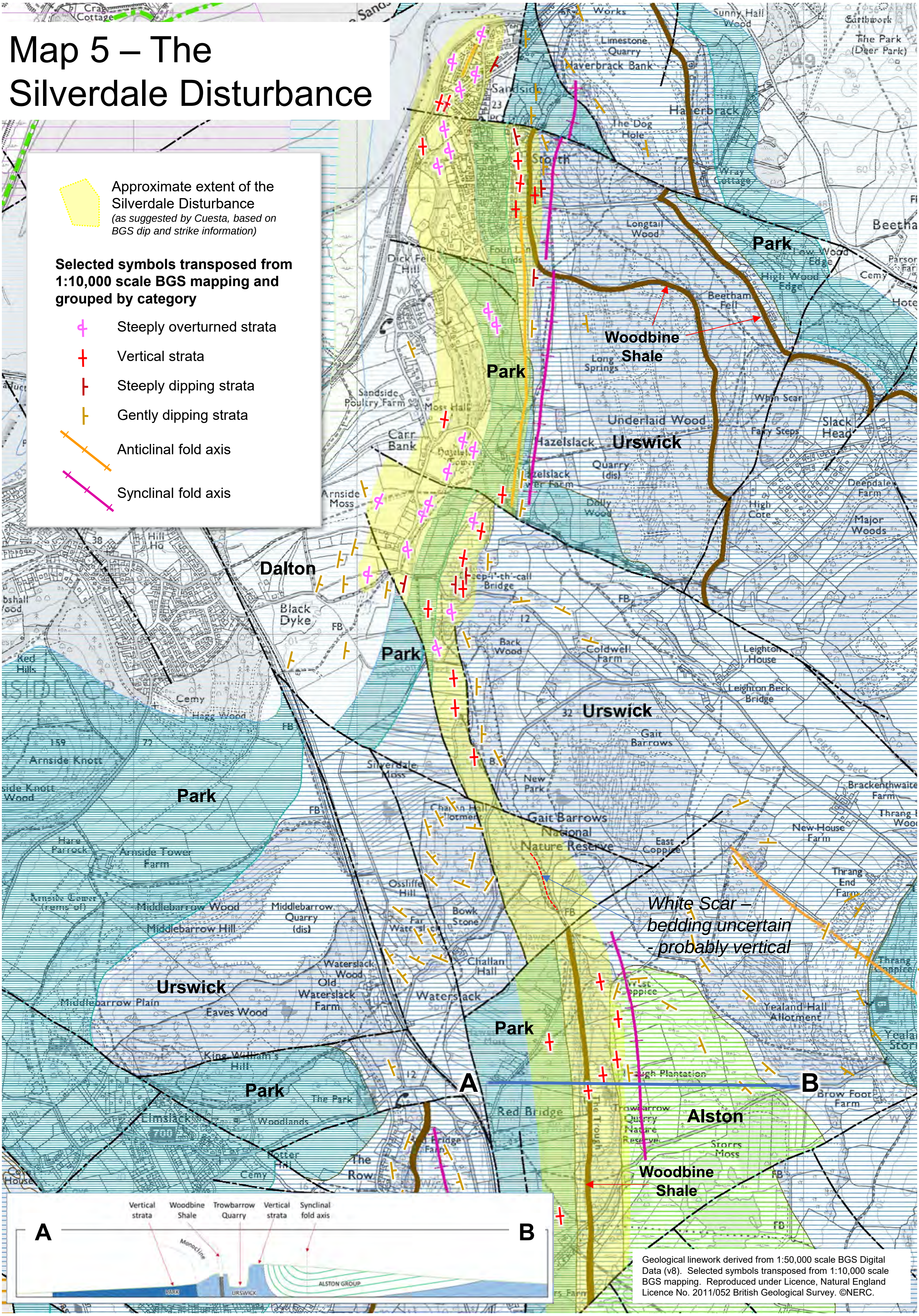
One of the main features, known as the Far Arnside Fault, is responsible for the entire shape of the coastline facing Morecambe Bay, and has resulted in the Urswick Limestone dropping down by around 1000m to the same level as the Park Limestone[3].

Further east, between Sandside and Leighton Moss, there is a more complex zone of deformation known as the ***Silverdale Disturbance*** (**Map 5**). This zone provides evidence of east-west compression (tight folding and reverse faulting) which again may have developed from an older, Caledonian feature in the underlying rocks. Over much of its length, the feature is seen to be an east-facing '*monocline*' – an asymmetric 's-shaped' fold in which some of the strata have been pushed up into a vertical or slightly overturned (westerly-dipping) position, as seen most spectacularly at Trowbarrow Quarry. The indicative cross-section in that area, as shown on **Map 5**, illustrates the form of the monocline and also shows how this incorporates the distinctive ***Woodbine Shale*** bed. The shale, being much weaker than the limestone on either side, has been eroded away to form a vertical-sided trough, which is seen most clearly immediately south of Trowbarrow Quarry (photograph on page 20, above).

Monoclines are characteristic of sedimentary rocks that have been deformed by movement along pre-existing vertical or steeply dipping faults in older strata beneath. Similar, east-facing monoclines are also found elsewhere in the north of England, including the Hutton Roof Monocline and further east, the Burtreeford Disturbance. Another feature of the Silverdale Disturbance is that its continuity is disrupted, in places, by faults trending WNW-ESE and SW-NE. One such disruption is seen at the north end of the Through Lane LGS, where vertical bedding on the southern side of the fault gives way abruptly to more gently-dipping strata to the north, with the vertical bedding displaced eastwards into the Sandside area. Between that area and Silverdale Moss, the disturbance generally appears to be a more complex feature than seen at Trowbarrow, with evidence of overturned, but easterly-dipping bedding which *might* be indicative of very tight '*isoclinal*' folding of the rocks (i.e. folds in which both limbs become almost parallel to each other). Overturned bedding is indicated by special symbols on the British Geological Survey's large-scale mapping of the area, some of which are reproduced on **Map 5**.

3 Rose & Dunham (1977): Geology of the Haematite deposits of South Cumbria. HMSO

# Map 5 – The Silverdale Disturbance



The Variscan Earth movements thus divided the Carboniferous strata up into a series of irregular blocks, raised up to different levels, tilted in places and affected to varying degrees by deep-seated fracturing. These blocks form the basic geological structure of the AONB and provide the starting point for the subsequent evolution of the modern landscape. Areas capped by the Urswick Limestone (such as Warton Crag, Middlebarrow Hill, Hale Fell, Summerhouse Hill, Heald Brow and the area around Sandside Quarry), together with those which form the crests of gently-dipping '*cuestas*' (escarpments), such as Arnside Knott (capped by Park Limestone), have tended to become areas of higher ground, whilst the intervening areas have been exploited to a greater extent by subsequent erosion.

Arnside Knott – a wooded limestone hill capped by Park Limestone and flanked by scree slopes.

Movement along the faults has also changed the orientation of the geological beds from their original horizontal placement. The gentle dip of some of the limestone beds has greatly influenced the way in which they are weathered and the subsequent landforms and landscapes which have developed.

This evolution of the landscape - sculpturing of the bedrock into its present form and further modification by the deposition of more recent sediments - has taken place under a wide range of climatic regimes over a period of at least 300 million years, since the end of the Carboniferous. The processes involved, at different times, have included:

- mechanical erosion by glaciers, waves and flowing water;
- intense mechanical weathering by freeze-thaw action;
- down-slope 'mass movement' of weathered soils and rock under the influence of gravity;
- intricate dissolution of the limestone by both rainwater and percolating groundwater; and
- deposition of sediments by ice-sheets, glacial meltwater, wind, rivers and tides.

Collectively, these are known as '*geomorphological*' processes and the development of the present-day landscape owes as least as much to them as it does to the underlying rocks and geological structures. Many of the processes have been continuous, though varying in intensity at different times, whilst others (notably the effects of glaciation) have been restricted to certain periods of time, dictated by climatic change.

### *The Deserts Return – the Permian and Triassic Periods*

*Immediately following the Variscan Earth movements, during the late "**Permian**" and "**Triassic**" Periods, terrestrial and shallow marine sediments were laid down within an arid, desert environment over much of North West England. Such deposits may once have existed within the Arnside – Silverdale area, but have since been removed by erosion. Further north, in the Vale of Eden in Cumbria, desert sandstones from these periods still remain, whilst further south over much of the Lancashire coastal plain, as well as offshore beneath the Irish Sea, extensive Triassic and Permian sandstones are preserved. In all of these areas, the rocks are characteristically red in colour, due to the presence of iron oxide (haematite) within the sediments.*

Red desert sandstones of Permian age exposed at a quarry in the Vale of Eden, Cumbria (© Cuesta)

During and after the mid-Triassic Period, sometime between 200 and 250 million years ago, more concentrated deposits of haematite were emplaced within the limestone strata to form localised bodies of iron ore. It is thought that the haematite was probably derived from the iron-rich Permo-Triassic sediments and deposited within zones of groundwater movement within the limestone. Examples can be seen at Red Rake on the Silverdale coast and in Middlebarrow Quarry. The ore bodies, which included copper as well as iron, formed the basis of localised mining activity prior to the 20th Century (e.g. at the now inaccessible Crag Foot Mine at the edge of Warton Crag and, more extensively in the Furness District, on the western side of the Kent Estuary, which became the most productive iron orefield in the world for a time during the second half of the 19th century).

Red haematite staining of Park Limestone adjacent to a vertical post-Carboniferous fault at Middlebarrow Quarry

## *Sunk without Trace – the Jurassic and Cretaceous Periods*

*At the end of the Triassic Period, some 200 million years ago, there was a further widespread incursion of the sea across the region, which probably remained submerged throughout the "**Jurassic**" and "**Cretaceous**" Periods.*

Jurassic limestones, sandstones and mudstones were widely deposited across much of England, as were the Cretaceous Chalk, Greensand and Gault Clay deposits. Any such strata which may once have been laid down within the Arnside-Silverdale area, however, has since been removed by the continuing action of relentless geomorphological processes.

## *Dissolving Limestone and Further Collisions – the Tertiary Period*[4]

*The Carboniferous Limestone surfaces probably remained buried beneath Permo-Triassic sediments until at least the middle of the succeeding "**Tertiary**" period, before being gradually 'exhumed' by erosion. Once exposed to the elements, they would have been subjected to the onset of 'karstification' – the dissolution (dissolving) of the limestone by a combination of rainwater, surface runoff and groundwater flow to produce a range of distinctive landforms and features at a variety of scales.*

The following page explains the formation of ***limestone pavements*** – one of the most distinctive features of the AONB - and their associated small-scale karstic features, including *'clints', 'grikes', 'runnels'* and *'kamenitzas'.* Whilst such features may originally have begun to form during the Tertiary Period, they are likely to have been refreshed after each episode of glacial erosion during the succeeding "**Quaternary**" Period, which would have stripped away the surface layers of rock, exposing new surfaces to karstic weathering. Most of the detailed karstic features seen today are therefore likely to post-date the last glaciation. Further details of the Quaternary Period are described from page 31 onwards.

By contrast, the larger-scale karstic features, as described on page 30, must have taken much longer to develop. These features include extensive cave systems, '*dolines'* (deep, circular depressions) and *'poljes'* (larger, flat-bottomed depressions with steep sides). Based on consideration of their size and on measured rates of limestone dissolution, it has been calculated that the dolines are likely to have been initiated at least 1 million years ago, in the early part of the Quaternary Period, and perhaps even earlier, as reactivated Permo-Triassic karst features.

The Deepdale Dolines are thought to have been at least partly controlled by the alignment of one of the many NW-SE – trending faults within the limestones, which either originated or were at least reactivated during the Late Tertiary '**Alpine**' episode of Earth movements (see below). The dolines located on Warton Crag contain Quaternary wind-blown sediments known as 'loess', which date from approximately 19,000 years ago, confirming that they had already been formed by that time.

[4]The 'Tertiary' Period of Earth history is a relatively dated term which encompasses what are now more commonly referred to as the 'Palaeogene' and 'Neogene' Periods. 'Tertiary' is however retained in this account as a more familiar term and for ease of comparison with many preceding texts.

## *Karstic Features of the Limestone Pavements: Clints, Grikes, Runnels & Kamenitzas*

*'**Karstic**' features are those created by the natural dissolution of soluble rocks, such as limestone, by slightly acidic rainwater, or by groundwater percolating through the rock, beneath the surface. The smaller features, which are characteristically developed on exposed limestone bedding planes, can take on myriads of different forms, collectively referred to as 'karren'. The terms all derive from the German name ('Karst') for the Kras limestone plateau near Trieste in Slovenia, where the first research on karst topography was carried out. The most common forms of karren seen within the AONB are:*


***'Clints'** (left) - flat-topped rocky platforms representing the dissected remnant surfaces of once continuous limestone beds.*

***'Grikes'** (left and below) - solution-widened joints within the limestone, forming deep, linear clefts which separate the clints.*


***'Runnels'** (below) - shallower channels running down-slope across tilted clint surfaces, draining into grikes or small potholes.*


***'Kamenitzas'** (right) - shallow, pan-shaped depressions formed by the dissolution of limestone in standing water, usually on horizontal limestone surfaces. Often with effluent runnels.*


*Also present, as finer details in some areas, are:*

***'Rillenkarren'** (below, left) - small flutes, 10 to 30 mm across and separated by sharp ridges and points, formed purely by the direct action of rainfall on exposed edges.*

***'Rundkarren'** (below) - karren forms with rounded edges; formed beneath a cover of soil or superficial deposits which may since have been removed.*

## *Larger-scale Karst: Pavements, Cave Systems, Dolines and Poljes*

*The **Limestone Pavements**, on which the various small-scale features are developed, are perhaps the most distinctive feature of the limestone outcrops seen within the AONB. Those at Gait Barrows are recognised as one of the finest examples of lowland limestone pavements in the world. The pavements are made up of individual 'bedding planes' (former surfaces of sediment deposition when the limestone was being laid down in shallow tropical seas), which have been exposed by the removal of overlying strata, either through dissolution and/or mechanical erosion (particularly by glaciers and ice-sheets). When first exposed, following the retreat of the ice sheets after each glaciation, these surfaces would have been more continuous than they are now, but dissolution would quickly begin to etch the familiar patterns of grikes, runnels and kamenitzas into the limestone.*


Gait Barrows


Hale Moss Caves

***Cave systems** provide evidence of limestone dissolution by flowing groundwater. This includes both 'phreatic' action (full-bore groundwater flow, creating characteristic circular cross sections) and 'vadose' action (evidenced by keyhole cross sections, formed by underground streams flowing at or above the level of the local water table). In both cases the caves indicate groundwater levels much higher than those of today. Examples are seen at the Hale Moss Caves SSSI (pictured left) and in places along the Silverdale coast.*


Deepdale Pond

***'Dolines'** – large, conical depressions on the surface of limestone outcrops, ranging from tens to hundreds of metres in diameter, and up to 100m in depth. Solutional dolines, such as those seen within the AONB (as distinct from collapse dolines and other forms) provide evidence of long-term, concentrated dissolution at particular locations, often controlled by major faults or other discontinuities within the limestone. Good examples are seen at Deepdale Pond (pictured right) and the Three Brothers on Warton Crag (below right).*


Three Brothers Doline

***'Poljes'** – very large, flat-bottomed depressions, usually with one or more steep sides, are commonly formed at the junction between limestone and interbedded impermeable strata, such as shale. Multiple springs, formed along the top of the shale beds, may contribute to the lateral expansion of Poljes, in contrast to the more focused vertical dissolution associated with solutional dolines. Examples within the AONB may include the depressions in which Hawes Water and Little Hawes Water (pictured left) have formed (but these may equally be composite dolines (see p.40 for discussion).*


Little Hawes Water

The **Alpine Orogeny**, resulting from the gradual northward collision of the African and Arabian tectonic plates into continental Europe during the Late Tertiary Period, was primarily responsible for the formation of the Alps and other fold mountain ranges in Europe and for more limited folding of Jurassic and Cretaceous strata in southern England. It was, however, also felt to some extent in north-west England. Here, relatively low levels of compression produced a series of low-angled thrusts, buckles and monoclinal folds, generally reactivating or reversing the original direction of movement on some of the faults created in the earlier Variscan Orogeny, perhaps including those within the Silverdale Disturbance.

## *Climate Change and Landscape Response – the Quaternary Period.*

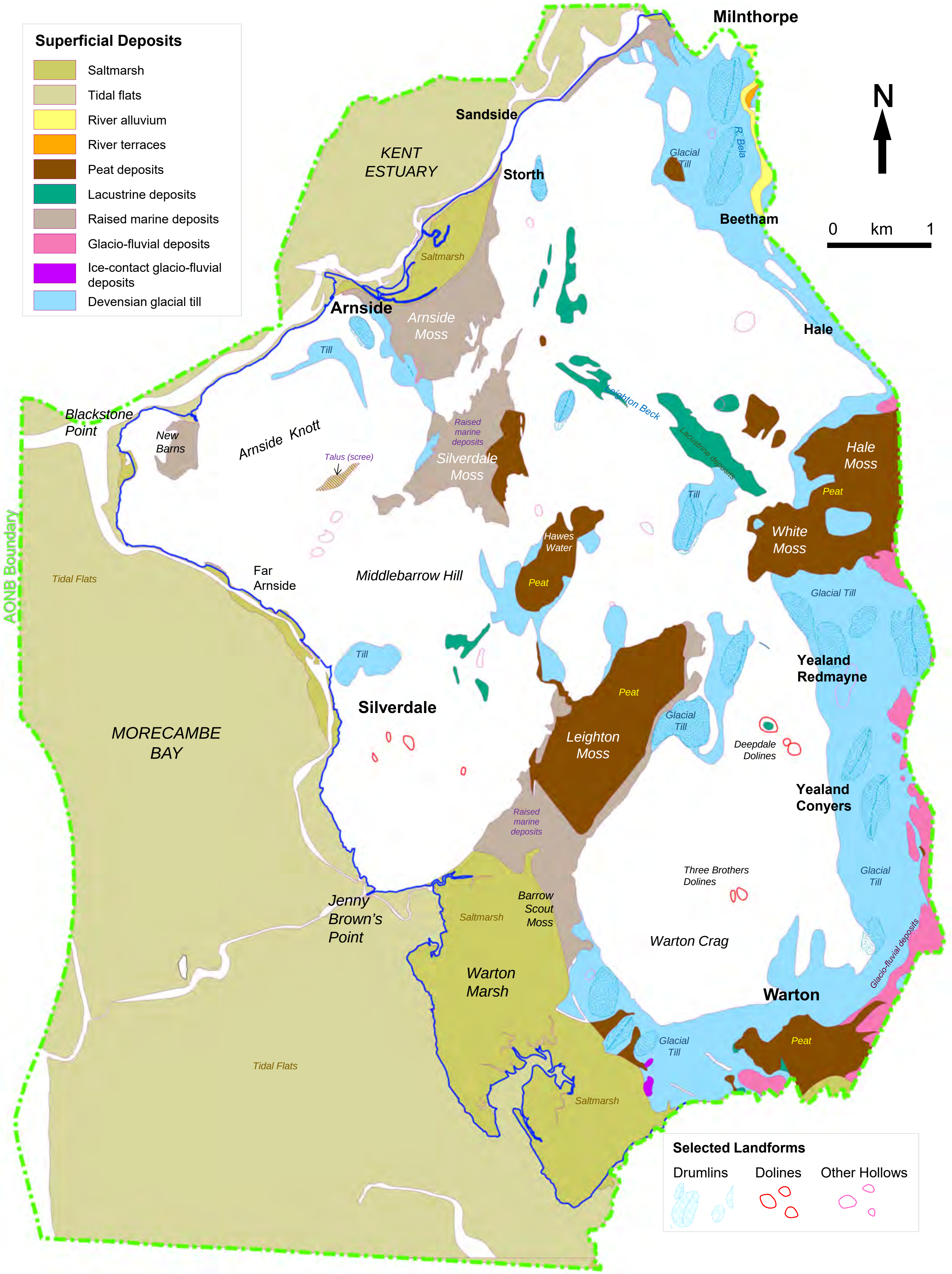
*The "**Quaternary**" Period of Earth history began around 2.6 million years ago and continues to the present day. Throughout the Quaternary there have been considerable variations in climate, sea level and environmental conditions, all of which have left their mark on the landscape. Over a similar timescale, the evolution of human species ('hominins') has taken place, with an ever-increasing influence on landscape character.*

Geologically, the Quaternary is divided into the "**Pleistocene**" (prior to about 11,700 years ago), during which Britain and Europe were subject to a series of alternating cold (glacial) and warm (interglacial) conditions; and the succeeding "**Holocene**" (the present interglacial) during which most of the present-day flora of the British Isles has developed, in parallel with the steadily increasing influence of human activity. The most recent part of the Holocene is often referred to as the "**Anthropocene**", in recognition of the growing impact of human civilisations, although the precise starting point for this has yet to be agreed.

As in previous episodes of geological history, the geomorphological processes operating during the Quaternary Period were responsible for the deposition of a wide range of sediments, as well as for the creation of both erosional and depositional landforms – the most recent of which are preserved in the modern landscape. In contrast to the deposits from earlier times, which became '*lithified*' (transformed into rock) by the weight of overlying strata which have since been eroded, the Quaternary sediments are relatively unconsolidated and are mapped separately as '*Superficial*' deposits, superimposed onto the surface of pre-existing 'bedrock' formations. The distribution of these deposits, as mapped by the BGS, are shown on **Map 6** on the next page. Also included on this map are various landforms, including the solutional dolines noted above, other enclosed hollows (which may or may not be dolines – no further explanation is given by the BGS) and a series of '*drumlins*' – large, oval-shaped, rounded hills which were formed by the streamlined moulding of glacial sediments beneath advancing glaciers and ice sheets.

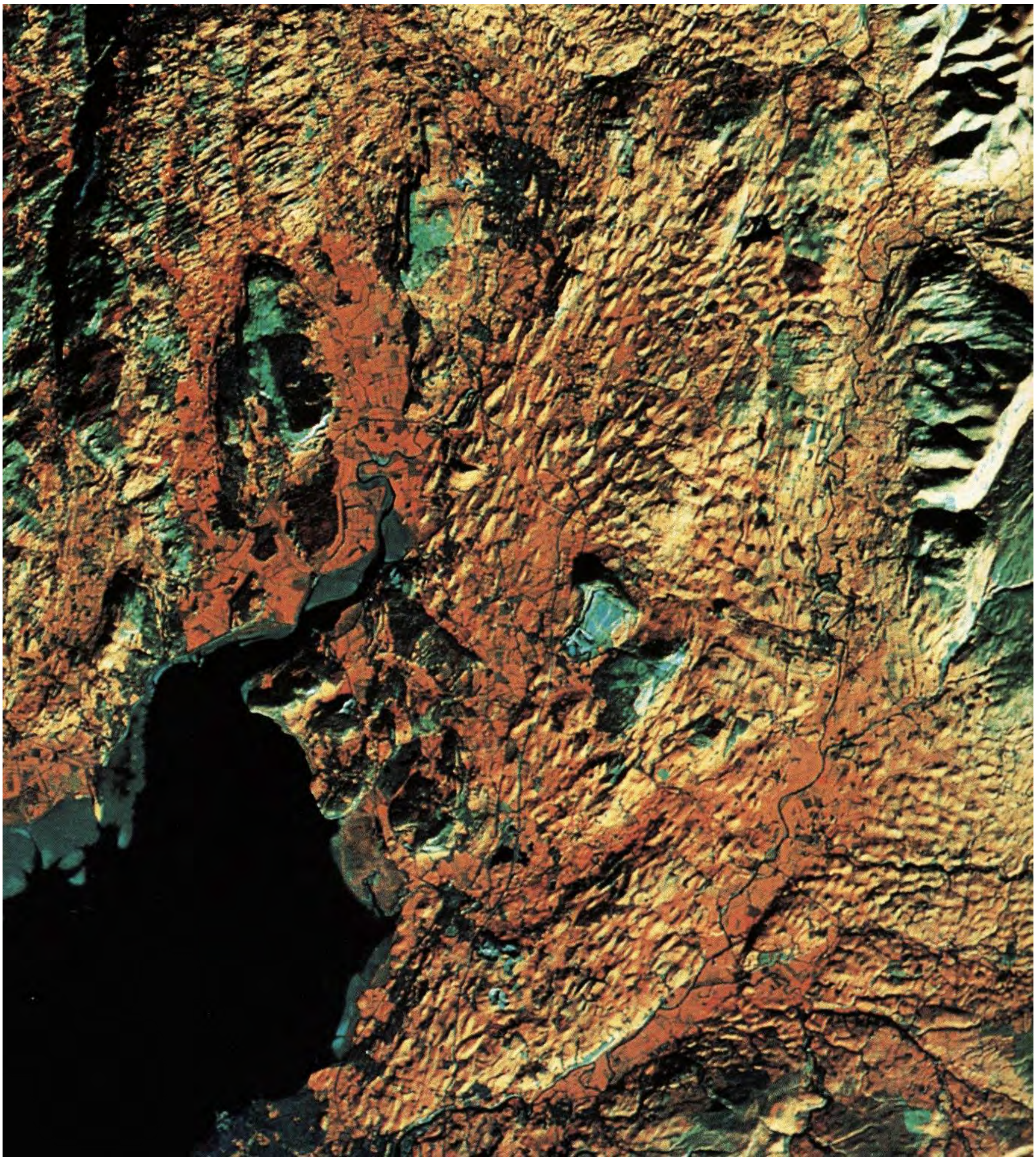
Classic drumlin landforms on the skyline at Crooklands, just outside the AONB (© Cuesta)

# Map 6 – Superficial Geology & Landforms




Geological linework derived from 1:50,000 scale BGS Digital Data under Licence, Natural England Licence No. 2011/052 British Geological Survey. ©NERC.

These characteristic glacial features are captured beautifully in the low-angled sunlit scene from an early false-colour Landsat satellite image (below) and are also clearly discernible from the contour patterns on Ordnance Survey maps. In the satellite image, areas of lush vegetation are shown in shades of orange and red, thin soils and bare rock outcrops in shades of blue and green, and areas of forest, open water and deep shadow in black. Areas of saltmarsh, which have changed substantially since this image was captured, appear blueish-grey in colour.



False colour Landsat image of the AONB and surrounding areas, with the drumlin 'swarms' picked out by low-angled sunlight (Image © British Geological Survey)

As the image clearly shows, the drumlins within the AONB form part of a much larger 'swarm' of similar landforms extending southwards from the eastern flanks of the Lake District and the western side of the Yorkshire Dales, providing dramatic visual evidence of the directions of ice flow during the last (Late Devensian) Glaciation.

## *Pleistocene – the Quaternary Ice Ages*

The Pleistocene saw not just one but several '*Ice Ages*' in Britain, separated by warmer *'interglacial'* stages. The alternation of warmer and colder climates during the Pleistocene has been revealed through the analysis of oxygen isotope variations over time in marine sediment cores. During each of the colder stages, glaciers developed in mountainous areas of northern Britain and coalesced into ice sheets which, in combination with others from Scandinavia, gradually extended southwards across much of England.

Each glaciation would have had a significant effect on the landscape of northern Britain, including the Arnside-Silverdale area. On each occasion, glacial erosion would have removed previously-weathered rocks and soils on the AONB's limestone hills, exposing fresh limestone surfaces to karstic dissolution. Each glaciation would also have contributed, incrementally, to the formation of over-deepened rock basins forming the areas of lower ground in-between the hills – subsequently to become occupied by tidal inlets, inland lakes and eventually lowland mosses during the "**Holocene**" (see below). The precise effects of each glaciation can only be speculated upon, however, since evidence of both erosion and deposition during these periods will have been obliterated or heavily modified by succeeding glaciations. Overall, the glacial sculpturing of the physical landscape was a cumulative process, taking place over many hundreds of thousands of years, adding detail to the changes which had been taking place more gradually over a much longer period of time, since the Carboniferous limestones were first exposed to weathering, erosion and dissolution, up to 300 million years ago.

### *The Last Glaciation*

Around 109,000 years ago, the climate began to deteriorate once again, heralding the start of the "**Devensian**" glaciation – the most recent extensive glaciation in Britain, and the last one to have affected the AONB area. Devensian ice probably began to advance from centres in the Lake District and North Pennines around 72,000 years ago but did not reach its maximum extent until about 23,000 years ago.

As well as contributing further to the scouring of limestone surfaces, the Devensian glaciation also saw the renewed deposition of glacial '*till*' at the base of the advancing ice sheets, re-working similar deposits from previous glaciations and creating the spectacular drumlins noted earlier. '*Till*' is a general term for the deposits produced by glaciers and ice sheets and is synonymous with the out-dated term '*boulder clay*'. The deposits are characteristically composed of a very wide range of unsorted sediment sizes, from fine-grained clays to very large boulders. This is in contrast to the deposits laid down by water, which are generally much better sorted into different sized sediments and also far more stratified (laid down in distinct layers).

Within the AONB, the long-axes of the drumlins are predominantly oriented NNE to SSW – broadly similar to the orientation of the major ice-scoured depressions beneath Arnside, Silverdale, Hawes Water and Leighton Mosses (see **Map 6**, above). Glacial till was also deposited more generally in between and beyond the drumlin features along the eastern side of the AONB and, to a far more limited extent, within other parts of the area, usually in areas of lower ground (including the ice-scoured depressions noted above) and at the base of steeper limestone slopes. Natural exposures of till within the area are limited but can be seen (from a view point on the A6) where the River Bela cuts into the large drumlin within the Dallam Estate deer park, to the south of Milnthorpe (see below).

Drumlins near Milnthorpe

Glacial till exposed by the River Bela at the base of a drumlin in Dallam Tower Park

In parallel with the formation of drumlins, and during the retreat of the Devensian ice, meltwater deposited '***glacio-fluvial***' sediments and created landforms such as ***'kames'*** (irregular, rounded mounds of sand & gravel formed by deposition within or on the surface of glaciers, which have since melted); ***'kettle holes'*** (circular, often peat-filled subsidence hollows within sand & gravel deposits, formed by the melting of underlying ice) and ***"eskers"*** (similar to kames but forming sinuous ridges, representing the former courses of meltwater streams within or at the base of glaciers).

None of these landforms, and only limited areas of glacio-fluvial sediments (including small areas of *'ice-contact'* sediments) are found within the AONB itself, but both landforms and deposits are well-developed just beyond the AONB boundary to the east of Carnforth. Within that area, close to the M6 motorway, the sand & gravel deposits have been extensively worked as a source of construction aggregate, leaving behind large, flooded excavations.

Glaciofluvial landforms – kettle hole and kames near Carnforth

**Cave systems**, which may also be of Devensian age, occur in the outcrop of Urswick Limestone adjacent to Hale Moss. They provide evidence of both '*phreatic*' action (full-bore groundwater flow, beneath the water table, dissolving the limestone on all sides to create characteristic circular cross sections) and '*vadose*' action (evidenced by keyhole cross sections, where the limestone was dissolved only on the sides and base of underground streams flowing at or above the level of the local water table). In both cases the caves indicate groundwater levels much higher than those of today, with vadose systems being linked to the levels of former lakes at Hale Moss, and the phreatic caves perhaps being formed under higher hydrostatic pressures beneath ice sheets. Caves of phreatic origin are also exposed in places at the coast.

Hale Moss Caves SSSI, developed within the Urswick Limestone outcrop to the south of Hale Fell

On Warton Crag, there is evidence of active stalagmite formation dating from 59,000 to 29,000 years ago (during the Middle Devensian), revealing that the caves here had already been formed and had ceased to be active phreatic systems, prior to that date. Other cave systems at lower elevations may, however, have continued to experience phreatic flow conditions in more recent times, and will have continued as vadose systems until the water table fell below the current base.

As noted earlier, relatively small-scale surface features on newly-exposed limestone pavements, such as *clints* (remnant surfaces), *grikes* (deep, solution-widened joints), *runnels* (shallower channels running down-slope across clint surfaces) and *kamenitzas* (shallow, pan-shaped depressions) will have developed following each phase of glaciation, and most of those seen today are likely to have been initiated during and after the last glaciation.

During the immediate **Postglacial** period, as the ice sheets retreated between 23,000 and 14,700 years ago, extensive areas of land would have been uncovered and exposed to intense '*periglacial*' weathering, in conditions similar to those found in Arctic tundra regions today. The slow process of soil formation would have recommenced as pioneer plant species began to colonise the exposed terrain. Evidence for the gradual spread of different plant species as the ice retreated is found in the record of contemporary pollen grains preserved in lake sediments and peat deposits at sites such as Hawes Water and Silverdale Moss (see page 38 for further details).

Hawes Water: a natural carbonate lake within a large karstic depression (see pp. 38 and 40 for discussion).

The pollen records from these sites show that vegetation would initially have been minimal, such that loose glacial sediments and frost-shattered limestone screes would have easily been washed downslope by surface runoff and mass-movement processes, including '*solifluction*' (the gradual movement of water-saturated soils and rocks affected by freeze-thaw processes). Stratified screes are particularly well-developed on the southern face of Arnside Knott and on all sides of Middlebarrow Hill (though here, they are now largely concealed by dense woodland). In both cases, the screes developed where the underlying rock (Park Limestone) is intensively jointed, making it particularly susceptible to frost action.

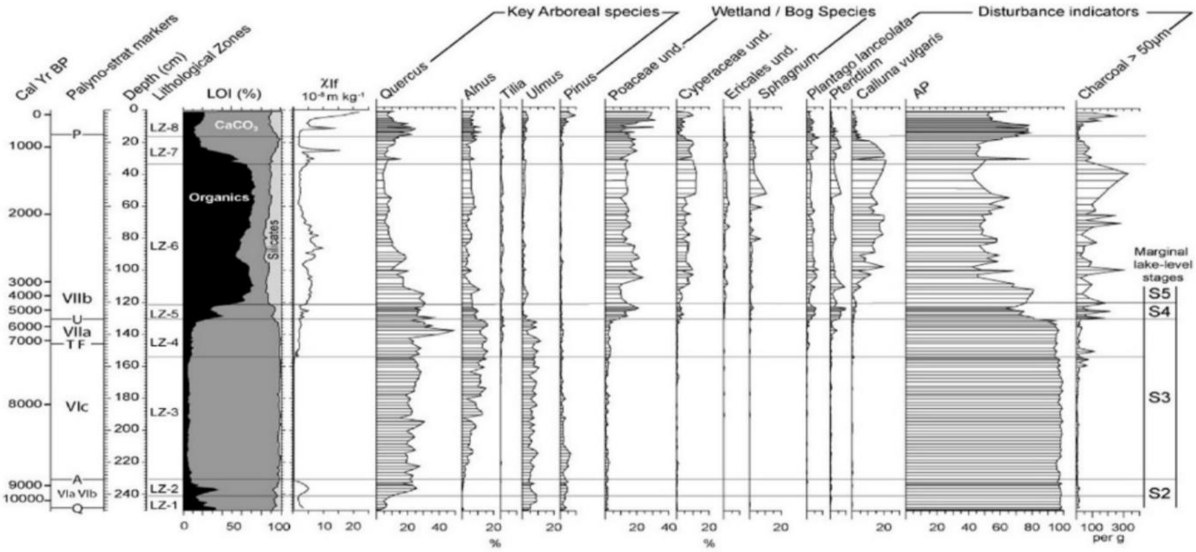
Scree slopes on the south side of Arnside Knott

Detail of cemented scree on Arnside Knott

## Hawes Water: A Natural Archive of Quaternary Climate Change

*Hawes Water – one of only two natural lakes remaining in Lancashire – has a special place in understanding the chronology of post-glacial environmental and climate change. Unusually, it is a carbonate lake, meaning that it is fed by surface water streams and groundwater which are rich in calcium carbonate, dissolved from the surrounding limestone hills. As the water flows into the lake, the calcium carbonate is precipitated out of solution to form deposits of carbonate mud, or '**marl**'. In the past, such deposits have accumulated around the margins of the lake, forming a 'bench' several metres thick. Whilst precipitation still occurs during the summer months, the mineral is re-dissolved back into the water during the winter, so that the marl no longer accumulates. Instead, peat is developing across the water-saturated surface of the marginal bench. Sediment cores, taken from various locations within the 'north field' adjacent to the lake, reveal the sequence of deposits which have accumulated here over all but the most recent part of the post-glacial period. They show a thick accumulation of marl above late glacial sediments, passing upwards into terrestrial fen peat deposits. Whilst the sediments themselves tell something of the story of changing conditions, the pollen grains the layers of sediment reveal far more detail about the vegetation of the surrounding area during each stage of development.*

*Pioneering research by Professor Frank Oldfield of Liverpool University, published in 1960, provided a detailed analysis of this natural 'archive', enabling the sequence of change to be established. More recently, researchers from the Universities of Liverpool, Exeter, Edge Hill and Lancaster have carried out further investigations of both the marginal bench and the lake floor to build up a 'multi-proxy' analysis spanning almost 14,000 years of the site's history (see papers by Marshall et al, 2002, 2007; Jones et al, 2002, 2004 and 2011; Bedford et al, 2004; and Lang et al, 2010).*




*The diagram shown here (from Jones et al 2011), relates to the last 10,000 years, and combines the results of palynology (pollen analysis) with sediment stratigraphy. The paper itself combines these with stable isotope records and changes in local chironomid (midge) populations, to produce a high-resolution record of environmental change.*

Returning to the story itself, sediment input from hillslopes into streams and rivers – particularly the River Kent – would have been much greater during immediate postglacial period than it is from the completely vegetated landscape seen today, adding to the substantial sediment load supplied from the retreating glaciers themselves. Together, these sediments would have caused the rivers to build-up broad floodplains occupied by highly dynamic braided channels with only limited stabilising vegetation.

Contemporary braided river within a broad valley 'sandur' with minimal valley-floor vegetation, in Iceland. (©Cuesta)

The braided floodplain surfaces would have been well below the present level of estuarine sediments, which have built-up in response to rising sea levels since the end of the Devensian period. Buried valleys cut into solid rock beneath Morecambe Bay, at elevations of -60 to -80m below present-day sea levels, testify to the much lower levels of the rivers during the Devensian (and earlier) glaciations.

Vast expanses of sand and gravel, grading downstream to finer-grained sands, silts and mud would thus have extended from the Kent floodplain and estuary far out beyond the present shoreline, into Morecambe Bay. Wind erosion of unvegetated silts and clays from these surfaces would have created frequent clouds of fine-grained dust, blown back onshore by prevailing south-westerly winds, to be deposited as '*loess*' on the surrounding hills. The limestone screes on Arnside Knott are in places mixed with loess sediments and with re-precipitated calcium carbonate (calcite crystals) giving rise to locally cemented scree deposits (see photo on page 37 above).

Along with much of northern Britain, the Arnside - Silverdale area would have been uninhabitable during the Devensian glaciation. Human (*Upper Palaeolithic*) occupation at that time would have been limited to areas beyond the glacial limits. Around 14,700 years ago, however, there was an abrupt amelioration in climate as temperate waters of the Gulf Stream returned to the western coasts of the British Isles, following the retreat of the North American ('*Laurentide*') ice sheet which had previously been blocking the circulation. It is likely that Palaeolithic hunter-gatherers would have begun to migrate northwards at this time, as the climate improved, and caves on the rocky outcrop of Warton Crag, in the southern part of the AONB may well have provided shelter for such people. The earliest known evidence for human occupation in the area, from Kent's Bank Cavern on the northern side of the Kent estuary, dates from around 10,000 years ago.

The warming climate is recognised as a marked change in the pollen record at Hawes Water and elsewhere and is known as the '**Windermere Interstadial**'. Whilst still cooler than the present day, the interstadial allowed previously exposed sediment to become stabilised by vegetation and allowed soil formation to recommence. Soils would have developed readily on areas of loess and glacial sediments, but much more slowly on exposed limestone surfaces.

At Hawes Water, distinctive shelly marl deposits of this Age are preserved beneath younger (Late Glacial and Holocene) sediments, including peat deposits. The marl is a particular type of *lacustrine* (lake) sediment associated with the natural precipitation of calcium carbonate from surface water draining in to the lake. The deposits indicate that, at this time, the lake was smaller than it is today and at least two metres lower than its present level. The hollow containing the lake is thought to have formed initially by karstic dissolution – perhaps as a large, pre-Devensian *polje* (see page 30), as suggested by Vincent (1985) and by Gale (2000) in his booklet on the Classic Landforms of Morecambe Bay, or perhaps as a composite *doline* feature, as suggested by the conical hollows beneath the superficial deposits, revealed by augering around the lake margins and within the adjoining moss (C. Patrick, pers. comm., 2018). Whatever its precise origin, it was subsequently modified by glacial erosion and by the deposition of glacial till during the Devensian. The till would initially have sealed the permeable limestone surface, allowing surface water to collect.

Wetland developed over peat and marl deposits at the NW margin of Hawes Water

Detail of the shelly marl deposits at Hawes Water

The Windermere interstadial was followed, between 12,600 and 11,700 years ago by a final resurgence of glacial conditions, during the Late Devensian - a period also known as the '**Younger Dryas**' stadial or '**Loch Lomond Readvance**'. Whilst the re-advance of glaciers was significant in parts of Scotland, in northern England it was limited to small corrie glaciers in the Lake District mountains. There was no glacial activity within the AONB itself. However, intensely cold periglacial conditions would have been more widespread, bringing a return to tundra vegetation and causing the disruption or even destruction of the immature soils that had begun to develop during the preceding interstadial. Lake sediments (lacustrine silts and clays) from this period are preserved at Hawes Water, overlying the interstadial marl. Such deposits are also mapped elsewhere by the BGS (as shown on **Map 6**), in locations which are no longer lakes, and lake sediments are also likely to be present beneath more recent peat deposits at Hale Moss and White Moss.

## *Holocene – Global Warming, Rising Seas and the Growing Influence of Man*

The succeeding "**Holocene**" sub-period (also referred to in some literature as the '**Flandrian**') began abruptly some 11,700 years Before Present (BP[5]), when the warm Gulf Stream current once more became re-established, providing a rapid ameliorating influence on the climate of the British Isles. The first stage of the Holocene, known as the '**Pre-Boreal**' Age, from 11,700 to 10,500 BP, was initially very cold, with low shrubs and only sparse stands of birch and pine trees, but the interval was then characterised by very rapid warming after 11,500 BP. Trees colonised the area from the south, mainly via the coastal lowlands, which were much more extensive than they are now, owing to lower sea level at that time (approximately 3m below that seen today).

It was during this interval when modern soil profiles would have finally begun to develop. These would have built on the remains of earlier, immature soils which had developed during the Windermere interstadial, before being disrupted by periglacial action, and also on freshly-exposed bedrock surfaces. The process of soil formation – especially on bedrock – has inevitably been extremely slow, continuing throughout the Holocene sub-period. It has also gone hand-in-hand with changes in climate, sea level, natural vegetation and human intervention, as described below.

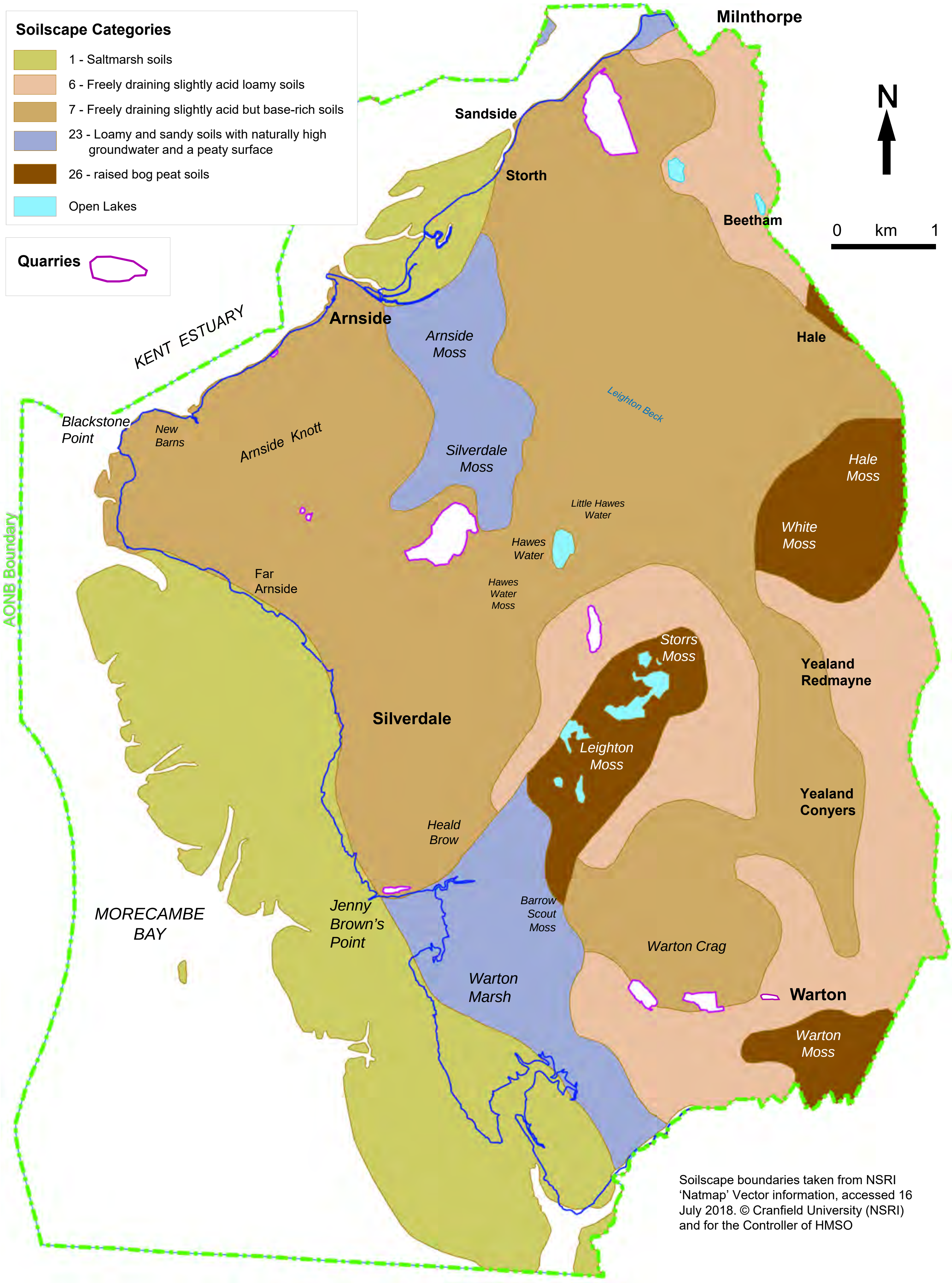
**Map 7**, on the following page, indicates the range of 'S*oilscapes*' present within the AONB. The categories shown were created by the National Soils Research Institute (NSRI), Cranfield University, as a simplification of their more detailed '*soil association*' and '*soil series*' maps. Although far more limited in detail, they provide a useful way of explaining how the different soil types are related to the underlying geological 'parent' materials on a broad (landscape) scale. At this level, only five different categories are recognised:

- **Soilscape 1 – Saltmarsh soils**: developed exclusively in areas of saltmarsh development, and therefore constantly changing in extent with the growth (accretion) and erosion of the saltmarsh in response to the changing position of the main channels within the Kent Estuary and Morecambe Bay. The seaward margin of the saltmarsh areas shown on **Map 7** are quite different, for example, to those shown on **Map 6** (superficial deposits), **Map 8** (landscape / seascape character) and OS topographic maps -all of which were created at different times.
- **Soilscape 6** – **Freely draining, slightly acid loamy soils**: developed in areas of glacial deposits which, in turn, are derived from a wide range of rock types eroded and transported by glaciers from source areas in the Lake District and Yorkshire Dales, further north. In contrast to the limestone geology of the AONB, these transported materials include many which are more 'acidic' (rather alkaline) in nature.
- **Soilscape 7 – Freely-draining slightly acid but base-rich soils**: developed preferentially on outcrops of limestone, and thus containing higher proportions of 'basic' (in this case Calcium carbonate) minerals.

*(list continues…)*

[5] Holocene dates are usually given in the form of years 'Before Present', where 'present' means the calendar year of 1950. In most cases the dates are obtained from radio-Carbon analysis of organic materials found within particular layers of sediment and those reported here are all calibrated dates (cal.BP) which have been corrected for systematic errors in some of the original analyses.

# Map 7 – Soilscapes




Soilscape boundaries taken from NSRI 'Natmap' Vector information, accessed 16 July 2018. © Cranfield University (NSRI) and for the Controller of HMSO

- **Soilscape 23 – Loamy and sandy soils with naturally high groundwater and a peaty surface**: developed in low-lying areas near the coast which are underlain by 'raised marine' sediments from times of higher sea level in the past. These areas subsequently developed into mosses (Arnside Moss, Silverdale Moss and Barrow Scout Moss) or coastal marsh (the inland portion of Warton Marsh).
- **Soilscape 26 – Raised bog peat soils**: although developed with areas which were once characterised by lowland raised bogs (including Leighton Moss, Storrs Moss, White Moss, Hale Moss and Warton Moss, those specialised habitats no longer exist, having been cut for peat and/or drained for agriculture in 18th and 19th centuries. Only the lower layers of groundwater-saturated peat remain in these areas, and the peaty soils now support fen, carr or reedbed habitats.

Map 8, on the following page, shows the distribution of Priority Habitats within the AONB, based on recent mapping carried out by Graeme Skelcher (2017)[6]. This new mapping is already incorporated in the AONB's current Management Plan and is being incorporated in the national priority habitat inventory by Natural England. Further discussion Further discussion of the habitat types and their relationship to the underlying geology is given in Chapter 3 of this report.

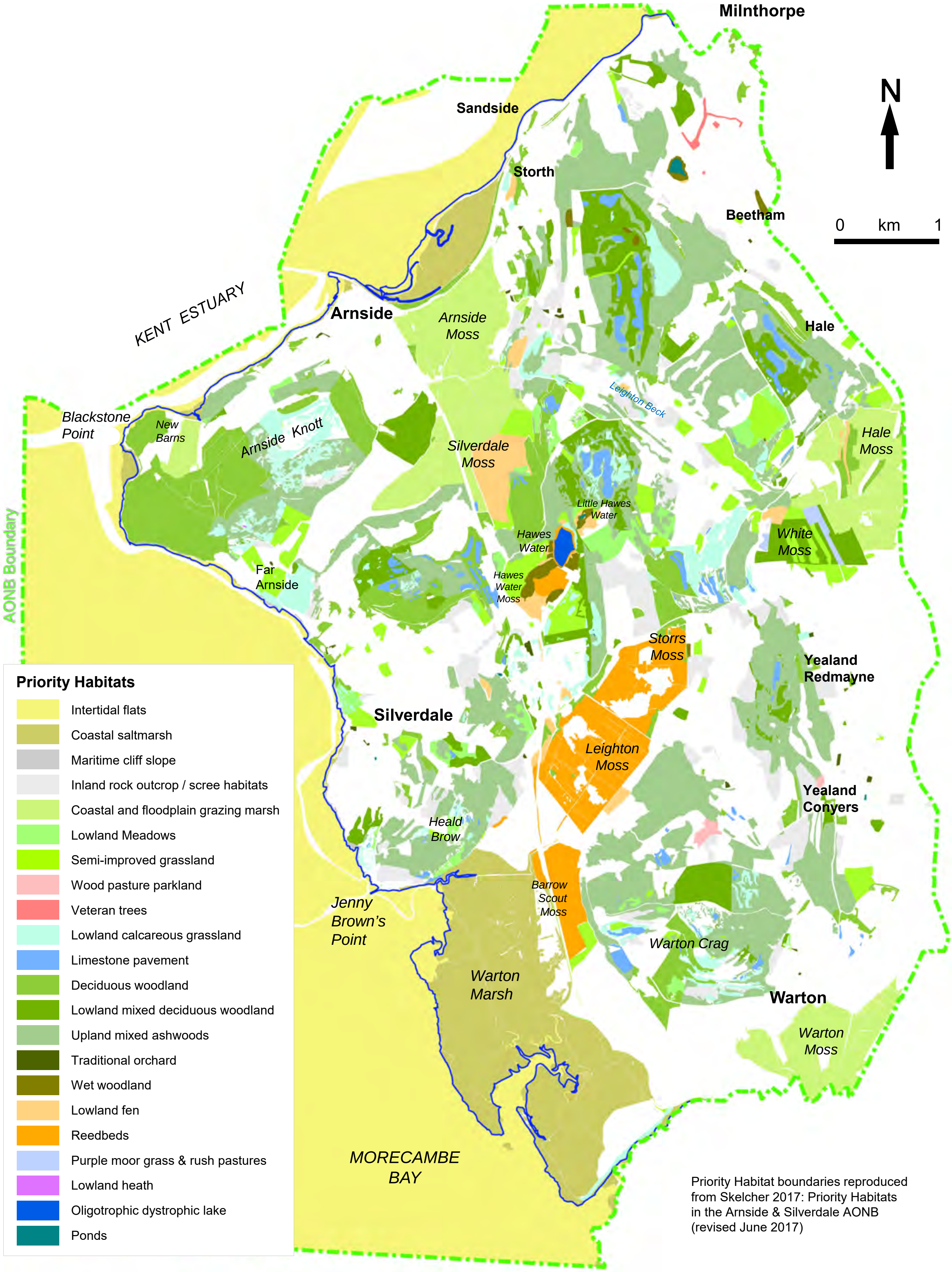
Returning once again to the geological story, the '**Boreal**' Age of the Holocene began some 10,500 years ago and coincided with the beginnings of a rapid, progressive rise in sea levels known as the "*Flandrian Transgression*". The rising sea levels were responsible for the deposition of marine clays and silts in each of the low-lying coastal areas within the AONB. These are shown on **Map 6** as '*raised marine deposits*' because they are well above present-day sea levels. At Silverdale Moss, core sampling, pollen analysis and dating of the Holocene sediments has revealed that, by the end of the Boreal, the sea had deposited marine clays over early Holocene peats before the area became re-colonised by sedges and finally raised mire (within the area shown as peat deposits on **Map 6**). A similar history took place at Leighton Moss, which had originally been a deep coastal inlet but subsequently developed into an extensive raised bog with peat developing on top of the marine clays[7].

Raised marine sediments are also mapped by the BGS more extensively in the Silverdale Moss area (beyond the peat deposits) and in the coastal lowlands at Arnside Moss and New Barns, although in those areas, no overlying peat deposits are shown on the BGS maps – presumably having been removed by cutting or ploughed for agriculture.

[6] Skelcher, G (2016, revised 2017) Priority Habitats in the Arnside and Silverdale AONB, A Report for the Arnside and Silverdale Partnership

[7] It is important to note that, although raised bogs had initially developed in these areas, with the bogs being sustained purely by rainfall (rather than groundwater), they have since been damaged by human activity (peat cutting and agricultural drainage), and the areas now contain only lowland fen peats and/or reedbeds – both of which are nevertheless important priority habitats in their own right.

# Map 8 – Priority Habitats




Priority Habitat boundaries reproduced from Skelcher 2017: Priority Habitats in the Arnside & Silverdale AONB (revised June 2017)

Silverdale Moss, seen from the slopes of Arnside Knott

Leighton Moss: an area of reedbed and open water habitat developed over peat deposits

Both the Flandrian Transgression and the development of Holocene peat deposits continued into the succeeding 'Atlantic' Age, which extended from 8,000 to 5,950 BP. This interval was warmer and moister than today's climate, reaching a 'climatic optimum' - the maximum extent of forest ecosystems across Europe - around 6,000 BP.

At Hawes Water, relatively low lake levels persisted until around this time, after which there was an abrupt and substantial rise of water level to about 1m above its present-day level. This sharp rise in lake level is out of sync with patterns of climate change at this time (when lake levels elsewhere often fell), but is coincident with the rise in sea levels, and suggests that the lake was, by this time, connected to the local groundwater regime, which would have responded to the progressive rise in sea level.

Detailed research on the sediment cores from Hawes Water has revealed that the abrupt rise in lake level was also coincident with a rise in human activity within the area. This is evidenced by characteristic changes in the pollen record – a rapid decline in tree pollen and a rise in that of species associated with open ground – which are indicative of forest clearance by Late Mesolithic farmers. This may have reflected the migration of coastal Mesolithic communities inland, in response to the rising sea levels. Andy Denwood's (2014) account of the post-glacial history of nearby Leighton Moss notes that buried wooden artefacts dating from 4,200 BC (i.e. 6,150 BP) mark the first evidence for human occupation in that area.

The period following 5,950 BP is known as the '**Sub-Boreal**' Age. It corresponds in time to the introduction of Neolithic cultures to northern Britain, bringing increased rates of forest clearance for agriculture. A stone axe originating from Langdale in the Lake District, and used by Neolithic farmers to clear land, was found on Warton Crag. Rates of forest clearance (in northern England generally) increased further as the Neolithic gave way to the Bronze Age, especially between 4,300 and 2,900 BP. Bronze Age weapons have been found near Leighton Moss and a large kerbed cairn on the south eastern edge of Summerhouse Hill also dates from around that time, testifying to the presence of Bronze Age culture within the area.

Limestone Woodland on Arnside Knott

At Hawes Water, the lake level is thought likely to have remained high until at least 5,000 BP. Thereafter, the sediment cores suggest that there was a significant drop in water level, resulting in a shrinkage of the lake and exposure of the calcareous marl around the edges of the lake to colonisation by terrestrial plants, leading to the development of organic-rich fen peat within a marginal wetland/swamp environment.

The warm temperatures of the Holocene thermal optimum persisted until the start of the Bronze Age, but the climate then began to cool, marking the start of a generally downward trend – linked primarily to declining levels of incoming solar energy (insolation) over this time. This continued into the succeeding '**Sub-Atlantic**' Age, and through to the start of the 'industrial' era in post-Medieval times, punctuated by relatively short-lived warming episodes during the early Bronze Age, during the Roman era and in the early Medieval period.

The early part of the Sub-Atlantic was characterised not only by climate change but also by the steadily increasing influence of humans on the landscape. Forest clearance (across much of northern England) gathered momentum during the Iron Age, particularly between about 2,400 and 1,800 BP, and again during the Early Medieval period. It is not specifically known whether these trends were mirrored in the Arnside-Silverdale area, but Iron-age communities are likely to have been present in the area.

Buildings and settlements constructed from local limestone, dating back to Medieval times around 800 years ago, are scattered throughout the AONB and contribute to the character and quality of the modern landscape. Warton village is listed in the Domesday Book of 1086 and its church is thought to have Anglo-Saxon origins, as may the oldest part of St Michael's Church in Beetham.

Warton Village, clustered around its Medieval church, with Warton Crag behind

Other notable Medieval buildings include Arnside Tower – a defensive 'tower house', built originally around 1340 AD, similar but smaller Pele towers at Hazelslack and Dallam, the older parts of Leighton Hall, Beetham Hall, and a number of farmsteads.

Arnside Tower

From the 16th Century onwards the agricultural landscape would gradually have been transformed by the process of 'enclosure' – division of the land into smaller fields by the construction of drystone walls (particularly on outcrops of the Dalton and Urswick Limestones) or hedgerows (more characteristic of the Park Limestone, which weathers into smaller fragments, less suitable, in some areas, for building walls).

Limestone walls on Dalton Limestone outcrop at Scar Close, below Warton Crag

Limestone wall in Urswick Limestone, on Warton Crag

Hedgerow boundaries on Park Limestone near Yealand Redmayne

The Sub-Atlantic trend of falling temperatures which had been seen from the Iron-Age through to the Medieval period, culminated in the '*Little Ice Age*' – the most recent thermal minimum, between the 17th and 19th centuries. Whilst that period of time saw glaciers advancing in some parts of the northern Hemisphere, including Europe and Iceland, there was no such impact in the UK, and therefore no obvious effects on landscape evolution.

A much greater impact on the AONB landscape over this period has been the further influence of human settlement and land use. Peat cutting for fuel in all of the former areas of lowland raised bog, primarily during the 18th Century, destroyed these habitats which are now extremely rare in the UK. Much of the peat cutting was linked to the operation of a former iron-smelting furnace at Leighton or to the salt industry and domestic fuel, in the case of Warton Moss.

This was followed, during the 19th Century, by various attempts to 'improve' such areas for agricultural use. At Hawes Water, for example, an artificial inflow and outflow were created in the 1800s, which lowered lake water levels enabling the surrounding land to be 'improved' from fen to arable land. Similar 'improvements', achieved by means of pumping rather than simple drainage, were seen at Leighton, Storrs and Arnside Mosses, beginning in 1830. In the case of Leighton Moss, a substantial embankment (1km in length) was constructed across the valley from the foot of Heald Brow to the base of Warton Crag and a steam engine with a paddle wheel pump was installed near Crag Foot. This pump drained water from behind the embankment to provide land for growing crops. Whilst the pump was in operation, the soil proved to be exceptionally fertile and the valley became known as the 'Golden Vale'. The pump became redundant in 1917 because of difficulties in maintaining fuel supplies, and the tall chimney at Crag Foot (see photo on next page) is the only surviving landmark.

Crag Foot Chimney

Leighton Hall Park - originally laid out in 1763

Other industrial heritage features, scattered throughout the AONB, include the remains of 36 lime kilns, where locally quarried limestone was ‘burnt’ to produce lime for agricultural and other uses. One of the most recently active kilns was constructed adjacent to Trowbarrow Quarry, which opened in 1868. Most of the buildings there were cleared in the 1970s, but remains of the kiln can still be seen.

The 18th Century saw the beginnings of quite different landscape transformations through the creation of historic designed landscapes such as those at Leighton Hall and the Dallam Tower Estate. The registered parkland at Dallam Tower is of national importance. Here, the presence of glacial landforms (drumlins) and the floodplain of the River Bela provide a natural setting into which the parkland has been introduced to dramatic effect.

Dallam Tower Deer Park and listed deer shelter

Stone-built houses in Yealand Redmayne conservation area

The 18th and 19th Centuries also saw the progressive development of Arnside, Silverdale, Warton and other villages, particularly following the introduction of the Lancaster - Furness Railway, including the Arnside Viaduct across the Kent Estuary in 1857 and the construction of the Sandside - Kendal branch line in 1867. The railways also facilitated the development of relatively large limestone quarries at Trowbarrow, Middlebarrow and Sandside. All of these now provide opportunities, in varying degrees, to observe the geology of the limestones, although Sandside is still an active quarry and Middlebarrow, though closed since 2000, has no public access other than a viewpoint from the quarry entrance. Trowbarrow, which closed as an active quarry in 1959, is now a geological Site of Special Scientific Interest and a Local Nature Reserve as well as a popular visitor attraction and climbing venue. It also has industrial historical interest relating to its former kiln, tramway and details of its pioneering role in the development of tarmacadam, which continued for a few years after the quarry itself was closed, using stone imported from nearby Sandside and Middlebarrow quarries. The works buildings were eventually demolished in the 1970s. Photographs of Middlebarrow and Trowbarrow Quarries are shown on page 19, above.

In parallel with these direct human interventions in the landscape, since the Little Ice Age, there has been a progressive warming trend and an associated 'eustatic' rise in global sea levels. This has been despite a stable or further declining trend in solar activity and is considered to be linked (in part, at least) to the accelerating post-industrial increase in atmospheric 'greenhouse' gases. Global temperatures began to rise noticeably during the 'Industrial Era', from about 1860 onwards, and global sea level is believed to have risen by between 10 and 20 cm during the past century. The latest 'best estimates', as noted in the area's Shoreline Management Plan (SMP2)[8], are that it will rise by approximately 50 cm in the next 100 years (i.e. an acceleration of a factor of 3 in the rate of change).

*Relative* sea levels in north west England[9] are currently rising at a rate of approximately 2.5 mm per year, and are likely to increase to around 7 mm/year after 2025 and to 10 mm/year after 2055.

Morecambe Bay: tidal flats and migrating channels

[8] Halcrow (2011): North West England and North Wales Shoreline Management Plan SMP2. Appendix C – Baseline Process Understanding.

[9] *'Relative'* sea level changes are those which take account of localised *'isostatic'* changes in the elevation of the land as well as global *'eustatic'* changes in the level of the oceans. In north-west England, the land surface has been rising since the end of the Pleistocene epoch, due to the isostatic 'rebound' of the landscape after the weight of former ice sheets was removed. The rebound has now almost ceased, however, so that continuing global sea level rise is now having a more immediate and direct impact on the coastline. The rates of relative change quoted here are the allowances recommended in Defra's latest (2006) guidance.

The inner Kent Estuary, seen from Arnside Knott

Unlike the preceding cooling trend, the recent and continuing climate changes are beginning to have effects on the landscape. Rising sea levels inevitably change the morphology and sediment dynamics of estuaries and coastal systems, such as Morecambe Bay, giving rise to increasing flood risk in low-lying coastal areas (including former coastal inlets such as Leighton Moss) and to changes in saltmarsh and beach levels. Such changes are gradual and have been barely noticeable so far within the Arnside-Silverdale area but the SMP2 document notes that the estuary is progressively infilling with sediment sourced from offshore, as sea levels rise, and will continue to do so.

Saltmarsh elevations generally keep pace with rising sea levels, but the pattern of saltmarsh accretion (growth) in some areas and erosion in other parts of the estuary is highly variable over time, being dependent on the unpredictable shifting of the main deep-water channels, driven by strong tidal currents. Similarly, beach elevations are constantly changing in response to the wider circulation of sediment within coastal cells. Whilst the limestone cliffs which occur around much of the AONB coastline have been more resilient to change – being generally subject to only very slow rates of coastal erosion, the degree of exposure of geodiversity features within the coastal rock outcrops is highly dependent upon the continually changing elevations of saltmarsh and beach deposits.

Recently developed active saltmarsh at Hazelslack Marsh

Eroding saltmarsh on the Silverdale Shore

In recent decades, an important new aspect of direct human intervention has featured in the development of the area's landscape: **conservation**. The AONB itself was designated in 1972, to conserve and enhance the natural beauty of the area. In addition, there are numerous scientific, environmental and historical designations which, between them, cover a high proportion of the terrestrial landscape and all of the marine environment of Morecambe Bay and the Kent estuary (as shown on **Maps 1** to **3**, in Chapter 1).

As an important part of this trend, some of the wetland areas are gradually being restored for the benefits of both wildlife conservation & tourism. Hawes Water, for example, is now managed as part of the Gait Barrows National Nature Reserve and re-naturalisation of the lake and its margins are being encouraged. As part of this, a sluice will be added to the artificial ditch that flows into Hawes Water from Little Hawes Water in order to manage water levels in Little Hawes Water to increase the amount of alkaline fen surrounding it. At Leighton Moss, which has previously been more extensively damaged by peat cutting and artificial drainage, recent dredging work has been carried out to further deepen the lagoons and channels to benefit wildlife, in particular the bittern. In addition, a large area at Warton Mires is currently being restored to wet grassland as part of the Warton Mires Project.

## *The Present-Day Landscape and Seascape*

The long history of geological and geomorphological evolution described in the foregoing sections, including the progressively increasing influence of human activity in recent centuries, has culminated in the landscapes and seascapes that we see today. These form an intricate mosaic of different landscape types, as illustrated in **Map 9**, on the following page.

The categories shown on this map are from a detailed landscape and seascape character assessment undertaken by the Arnside & Silverdale AONB Partnership and LUC in 2015.

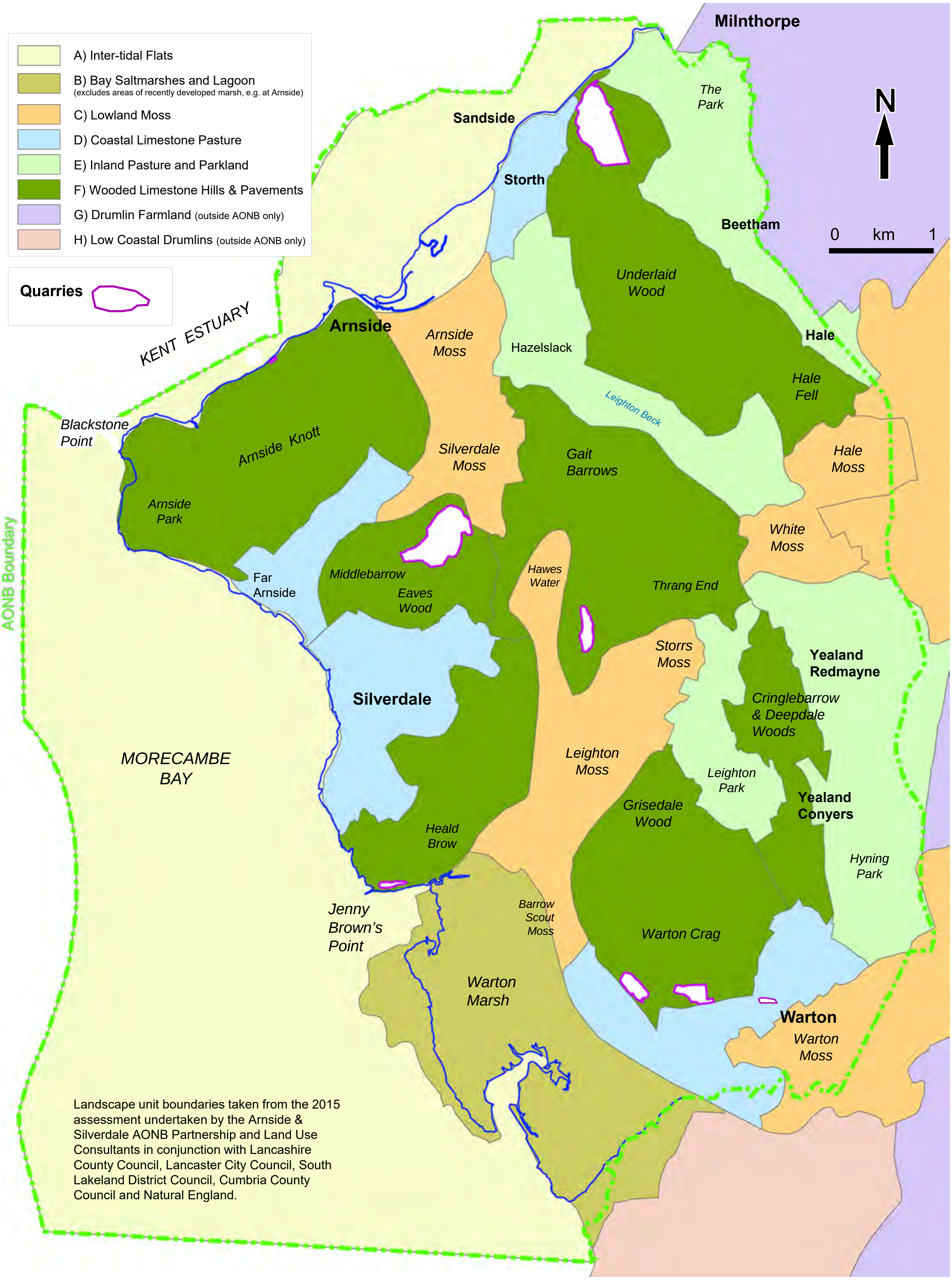
Six main character types are identified within the AONB, together with three others in directly adjoining areas, which form part of the AONB's setting. The six categories within the AONB are:

- **A. Intertidal Flats**
- **B. Bay Saltmarshes and Lagoons**
- **C. Lowland Moss**
- **D. Coastal Limestone Pasture**
- **E. Inland Pasture and Parkland**
- **F. Wooded Limestone Hills and Pavements**

The three additional character types adjoining the AONB are:

- **G. Drumlin Farmland**
- **H. Low Coastal Drumlins**
- **I. Lowland Valley & Coastal Margins** *(identified primarily on the northern shore of the Kent estuary and therefore not shown on Map 8)*

# Map 9 – Landscape & Seascape Character Types



# 3. The Geological Framework

## *Introduction*

*The geological framework set out in this chapter follows on from the Geological Story outlined in Chapter 2. It describes the rocks, sediments and landforms in more detail and explains their various influences on the AONB's natural beauty, landscape character, soils, biodiversity, economy, built heritage and recreational activities, with notes on existing measures for their conservation.*

The following sections of this chapter deal with each of the rocks, sediments and minerals that shape the landscape of the AONB in turn. These include the Carboniferous Limestones: the ***Dalton Formation***, the ***Park Limestone Formation*** and the ***Urswick Limestone Formation***, including the ***Woodbine Shale***, and the ***Alston Formation***; followed by ***mineralisation*** during the Triassic period and then the suite of ***Quaternary sediments***.

None of the Quaternary sediments within the AONB have specific formation names. Instead, they are described by type of deposit, in an approximate chronological order: ***glacial till, glacial erratics, glaciofluvial deposits, talus (scree), loess, lacustrine deposits, raised marine deposits, peat, tidal flat deposits*** *and* ***saltmarsh***. Also included are the tipped ***slag materials*** from the Carnforth iron works which form a feature of the more recent ***Anthropocene***.

In each case, a description of the rock formation or sediment is given along with its occurrence and typical features followed by an account of the influence each formation or sediment has on the natural beauty, landscape, soils and biodiversity, its economic and recreational use including the built environment, and the conservation of that aspect of the AONB's geodiversity. For the limestone formations, brief notes on the types of fossils commonly seen are included.

A relatively recent concept in conservation planning is that of 'Conserving Nature's Stage'[10] which focuses attention on the geodiversity as creating the backdrop or starting point - 'the stage' - for the wealth of biodiversity - 'the actors' - that are found. It is considered that geodiversity has as much influence on species diversity as climate (and, through topography, also influences climate). The concept recognises the importance of both the underlying geology and ongoing geomorphological processes in creating the necessary dynamic environments that allow species to flourish. It provides a robust, coarse-filter[11], approach that allows habitats and communities to move and reorganise as a reaction to changing environmental conditions, rather than trying to protect static 'museums of the past' in response to climate change. In following this approach, as well as considering sensitivity to climate change, a greater understanding of the interactions between geodiversity and biodiversity are required and this chapter attempts to make some of these connections for the AONB. Therefore, sites designated and conserved for both their biological and geological interests are described and the geological influence on the significant biodiversity is identified in each case. Geological SSSIs and LGSs, together with

[10] See: Anderson, M.G. & Ferree, C.E. (2010) Conserving the Stage: Climate Change and the Geophysical Underpinnings of Species Diversity, *PLoS ONE* **5(7)**: e11554. https://doi.org/10.1371/journal.pone.0011554; Beier, P. & Brost, B. (2010) Use of Land Facets to Plan for Climate Change: Conserving the Arenas, not the Actors, *Conservation Biology* **24**:701–710; and, a number of papers in the Special Section: Conserving Nature's Stage (2015), *Conservation Biology* **29**: 613-701.

[11] The conservation of representative broadly defined environments as a way of conserving most species.

the NNR and LNRs are shown on **Map 1**. Biological SSSIs, SPAs, SACs and Ramsar sites are shown on **Map 3**.

Information on the location and occurrence of geological strata and deposits is taken from the most recent British Geological Mapping[12] and this provides the basis for the bedrock geological outcrops shown on **Map 4**, the more detailed information relating to the '*Silverdale Disturbance*' structure on **Map 5**, and the superficial Quaternary age sediments and landforms shown on **Map 6**. These and other maps are presented within the previous chapter. An online map resource complied by the University of Sheffield: BRITICE[13] was also consulted for information on the location of landforms associated with the last British Ice Sheet, and additional mapping of drumlin landforms, from aerial photographs and topographic maps, was undertaken by the authors.

Further information on the characteristics and geomorphological features associated with the geological strata and deposits is based on our own fieldwork including the audit of geological sites (Appendix A), supplemented by correspondence and meetings with local geologists (see acknowledgements at the end of this report) and by information from academic papers and local guidebooks, as listed in the References section.

Generalised information on soil type has been obtained from Soilscape England[14] and on soil quality from the Agricultural Land Classification[15]. Information on soils and associated habitats was also obtained from the national database of priority habitats[16] and local specialised survey mapping for the AONB[17], together with useful information shown on the SSSI citations. **Map 7** shows the Soilscape categories, **Map 8** shows the priority habitats within the AONB, and **Map 9** shows the area's landscape and seascape character types.

## *Geological Structure:*

As explained in Chapter 2, the landscape of the AONB is controlled, not simply by the nature and distribution of the geological strata, but also by the way in which these have been fractured, displaced, tilted and contorted (in places) by '*tectonic*' forces (large-scale movements of the Earth's crust) at various times in the geological past. It is useful, therefore, to consider these aspects of the area's geological structure before examining the individual rocks and sediments.

Movement has taken place along a series of major faults (significant planar fractures or discontinuities cutting through the rocks) as shown on **Map 4**. Within the zone of the '*Silverdale Disturbance*', as shown on **Map 5**, and to the west of Arnside Knott, the rocks have also been subject to folding and/or faulting, whilst in other areas they either remain horizontal or tilted by only a few degrees. Some examples are illustrated in the photographs below.

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[12] *Geology Digital Dataset v8* (2017) 1:50,000 British Geological Survey: V8 includes new mapping for the Arnside and Silverdale AONB: Sheet 049 Kirkby Lonsdale. The mapping is created from slightly more detailed 1:10,000 'field sheets'.

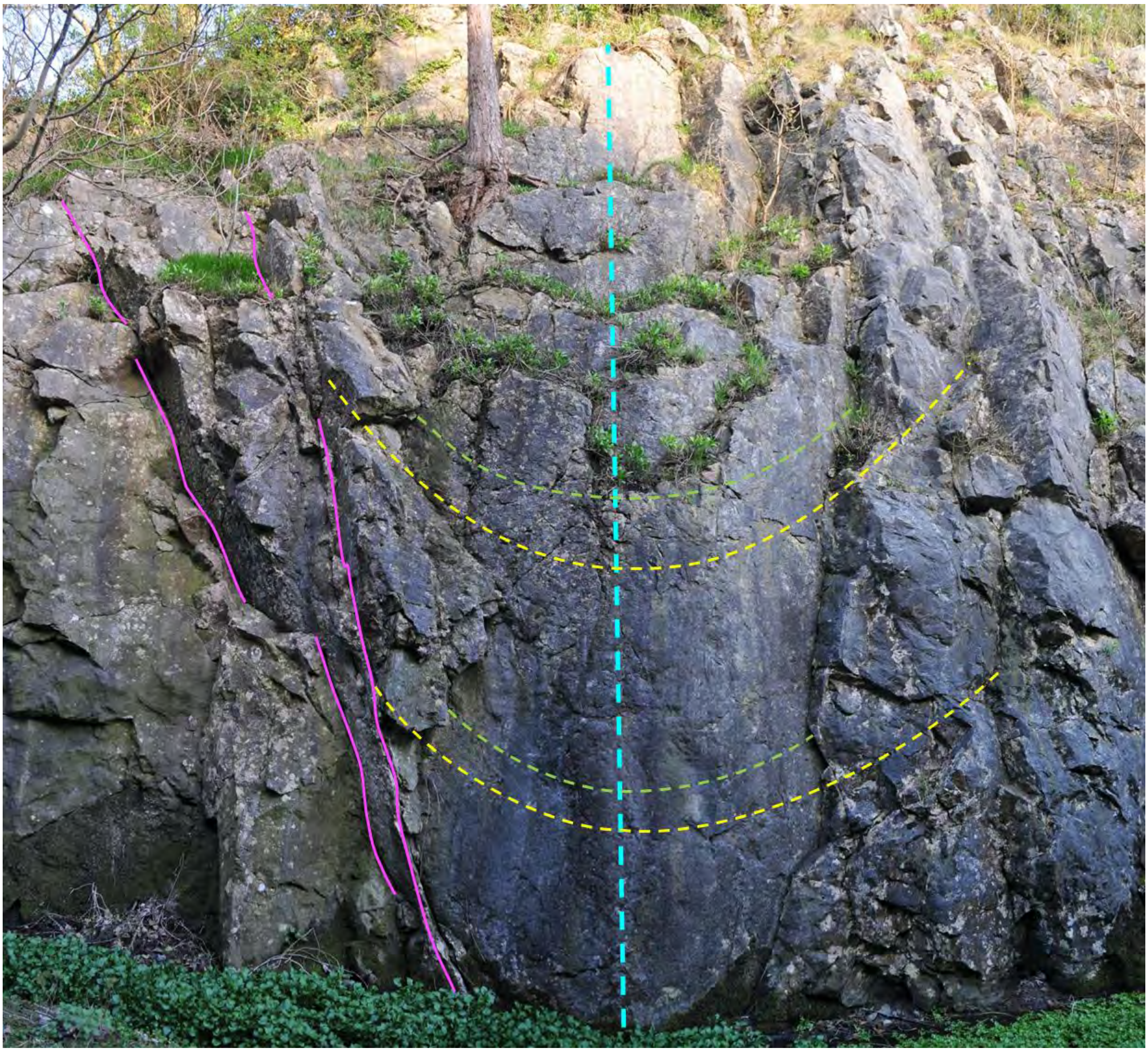
[13] https://www.sheffield.ac.uk/geography/staff/clark_chris/britice_v2/index, Clark, C. D. *et al*, (2017) *BRITICE Glacial Map, Version 2: A map and GIS database of glacial landforms of the last British Irish Ice Sheet*. Boreas

[14] *Soilscape England* (2005) 1:250, 000 Scale, National Soil Resources Institute: created from the more detailed National Soil Map with the purpose of communicating a general understanding of the variations in soil types, and how soils affect the environment.

[15] *Agricultural land Classification* (2010) 1:250,000 Scale, Natural England: Part of the Planning System of England and Wales. Soil Grades 1, 2 and 3a are classed as 'best and most versatile land' and receive greater protection from development.

[16] *Priority Habitat Inventory* (version 2.1) 1:10,000 Scale, Natural England: this spatial dataset describes the geographic extent and location of Natural Environment and Rural Communities Act (2006) Section 41 habitats of principal importance.

[17] Skelcher, G (2016, revised 2017) *Priority Habitats in the Arnside and Silverdale AONB*, A Report for the Arnside and Silverdale Partnership.



Complex geological structures within the 'Silverdale Disturbance', as exposed within the Sandside Cutting LGS: the Dalton Beds here are tilted into a very steeply-dipping orientation and are affected by additional folds and faults. The blue line indicates a sub-vertical axis, around which the beds have been folded (the yellow and green lines indicating the former continuity of individual beds), whilst the magenta-coloured lines on the left indicate steeply-angled fault planes.

‘Slickensides’ (parallel grooves and ridges) seen on the underside of a low-angled fault plane exposed in the Sandside Cutting LGS, revealing the direction of sliding of one bed against the other.

Tilted beds of Urswick Limestone at Jenny Brown’s Point
(note remnant horizontal area of eroded saltmarsh, exposed at low tide)

The gentle dip of some of the limestone beds has also greatly influenced the way in which they have been weathered (in particular by karstic dissolution processes) and the landforms and landscapes which have been created as a result.

More generally, the structural geology is fundamental to the pattern of outcrop (the distribution of the different geological formations occurring directly beneath the land surface), the orientation of the geological beds and subsequent development of the landforms. In particular, the 'Block and Basin' topography that forms such a typical part of the landscape is attributed largely to the pattern of faults, with hills - such as Warton Crag, Trowbarrow Hill, Middlebarrow Hill, Hale Fell and Arnside Knott - forming the upstanding 'blocks' and the mosses - such as Leighton Moss, Silverdale Moss, Arnside Moss, Hale Moss and the Hawes Water Mosses and Lakes – forming in the basins. Faults have also influenced the location of the Triassic mineralisation that has occurred within some of the limestones.

Alternating blocks of wooded limestone hills and lowland mosses, as seen from Summerhouse Hill, looking north-west across Leighton Hall Park, Leighton Moss and Middlebarrow Hill towards Arnside Knott

The more dramatic monoclinal folding seen within the Silverdale Disturbance has had a more obvious and direct influence on the landscape, with the vertical and even overturned strata (as seen most spectacularly within the Trowbarrow Quarry SSSI, the Throughs Lane LGS and the Sandside Cutting LGS) becoming features of geological conservation interest in their own right, as well as influencing the pattern of weathering and landform development (e.g. along the narrow outcrop of the vertically-tilted Woodbine Shale). The vertical beds of limestone at Trowbarrow Quarry have also created an excellent variety of well-used climbing routes (see photograph on next page).

Geological structures, including both faults and steeply-dipping strata, have also influenced quarrying practices in the area – this being an essential aspect of safe design in the case of modern quarries, such as Sandside, but perhaps not quite so evident at Trowbarrow and other long-disused quarries.

Notwithstanding these various important influences on the landscape, geoconservation and even economic activity, geological structures are not considered further as a 'resource'. Rather, their influence is considered in relation to each of the main geological formations within the Carboniferous Limestone sequence, as detailed in the following pages.

Vertically- tilted beds of Urswick Limestone at Trowbarrow Quarry provide excellent opportunities for rock climbing

## *Martin Limestone Formation and Red Hill Limestone Formation*

The Martin Limestone Formation and Red Hill Limestone Formation are only found underlying the saltmarsh and raised marine deposits between Arnside and Storth, adjacent to the River Kent. These geological formations do not occur directly at the surface ('outcrop') within the AONB and therefore do not have a significant influence on the landscape or amenity of the area.

## *Dalton Formation*

***The Dalton Formation outcrops less extensively within the AONB and, overall, exerts a more muted influence on the landscape where it does occur. The Dalton Formation is best-exposed at the coast between Arnside and Blackstone Point, where the small-scale structures are particularly interesting. The fossils within the Dalton Formation were of significance in first-identifying the limestone succession and remain a potential valuable interest today for raising awareness of the AONB's geodiversity to all ages.***

Dalton Formation adjacent to Arnside Coastguard station: the alternating horizontal shale and limestone beds are clearly seen to the left with contorted beds in the middle section between two faults

Dalton Formation at Blackstone Point: differential weathering leaves the limestone beds jutting out above the shale beds

| | |
|---|---|
| **AONB Landscape Character** | Supports AONB Type C: Coastal Limestone Pasture and Type E: Inland Pasture and Parkland. Within Frith Wood forms part of Type F: Wooded Limestone Hill and Pavements |
| **Soilscape Category** | No. 7: Thin, freely draining, slightly acidic but base-rich soils |
| **Agricultural Land Quality** | Grade 5, Very Poor |
| **Priority Habitat** | Predominantly **deciduous woodland or lowland mixed deciduous woodland and upland mixed ash woodland** with some lowland calcareous grassland or lowland meadows and smaller patches of inland rock outcrop / scree, limestone pavement, traditional orchard, lowland grazing marsh and lowland fen. |
| **Biological SSSIs** | Frith Wood Unit of Arnside Knott |
| **Geological SSSIs** | None |
| **LGS** | Sandside Cutting, Arnside Foreshore, Far Arnside, Blackstone Point |

## Description, Occurrence and Typical Features

The Dalton Formation comprises dark grey, muddy limestones arranged in obvious layers, known as beds. The total thickness of the Dalton Formation in the AONB is around 120m. Alternating beds of limestone and shale are particularly evident in the middle part of the formation and the upper part of the unit is often '*dolomitised*' (the partial replacement of the original calcium carbonate by magnesium carbonate, in this case, after deposition and burial). Macrofossils (those that can be seen) are common, including solitary and colonial corals[18], brachiopods[19], crinoids[20] and some gastropods[21]. The presence of many fossils enabled the establishment of a limestone succession (an order and relative age to the different layers)[22]. Some of the fossils found in the Dalton Formation are shown in photographs at the end of this section.

The Dalton Formation is particularly well exposed in natural outcrops around the coast from Arnside to Blackstone Point and within two disused small quarries, one at Arnside and one at Blackstone Point. The Dalton Formation is also exposed within Sandside Cutting, Scout Crag Quarry and underlies the River Bela at Heron Corn Mill in Beetham. Otherwise the Dalton Formation is found underlying the lower northern slopes of Arnside Knott, lower eastern slopes of Hale Fell, lower slopes of Warton Crag and the villages of Arnside, Yealand Conyers, Yealand Redmayne and part of Warton. It is also exposed within the lower part of the cliffs and foreshore around Know End Point.

Around the coast at Arnside and Blackstone Point, overhanging beds of the relatively harder limestone beds are obvious, with the relatively softer shaly beds having been more easily eroded. Folding of Dalton Formation alongside the Arnside Coastguard Station also shows that when pressure is exerted by tectonic forces, the weaker shaly beds tend to deform and crumple whilst the relatively stronger limestones, bend or tilt. The Dalton Beds have been tilted through the influence of the Silverdale Disturbance to a near vertical position around Storth as seen in the exposures at Sandside Cutting. To the north-west of Sandside, Summerhouse Point has easily accessible Dalton outcrops and is one of few Dalton sites with karren features.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The Dalton Limestone Formation generally has a subdued influence on natural beauty, except along the Arnside foreshore where it forms extensive low cliffs and a narrow wave-cut platform. It outcrops less extensively than the other Carboniferous Limestones across the AONB and, overall, exerts less influence on the landscape although has a marked effect on topography in some places, such as the limestone ridge in the vicinity of Storth. It does lend support to AONB Landscape Character **C**: *Coastal Limestone Pasture* and Landscape Character **E**: *Inland Pasture*

[18] Marine invertebrates with soft-bodied organisms (polyps) related to sea anemones and jellyfish. They secrete skeletons made of calcium carbonate which is the part most likely to remain in the fossil record.

[19] Marine invertebrates with two hard shells, known as 'valves' on the upper and lower surfaces, unlike the more commonly occurring bivalve molluscs alive today which have two shells in a left and right arrangement.

[20] Marine invertebrates with a 5-star symmetry, like the starfish alive today but usually attached to the sea floor by a stem.

[21] Invertebrates with a whorled or spiral shell, includes the species of snails alive today.

[22] See Garwood, E. J. (1912) The Lower Carboniferous succession in the north-west of England, *Quarterly Journal of the Geological Society of London*, **68**, 499-586; and Garwood, E. J. (1916) The Faunal Succession in the Lower Carboniferous Rocks of Westmorland and North Lancashire, *Proceedings of the Geologists Association* **27** (1);

*and Parkland*. Within Frith Wood, on Arnside Knott, the Dalton Formation locally forms part of Landscape Character **F**: *Wooded Limestone Hills and Pavements*.

Where the Dalton Formation is tilted to near vertical within the area affected by the Silverdale Disturbance, ridges, such as those in western Storth, are formed due to the differential weathering of the relatively harder limestone and softer shaly beds.

The soils formed on the Dalton Formation tend to be thin, freely draining, slightly acidic but base-rich soils. On slopes, these are also generally immature soils, known as a 'Rendzina'[23]. The soils are typically of very poor quality for agriculture but provide suitable conditions for the development of calcareous grassland and woodland.

The main priority habitats occurring within the Dalton Formation are deciduous woodland and upland mixed ash woodland. These occur within the Storth area, the northern lower slopes of Arnside Knott and on the lower slopes of Warton Crag. Frith Wood, part of the Arnside Knott SSSI is a priority habitat for deciduous woodland and the only SSSI unit designated for biological interest within the Dalton Formation.

Other areas of priority habitat are much smaller in extent and include lowland calcareous grassland and lowland meadows within the Storth area and on the lower slopes of Arnside Knott. Some inland outcrop and patches of traditional orchard are also present within the Storth area and some inland outcrop and limestone pavement is present on Warton Crag. Lowland grazing marsh is found overlying the Dalton Limestone that separates Arnside Moss from Silverdale Moss and a small area of lowland fen is found on the southern outskirts of Storth.

| **Table: 3.1 Biological SSSIs within the Dalton Formation** | | |
|---|---|---|
| **Site Name (County)** | **Status** | **Interest** |
| Arnside Knott, Frith Wood Unit (Cumbria) | SSSI | • Calcareous woodland supported by the slightly acidic but base-rich soils typically formed on limestones. |

## Economic and Recreational Use, and Built Heritage

The Dalton Limestone has been quarried in the past on a small scale at Arnside and Blackstone Point for use in local quay construction and at Scout Crag quarry where the material was used as a flux in the local Carnforth Iron Works.

More generally, it is likely to have been used in the construction of stone buildings within settlements located on or close to the outcrop, particularly Arnside, Sandside and Storth, although the specific provenance of stone used in individual buildings has not been assessed. Similarly, Dalton Limestone has been utilised in the construction of drystone walls in certain areas (e.g. at Scar Close to the west of Warton, as pictured on page 48 above).

[23] Rendzina soils are humus-rich shallow soils usually formed from carbonate rock. Rendzina soils are often found in karst regions, particularly below scarps on slopes. Rendzinas represent a transitory stage in soil development but can persist if soil loss by erosion counteracts soil development.

The Mill at Beetham makes use of a natural step in the Dalton beds to build up the weir to power the water wheel. The natural step feature is a 'knickpoint', formed by the resistance of this relatively strong limestone bed to downward erosion by the river.

## Conservation of the Geodiversity

There are no SSSIs designated for geological interest within the Dalton Formation. However, there are three LGS. A small section of the cliffs around Know End Point within the Silverdale Shore LGS also shows Dalton Formation outcropping beneath the Park Limestone Formation. However, the main cliff exposures there are of the Urswick Limestone Formation and Park Limestone Formation, therefore the Silverdale LGS is not included within this list.

**Table 3.2: Geological Sites within the Dalton Limestone**

| Site Name (County) | Status | Interest |
|---|---|---|
| **Sandside Cutting** and Throughs Lane (Cumbria) | LGS | The Dalton Formation is found within the Sandside Cutting part of this LGS, where the interest comprises:<br>• Vertical and overturned (beyond the vertical) beds of Dalton Limestone Formation associated with the Silverdale Disturbance, an east facing monocline.<br>• Numerous steeply dipping faults with slickensides (striations and polishing caused by the movement along the fault) and fossil corals exposed on some fault planes. |
| Arnside Foreshore (Cumbria) | LGS | • Geological structure on a small scale: Crumpled, contorted and folded beds, together with faults.<br>• Currently the small quarry at Arnside is included within the LGS although the geological interest is largely obscured by vegetation. |
| Blackstone Point (Cumbria) | LGS | The Dalton Formation is exposed at Blackstone Point and the interest is:<br>• Fossils: solitary and colonial corals, crinoids, brachiopods and gastropods<br>• The differential weathering of the alternating limestone and shaly beds. |
| Far Arnside (Cumbria) | LGS | The Dalton Formation has recently been re-exposed at Far Arnside following erosion of the saltmarsh and the interest is the fossils: solitary and colonial corals, crinoids, brachiopods and gastropods. |

## Fossils in the Dalton Limestone

The Dalton Limestone is associated with sub-zones (d) and (e) of Garwood's (1912) zonal divisions of the Lower Carboniferous strata of North-West England, now recognised as part of the **Arundian** Age of the Carboniferous period. The zonal divisions were based on fossil types which were found to be most useful as indices for each one, on account of their wide distribution over the area and unique association with the zones, sub-zones and individual bands (or beds) in question.

Sub-zone (d) was described by Garwood as the '*Chonetes Carinata'* sub-zone, which formed the upper part of the '*Michelinia Grandis'* Zone. Both of these fossils (varieties of Brachiopod and colonial tabulate coral, respectively) are diagnostic of this sub-zone. Others, which are characteristic of the zone, but not unique to it include: *Michelinia tenuisepta, Caninia cylindrica, Cyathophyllum multilamellatum, Zaphrentis konincki, Zaphrentis kentensis* and *Schellwienella* (cf. *crenistria*).

Sub-zone (e) was described by Garwood as the 'Gastropod Beds' and formed the lower part of the succeeding *Productus Corrugato-Hemisphericus* zone, the latter being a distinctive form of *Brachiopod* fossil. As noted by Garwood, this zone contains no individual species of gastropod that can be identified as diagnostic. Rather, it is usually characterised by a rich assemblage of gastropods and other molluscs, such as *Bellerophon, Euomphalus* etc. The beds contain many species in common with the underlying sub-zone (d), but *Michelinia* and *Chonetes Carinata* are diagnostically absent. The brachiopod *Seminula* occurs abundantly near the base, together with a large form of Diphyphylloid *Lithostrotion* (colonial coral).

Crinoid 'ossicles' (stem fragments) are also commonly seen, though were not explicitly noted by Garwood.

At Far Arnside, investigations by Balderstone & Dewey (2003) identified several examples of *Siphonophylla sp*., a distinctive solitary rugose coral. These authors also suggest that the Dalton Formation in that area continues upwards into the succeeding **Holkerian** Age of the Carboniferous, to incorporate beds containing *Lithostrotion araneum* – a type of colonial coral which did not exist during the Arundian Age.

Above Left: *Siphonophyllia sp*. – a solitary rugose coral.

Abve Right: the whorled shell of a *Gastropod.*

Right: an expanse of colonial coral, possibly *Lithostrotion sp.*

Below Left: *Brachiopod* valves, giving a lumpy appearance to the limestone.

Below Right: Crinoid 'ossicles' (fragments of fossil sea lillies), perhaps *Cyathocrinus sp*., seen as various-angled cross-sections through the cylindrical stems. The hole that gives some of the sections a 'polo mint' appearance would have contained the animal's soft tissue and nervous system.

## *Park Limestone Formation*

***The Park Limestone Formation contributes significantly to landscape and biodiversity, being associated with undulating or corrugated ground, steep slopes, scree slopes and calcareous grassland. Most of the construction aggregate quarried within the AONB is sourced from this formation. Large scale geological structures are exhibited within the Park Limestone at the coast and coastal erosion has exposed phreatic caves.***

Above Left: Undulating farmland within the Park Limestone Formation on the Silverdale coast

Above Right: purple-ish grey Park Limestone Formation exposed within Middlebarrow Quarry, overlain at the top of the sequence by lighter-coloured limestone of the Urswick Limestone Formation.

Below Left: Phreatic Cave at Silverdale Cove

Below Middle: Park Limestone Formation exposed at Arnside Point, showing the blocky, heavily jointed limestone.

Below Right: Park Limestone Formation being worked at Sandside Quarry. A distinct fault is shown in the middle of the photograph, around which extraction of the rock is more difficult

| | |
|---|---|
| **AONB Landscape Character** | Shapes the majority of Type C: Coastal Limestone Pasture and contributes to Type E: Inland Pasture and Parkland. On Arnside Knott, The Park Limestone Formation forms part of Type F: Wooded Limestone Hills and Pavements. |
| **Soilscape Category** | No. 7: Thin, freely draining, slightly acidic but base-rich soils. |
| **Agricultural Land Quality** | Grade 5, Very Poor |
| **Priority Habitat** | Predominantly **deciduous woodland or lowland mixed deciduous woodlands, upland mixed ash woodland and lowland calcareous grassland** with some inland rock outcrop / scree, limestone pavement, maritime cliff and slope, semi-improved grassland and patches of traditional orchard, lowland heath, lowland meadow and wood pasture parkland. |
| **Biological SSSIs** | Arnside Knott, Far Arnside and Warton Crag |

**Geological SSSIs** None

**LGS** Blackstone Point, Silverdale Shore, Warton Crag

## Description, Occurrence and Typical Features

The Park Limestone Formation comprises unbedded or poorly bedded, pale grey limestone made up of sand-sized grains and is around 125m in thickness. Most of these grains are of carbonate but some are recrystallized lime mud. The absence of clearly-defined bedding planes within the limestone is thought likely to be due to both continuous deposition and to subsequent bioturbation (reworking of the sea floor sediments by plants and animals, including burrowing, ingestion and defecation of sediment). Smaller fossil fragments rather than complete fossils are more often found within the Park Limestone.

The Park Limestone forms the hill of Arnside Knott, King William's Hill, the middle and lower slopes of Middlebarrow Hill and the middle slopes of Warton Crag and Hale Fell. It underlies Elmslack and Silverdale villages, the Silverdale golf course and part of Warton village.

Breaks or fractures, known as joints, are common and closely spaced within the Park Limestone Formation. This 'blocky jointing' is often seen with calcite crystallisation or iron oxide staining on surfaces.

The Park Limestone is also well exposed at the coast between Arnside Point and Silverdale. A particularly interesting section of coast between Arnside Point and Park Point shows a broad 'syncline' (where the rocks have been folded by tectonic forces into a concave 'smile' shape). Faults are also evident and show displacement of the rocks (see page 23 of Chapter 2 for photographs). Shingle beaches have also been recently exposed in places along the length of the coastal outcrop of the Park Limestone, due to erosion of the saltmarsh, and a number of caves are exposed in the low cliffs. Once thought to be a product of marine erosion, the circular shape of several of these caves suggests formation in phreatic conditions, beneath the water table, where dissolution of the limestone has taken place in all directions.

The minerals found within the AONB are mostly associated with the Park Limestone Formation, particularly towards the boundary with the underlying Dalton Formation and are discussed in a later section on mineralisation, on page 83 below.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The Park Limestone again contributes to natural beauty in a rather understated way, tending to form areas of gentle, rolling pasture rather than the hills and pavements associated with the succeeding Urswick Limestone. It does, however, form the majority of Arnside Knott which is a major attraction for visitors in the north western part of the area.

The blocky jointing which characterises much of the Park Limestone typically weathers to produce scree on steeper slopes, such as those on the south side of Arnside Knott (see page 94) and on Middlebarrow Hill.

Where the Park Limestone remains horizontally bedded, it forms a gently undulating landscape, and where it has been tilted vertically, within the Silverdale Disturbance, it forms a 'corrugated' landscape. In both cases, this is because the heavily jointed limestone weathers unevenly. Hedges more often mark field boundaries as the rubbly, fragmented nature of the Park Limestone Formation makes it less suitable than either the Dalton or Urswick Limestones for building walls.

The Park Limestone Formation shapes the majority of AONB Landscape Character **C**: *Coastal Limestone Pasture* and contributes to AONB Landscape Character **E**: *Inland Pasture and Parkland*. Only on Arnside Knott does the Park Limestone support Landscape Character **F**: *Wooded Limestone Hills and Pavements*.

Like the Dalton Formation, the soils formed on the Park Limestone Formation are thin, freely draining, slightly acidic but base-rich and an immature rendzina soil is often present on the hilly slopes. This soil provides conditions suitable for the development of calcareous grassland and woodland.

Priority habitat for calcareous grassland perhaps most commonly occurs on the Park Limestone Formation and can be identified in several areas such as to the south of Moss Lane and within SSSIs designated for their biological interest including: Arnside Knott SSSI, Far Arnside SSSI and the lower slopes of Warton Crag SSSI. Arnside Knott SSSI and Warton Crag SSSI also include areas of priority habitat for deciduous woodland and this, together with priority habitat of upland mixed ash woodland are found also within the lower slopes of Middlebarrow Hill, Hale Fell and around Yealand Conyers and Yealand Redmayne.

Priority habitat of maritime cliff and slope is identified where the Park Limestone Formation is exposed at the coast and inland rock and scree outcrop priority habitat at King William's Hill, Hale Fell and Warton Crag. Patches of traditional orchard, lowland heath and wood pasture parkland priority habitat are identified at Storth, Far Arnside and Yealand Conyers respectively and some limestone pavement priority habitat on Warton Crag. Some very tiny areas of lowland meadow are present on Arnside Knott.

Rocky ledges within former quarries, such as Warton Crag and Middlebarrow, and even those within the operational Sandside Quarry, provide ideal sites for nesting birds, including ravens and peregrine falcons.

**Table 3.3: Biological SSSIs and LNR within the Park Limestone Formation**

| Site Name (County) | Status | Interest |
|---|---|---|
| Arnside Knott (Cumbria) | SSSI | • Limestone habitats and species with the **calcareous grassland** being particularly important. |
| Far Arnside (Cumbria) | SSSI | • Cliff top limestone **calcareous grassland** supporting a rich variety of plants including several rare and endangered species. |
| Warton Crag (Lancashire) | SSSI and LNR | • Limestone habitats and species, with the **calcareous grassland** being particularly important and of national importance for butterflies and moths.<br>• The SSSI does not include Warton Crag Quarry, but this is included within the LNR with a particular interest there being the nesting ravens and peregrine falcons although small climbing groups are also permitted outside the nesting season. |

## Economic and Recreational Use, and Built Heritage

The Park Limestone Formation was extracted at Warton Crag Quarry (historically) and Middlebarrow Quarry (more recently) and is still extracted at Sandside Quarry for use as a construction aggregate. Much of the material from Warton Crag Quarry was used in the construction of the nearby M6 motorway. The more consistent nature of the Park Limestone Formation makes it the easiest limestone to extract within the AONB, and the most suitable for crushed rock aggregate production.

The properties which make it suitable for crushing, however, (i.e. poor bedding and intensive jointing) also make it less desirable for use as a building stone. As a consequence, the Park Limestone has probably been used only to a limited extent, in the construction of stone buildings within settlements located on or close to the outcrop, such as Far Arnside and parts of Silverdale. In most areas, although the specific provenance of stone used in individual buildings has not been assessed, it is thought likely that the more competent limestone of the Urswick Formation would have been used preferentially for such work. Similarly, as noted in Chapter 2, the Park Limestone has also rarely been used for the construction of drystone walls, with a preference for hedgerows being used as field boundaries within its outcrop areas.

The disused Warton Crag Quarry is utilised for recreational rock climbing. This includes the lower part of the faces within the Park Limestone Formation. However, those faces are much less stable than those which are wholly within the overlying Urswick Limestone Formation.

## Conservation of the Geodiversity

There are no geological SSSIs within the Park Limestone Formation but there are three LGS. The Park Limestone is also exposed within the Sandside Cutting LGS, but only within a small northern section with the main interest there being the exposures of the Dalton Formation.

There are good exposures in the disused and inaccessible Middlebarrow Quarry and at the active Sandside Quarry. However, no public access is possible.

**Table 3.4: Geological Sites within the Park Limestone Formation**

| Site Name (County) | Status | Interest |
|---|---|---|
| Far Arnside (Cumbria) | LGS | • Good cliff exposures showing the blocky, jointed nature of the Park Limestone Formation with red iron oxide staining and calcite crystals on some surfaces.<br>• The structural geology including synclines and faults and associated fault breccias, a rock formed of angular fragments in a finer matrix. The breccias were created by the grinding action of movement along the fault.<br>• Dolomitisation, a geological process where magnesium ions replace calcium ions within the limestone (replacing calcite with dolomite). |
| Silverdale Shore (Lancashire) | LGS | • Good exposures showing the blocky jointed nature of the Park Limestone Formation with red iron oxide staining on some surfaces.<br>• Faults, fault breccias and dolomitisation. |
| Warton Crag (Lancashire) | LGS | • Exposures of the Park Limestone Formation within the former Warton Crag Quarry and natural exposures on the lower part of the hillside. |

## Fossils in the Park Limestone Formation

The Park Limestone is associated with sub-zones (f) and (g) of Garwood's (1912) zonal divisions of the Lower Carboniferous strata of North-West England, now recognised as the **Holkerian** Age of the Carboniferous period. Of these, only sub-zone (g) can be recognised within the AONB. This was named by Garwood after the cerioid colonial coral '*Nematophyllum minus'* (another form of *Lithostrotion*) and formed the upper part of the *Productus Corrugato-Hemisphericus* zone. In addition to these diagnostic fossils, this unit also contains abundant specimens of the brachiopod *Chonetes papilionacea*. In many areas, however, the Park Limestone contains only fragmented fossils, including numerous crinoid ossicles, as well as corals, brachiopods and other species, which are difficult to identify.

colonial rugose coral (*Siphonodendron martini* - formerly *Lithostrotion martini*)

## Urswick Limestone Formation including the Woodbine Shale

***The Urswick Limestone Formation together with its associated Karst geomorphological features, particularly the limestone pavements, is the most widespread and significant geological influence on the biodiversity and landscape of the AONB and this is recognised by the numerous sites designated for nature conservation.***

Thickly bedded, gently dipping, Urswick Limestone Formation at Jack Scout on the Silverdale shore.

(left) Inland outcrop of thickly bedded Urswick Limestone Formation at the Fairy Steps.

(

limestone pavement developed on Urswick Limestone at Hale Fell

Upper Left: 'Keyhole' shaped cave entrance at Hale Moss Caves indicative of both phreatic and vadose action

Upper Right: Palaeokarst surface in vertical beds at Trowbarrow Quarry, the pitted surface is believed to have been formed by the rootballs of trees

Right: Undulating palaeokarst surface at Sandside Quarry

Bottom Left: wetland created within a doline depression at Beetham Holiday Homes

Bottom Right: Two horizontal benches separated by a steep scarp within the Urswick Limestone Formation near Woodwell, Silverdale.

Above Left: Erosion of the Woodbine Shale in vertical beds creating 'The Trough' at Trowbarrow

Above Right: Erosion of the gently dipping strata at Cow's Mouth on the Silverdale Coast has created a 'slack' (an area of lower ground) along the outcrop of the Woodbine Shale, at the centre of the cove, and a steep scarp in the overlying limestone beds on the right, due to undercutting of the shale which has removed support for the rock mass above.

Right: The Woodbine Shale around Silverdale appears to influence the development of springs such as Woodwell.

Below: Vertical beds of Urswick Limestone Formation at Trowbarrow Quarry

| | |
|---|---|
| **AONB Landscape Character** | Underpins Type F: Wooded Limestone Hill and Pavements |
| **Soilscape Category** | No. 7: Thin, freely draining, slightly acidic but base-rich soils |
| **Agricultural Land Quality** | Grade 5, Very Poor |
| **Priority Habitat** | Predominantly **deciduous woodland or lowland mixed deciduous woodlands, upland mixed ash woodland and lowland calcareous grassland, inland rock outcrop / scree and limestone pavement** with maritime cliff, semi-improved grassland, lowland meadows and smaller patches of wet woodland, lowland heath and wood pasture parkland. |

| | |
|---|---|
| **Biological SSSIs** | 12 SSSIs: Cringlebarrow & Deepdale, Gait Barrows, Marble Quarry and Hale Fell, Middlebarrow, Thrang Wood, Thrang End & Yealand Hall Allotment, Thrang Wood, Underlaid Wood & Warton Crag, Coldwell Farm Pasture, Jack Scout & Silverdale Golf Course. |
| **Geological SSSIs** | Trowbarrow, Hale Moss Caves, Gait Barrows |
| **LGS** | 6 LGS: Far Arnside, Blackstone Point, Sandside Cutting & Throughs Lane, Silverdale Shore, Warton Dolines, Warton Crag and Burton Well. |

## Description, Occurrence and Typical Features

The Urswick Limestone Formation is around 120m in thickness and comprises mainly thickly and well-bedded pale grey limestones with a large proportion of sand-sized grains. These limestones are known as grainstones or calcarenite. *Thalassinoides* trace fossils are evident. These are the remains of burrows, often infilled, that were made by worms, fish or more typically crustaceans. There is also commonly darker mottling which is generally an indication of burrow infill (and described as 'pseudobreccia'). The limestones also have a rubbly texture (due to the weathering of the burrows), especially adjacent to scattered partings and thin beds of grey and varicoloured clay. Macrofossils. including solitary and colonial corals, and brachiopods are present. There have also been finds of some larger fossils, such as that of *Rayonnocerous*, an 'orthocone' (straight-shelled) nautiloid[24] which is recorded on the Leighton Moss Legacy Project website[25] as one aspect of the local area that local residents consider contribute to its special nature. Further details of the fossils and trace fossils found within the Urswick Formation are given, along with photographs, on page 81, below.

About 30m above the base of the Urswick Formation, the **Woodbine Shale** forms a significant muddy layer about 6m thick comprising several beds of shale separated by very thin beds of limestone.

As explained in Chapter 2, during the formation of the Urswick Limestone, in between periods when limestone was being laid down in shallow seas, there were many periods of non-deposition when the sea-bed became emergent, and subject to the effects of weathering, dissolution and even soil formation. These are marked in the geological record by undulating boundaries known as 'palaeokarst' surfaces. These are well displayed at Trowbarrow Quarry, where, as the beds have been tilted into a vertical position, as part of the '*Silverdale Disturbance'*. One 'wall' of the quarry, in particular, has a very evident red-stained and pitted palaeo-karst surface. At the active Sandside Quarry and at the disused Middlebarrow Quarry, the boundary with the underlying Park Limestone Formation is marked by a more undulating erosion surface, with relief of up to 50m in places[26]. Another consequence of the periodic exposure of the developing limestones above sea level was that this allowed meteoric water (rainfall) to infiltrate the sediment and to redistribute dissolved calcium carbonate as calcite cement,

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[24]Nautiloids are cephalopods (advanced molluscs) and are related to octopus and squid. They are largely extinct today, although one or two species persist.

[25]The Legacy Project is a collection of photos and recordings of stories and memories that make Leighton Moss and surrounding area special, photos: http://heritagephotoarchive.co.uk/f312620238 and map with links: https://ww2.rspb.org.uk/community/placestovisit/leightonmoss/b/leightonmoss-blog/archive/2014/04/11/the-natural-legacy-discovery-project.aspx

[26] C. Patrick, Pers. Comm, 2018

thereby strengthening the limestone and increasing its resistance to subsequent erosion, particularly within the upper part of each bed.

The outcrop of Urswick Limestone Formation is widespread across the AONB. Striking outcrops of thickly bedded Urswick Limestone are particularly evident at Fairy Steps, inland, and on the coast at Jack Scout. The Urswick Limestone caps the majority of the hills and ridges in the area, such as Warton Crag, Hale Fell, Middlebarrow Hill, and Underlaid Wood.

The alternation of thicker, resistant limestone units separated by thin beds of weaker shale, together with the frequent occurrence of palaeokarstic surfaces, both lend themselves to the formation of prominent limestone 'scars' within the landscape, separated by 'slacks' along the outcrops of shale. Where the strata are horizontal, this gives rise to characteristic terraces or steps in the landscape. Where geological beds are dipping, the slacks form linear hollows at the base of the tilted limestone scars. A very significant 'slack' is formed where erosion of the full thickness of Woodbine Shale occurs. Where geological beds have been tilted into a vertical position as seen within parts of the Silverdale Disturbance, the erosion of the Woodbine Shale forms a vertical 'notch' or 'trough' with steep limestone scarps on either side.

The majority of surface karst features seen within the AONB are within the Urswick Limestone Formation, including almost all of the limestone pavements, dolines and poljes, together with many of the caves and associated speleothems[27]; the 'wells' (springs) around Silverdale, and associated localised tufa[28] formations. The Woodbine Shale, due to its relatively impermeable nature, appears to influence the development of springs above its outcrop.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The Urswick Limestone caps almost all of the hills within the AONB (except Arnside Knott) and accounts for the majority of limestone pavement. With the hills being such prominent features and the lowland pavements in this area being so iconic, the formation therefore has a very dominant influence on the natural beauty of the overall landscape mosaic which makes up the AONB. At a more detailed level, the Urswick Limestone is also responsible for the natural beauty of a number of very specific visitor attractions, such as the Fairy Steps, Deepdale Pond and the coastal cliffs at Jack Scout.

The formation clearly underpins virtually all of AONB Landscape Character **F**: *Wooded Limestone Hills and Pavements*, the main exceptions being Arnside Knott, the southern and eastern flanks of Warton Crag, and the north-eastern flank of Underlaid Wood, which extend onto outcrops of Park Limestone.

The weathering of the Urswick Limestone Formation into scarps, slacks and terraces creates a very distinctive ribbed or stepped landscape that is widespread across the AONB. Drystone walls are a common feature within farmland, making good use of naturally occurring boulders of intact Urswick Limestone. Remnant limekilns, evidence of the historical lime industry are scattered across this limestone landscape. Elsewhere the ubiquitous wooded and open limestone pavements add interest and beauty.

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[27] cave formations such as stalactites and flowstone, formed from precipitated calcium carbonate and other minerals

[28] produced by the precipitation of calcium carbonate from fresh water

The absence (through erosion) of the Woodbine Shale forms a significant, widely distributed, intermittent linear feature throughout the AONB, for example as a trough at Trowbarrow, Throughs Lane and the lower Fairy Steps and as a slack at Cow's Mouth and Burton Well.

Like the Dalton Formation and Park Limestone Formation, the soils formed on the Urswick Limestone Formation are thin, freely draining, slightly acidic but base-rich (a Rendzina soil) providing ideal conditions for the development of calcareous grassland and woodland. Soils on open limestone pavement can be almost non-existent. Priority habitat for deciduous woodland, upland mixed ash woodland, limestone pavement, inland outcrop / scree and calcareous grassland are all supported by the Urswick Limestone Formation. Where the Urswick Limestone Formation outcrops at the coast, maritime cliff priority habitat is supported. Also supported to a lesser extent are: semi-improved grassland, lowland meadows, lowland heath and wood pasture parkland. Some wet woodland is found in Underlaid Wood which appears to be associated with the Woodbine Shale.

There is a fundamental connection between the Urswick Limestone and its associated biodiversity. A wide range of trees and plants is supported across the limestone pavements including ancient Yew and Juniper. Moreover, the AONB provides the northern limits of some species as the lowland woodlands on limestone pavements warm up quickly in spring, compared with pavements at higher altitude elsewhere in northern England. The microclimate of the deep grikes in the limestone pavements enables the flourishing of particular plant species which, in turn, provides the habitat for an important suite of invertebrates, particularly butterflies. Without the limestone and its karst features, many rare and important habitats simply would not exist.

There are 12 SSSIs designated for their biological interest on the Urswick Limestone Formation within the AONB. Eight of these are designated for the significant limestone habitats supported by the limestone pavements. They overlap with more extensive Limestone Pavement Orders, as shown on **Maps 1** and **2**, and also form part of the Morecambe Bay Pavements SAC, as shown on **Map 3**, in Chapter 1. They comprise: Cringlebarrow and Deepdale, Gait Barrows, Marble Quarry and Hale Fell, Middlebarrow, Thrang End and Yealand Hall Allotment, Thrang Wood, Underlaid Wood and Warton Crag. Eaves Wood SSSI is primarily designated for its outstanding assemblage of rare and uncommon plants. The remaining 3 biological SSSIs located on Urswick Limestone outcrops (Coldwell Farm Pasture, Jack Scout and Silverdale Golf Course) are designated primarily for calcareous grassland.

**Table 3.5: Biological SSSIs with the Urswick Limestone Formation**

| Site Name (County) | Status | Interest |
|---|---|---|
| Marble Quarry and Hale Fell (Cumbria) | SSSI | • **Limestone habitats** including open and wooded limestone pavement, scrub, broad-leaved woodland and calcareous grassland.<br>• The habitats, especially the **limestone pavements**, support a rich flora including a number of **scarce and uncommon species**. |
| Middlebarrow (Cumbria) | SSSI | • **Limestone habitats** including open and wooded limestone pavement, scrub, broad-leaved woodland and species-rich calcareous grassland.<br>• The habitats, especially the **limestone pavements**, support a rich flora including a number of nationally **rare and scarce species**. |
| Underlaid Wood (Cumbria) | SSSI | • **Limestone habitats** including open and wooded limestone pavement, **scars** (particularly **high scars** around Beetham Fell and Fairy Steps), scrub, broadleaved woodland and calcareous grassland.<br>• The habitats, especially the **limestone pavements**, support a rich flora which includes a number of scarce and uncommon species. |
| Coldwell Farm Pasture (Cumbria) | SSSI | • **Limestone habitats**: A small site of **calcareous grassland** supporting three types of unimproved herb-rich grassland. |
| Cringlebarrow and Deepdale (Lancashire) | SSSI | • **Limestone habitats**: **calcareous** hazel-ash **woodland**, but also contain the most extensive sessile oak-ash-lime woodland known in Lancashire.<br>• Within the hazel-ash woodland the presence of **limestone pavement** and yew woodland adds diversity of interest to the site.<br>• The site contains a complex of **limestone features of outstanding importance**, including the limestone pavement and Deepdale doline. |
| Eaves Wood (Lancashire) | SSSI | • **Limestone habitats**: Eaves Wood consists mainly of northern calcareous hazel-ash **woodland** with smaller areas of upland sessile oak woodland and sessile oak-ash-lime woodland.<br>• The prime interest of this site, however, lies in the richness and diversity of the herbs with an outstanding assemblage of **rare and uncommon plants**. |
| Gait Barrows (Lancashire) | SSSI and NNR | • Contains nationally important examples of **limestone pavement** and northern **calcareous** hazel ash **woodland**,<br>• Outstanding **assemblage of plant species and invertebrates**, including the wood ant and 26 species of butterfly, including the nationally rare High Brown Fritillary and Duke of Burgundy. |
| Jack Scout (Lancashire) | SSSI | • **Limestone habitats**: an area of **calcareous grassland**.<br>• The calcareous grassland habitat supports several **rare and notable plants.** |
| Silverdale Golf Course (Lancashire) | SSSI | • **Limestone habitats**: A small site with a westerly facing ridge of limestone with thin, calcareous soils and surface exposures of rock supporting a moderately species-rich unimproved, **calcareous grassland** habitat. |
| Thrang Wood (Lancashire) | SSSI | • **Limestone habitats**: wooded **limestone pavement** and **scars**, yew **woodland** and broad-leaved woodland, forming an integral part of the Gait Barrows woodland complex. |
| Thrang End and Yealand Hall Allotment (Lancashire) | SSSI | • **Limestone habitats**, including calcareous and acidic grasslands, bracken, heather, hawthorn and hazel scrub and woodland. The type of habitat depends on the dissection and tree cover of the pavement.<br>• Both base-rich soils and areas of deeper, more acidic glacial drift.<br>• The largest area of **limestone pavement** in Lancashire.<br>• Over 200 plant species including a number of **species with a restricted distribution**.<br>• Yealand Hall Allotment is an important locality for **butterflies** including several uncommon species. |
| Warton Crag (Lancashire) | SSSI | • **Limestone habitats**: the best example of **calcareous grassland** in Lancashire, some good examples of limestone pavement, an area of northern calcareous hazel-ash woodland.<br>• The terraces are covered by **loess**, which has given rise to quite a deep brown-earth soil supporting **neutral grassland**, now largely dominated by bracken and scrub<br>• The habitats support a number of plant species which are nationally rare or very restricted in their distribution. |

## Economic and Recreational Use, and Built Heritage

Historically, limestone was extracted, burnt and slaked to form hydrated lime, used for mortar, lime-wash and as a soil conditioner to improve agricultural land. By the 1800s, small-scale quarrying was common in the area, and 36 former limekiln sites have been identified within the AONB (within the Park and Dalton as well as Urswick Limestone outcrops). Most of the kilns were substantial stone-built structures and are important landscape and industrial heritage features in their own right. The limestone from many quarries was also used extensively in other local building work, both as rubblestone and as roughly-dressed blocks. This is evident in many of the AONB's oldest buildings as well as in drystone wall field boundaries and it contributes significantly to the character of most villages. The old quarry at Jenny Brown's Point is thought to have been used predominantly as a source of building stone for local quay construction.

The expansion of the railways to this area in 1857 opened-up wider markets for quarry products, and larger-scale operations became possible. The Urswick Limestone was quarried at Trowbarrow and Middlebarrow quarries from the mid-19$^{th}$ Century to the mid-20$^{th}$ Century and at Sandside from the mid-20$^{th}$ Century. Sandside and Middlebarrow were subsequently deepened into the underlying Park Limestone Formation, leaving the Urswick Limestone exposed only within the uppermost benches. By the end of the 19$^{th}$ Century, Ordnance Survey maps show a major lime works operation adjacent to a short railway siding at Trowbarrow, and an artist's impression of the Hoffman kiln and associated buildings is shown on a fading interpretation board at the site today.

James Ward, the pioneering founder of the Northern Quarries Company at Trowbarrow, developed a range of tar-bound road surfacing and flooring products including 'Quarrite', a superior type of bituminous macadam. This innovative product, which utilised scientific analysis and grading of the quarried limestone to improve its performance, combined heated limestone chippings with hot tar brought-in from the Carnforth gasworks. This was in national demand and gathered an international reputation in the early 20$^{th}$ Century. Trowbarrow closed in 1959 and the works buildings were cleared in the 1970s.

The quarries also supplied building stone from the Urswick Limestone, on a larger scale than had been done previously. This would have included the extraction of large blocks of stone, made possible by the 'competent' thickly-bedded nature of this particular formation, which would then have been cut to size and used extensively in local building construction throughout the AONB. At Arnside, for example, there is very little use of brick in local buildings – almost all are constructed from limestone 'ashlar' blocks (finely-cut stone) and/or more irregular limestone rubble. Urswick Limestone would have been used for this purpose in preference to the less competent Park Limestone and the more thinly-bedded Dalton Formation, neither of which are well-suited to the production of ashlar blocks. Building stone production would have diminished during the mid-20$^{th}$ Century, however, as Trowbarrow closed and as Sandside and Middlebarrow quarries were deepened into the underlying Park Limestone, which is far more suited to crushed rock aggregate production.

Prior to the protection afforded by Limestone Pavement Orders, introduced by the Wildlife and Countryside act, 1981, many of the natural pavements were deliberately worked and/or vandalised to produce decorative 'water-worn' limestone. Numerous examples can be seen in gardens and walls throughout the AONB.

The trough or slack created by the erosion of the Woodbine Shale is often used as a byway. For example, as a footpath, by Burton Well, Trowbarrow Quarry, the Lower Fairy Steps and up from Cow's Mouth at Jack Scout and in some cases as a road, such as at Throughs Lane.

Recreational rock climbing is a popular activity on natural exposures of Urswick Limestone, such as at Fairy Steps and Warton Crag, within disused quarries, particularly Trowbarrow, and on the coast at Jack Scout. Fairy Steps has been a popular tourist destination since Victorian times and is particularly well known as a beauty spot by those who live in Lancashire.

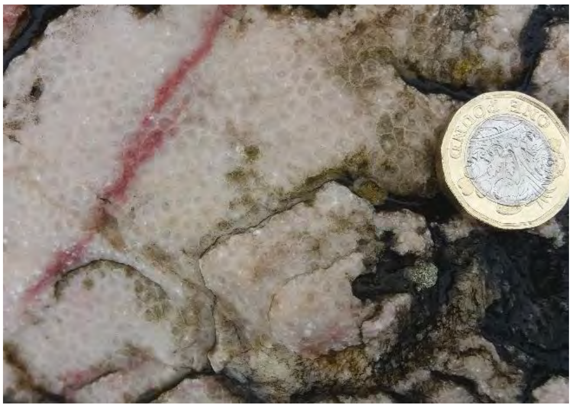
## Conservation of the Geodiversity

Although the Urswick Formation, with its associated karst geomorphological features is, by far, the most widespread and significant geological influence on the biodiversity and landscape of the AONB (the other main influence being the former lowland raised peat bogs), and whilst this is recognised by the numerous nature conservation designations within the Urswick outcrop, the geological features are often protected unintentionally, rather than directly. They are however described, at least briefly, in the Natura 2000 Standard Data Form, the Limestone Pavement Orders and SSSI Citations designated for biological interest (See table 3.5 above). More specifically, there are two SSSIs designated for their geological interest (Trowbarrow and Hale Moss Caves); one SSSI designated for both geological and biological interest (Gait Barrows); and six Local Geological Sites within the Urswick Limestone Formation. These are described in table 3.6 on the following page.

| Table 3.6: Geological Sites within the Urswick Limestone Formation | | |
|---|---|---|
| **Site Name (County)** | **Status** | **Interest** |
| Trowbarrow (Lancashire) | SSSI and LNR | • A **complete section through the Urswick Limestone**, with the Upper Urswick being best displayed and showing a variety of **carbonate lithologies** of outstanding interest for the understanding of sedimentary environments. It is the most important shelf limestone locality in northern England.<br>• A variety of **sedimentary types and features** occur, including palaeokarst surfaces, clay wayboards (clay layers interbedded within the limestones), coals, stromatolites and oncolites (structures in the rock, that give evidence of large bacterial growth in the sedimentary environment), pseudobreccias (formed as a result of the trace fossil burrows), as well as more normal marine carbonates with shelly faunas.<br>• The influence of the **Silverdale Disturbance** (vertical and slightly overturned beds) and erosion of the Woodbine Shale ('The Trough') is also clearly evident.<br>• Trowbarrow is of national importance for quiet recreational rock climbing. The LNR extends beyond the SSSI boundary to include the quarry floor and mountain biking is permitted at the southern end. |
| Gait Barrows (Lancashire) | SSSI and NNR | • Contains nationally important examples of **limestone pavement** including a good range of solution features: potholes, scallops, upstanding calcite veins and large solution pans (kamenitzas).<br>• The pavement edges were worked in the past and the quarried scars provide excellent profiles through limestone pavement and erosion features developed on bedding planes which were originally below the surface. |
| Hale Moss Caves (Cumbria) | SSSI | • Small **maze cave systems** in the low limestone bluffs on the western side of the Hale Moss depression, most probably associated with former lake levels. The sub-circular cross section of the cave entrances indicates formation by phreatic action (beneath the water table) where dissolution of the limestone takes place in all directions. However, some of the caves must also have been created subsequently by running water (vadose action) evidenced by the keyhole cross section of some of the cave entrances. The vadose action typically creates a trench eroded by an underground stream.<br>• Small areas of intact **limestone pavement** supporting diverse woodland and calcareous grassland habitat. |
| Far Arnside (Cumbria) | LGS | • Due to movement along faults, small exposures of Urswick Limestone Formation are seen to abut the main exposures of Park Limestone formation, particularly at Park Point, where surfaces of limestone pavement within the Urswick Limestone are also evident along the shoreline. |
| Sandside Cutting and Throughs Lane (Cumbria) | LGS | The Urswick Limestone Formation is found in the Throughs Lane part of this LGS:<br>• Throughs Lane itself follows a trough eroded along the vertically-tilted outcrop of the Woodbine Shale, with vertically-bedded outcrops of Urswick Limestone on both sides of the road.<br>• Taken together, these features provide evidence for the **Silverdale Disturbance**.. |
| Silverdale Shore (Lancashire) | LGS | • Good exposures of the thickly bedded Urswick Limestone Formation at Jack Scout.<br>• Springs emanating from the limestone.<br>• Gently dipping **limestone pavement** and polished surfaces of Urswick Limestone around Jenny Brown's Point with good fossil interest, particularly brachiopods, corals and trace fossil burrow beds. |
| Warton Crag (Lancashire) | LGS | • Historic quarries including Warton Crag Quarry.<br>• Good exposures of the lower and middle part of the Urswick Limestone Formation within the quarries and natural outcrops.<br>• **Karst and Landscape Features**: limestone pavement, dolines, scarps and steps. |
| Warton Dolines (Lancashire) | LGS | • **Karst Features**: A number of karstic depressions (not all of which are dolines or at Warton) including Hawes Water and Little Hawes Water lakes, Deepdale Pond, dolines adjacent to the Three Brothers erratics and other dolines to the northwest of the summit of Warton Crag. |
| Burton Well (Lancashire) | LGS | • **Karst Features**: Small spring emerging from beneath a scarp of Urswick Limestone. The spring flows through a polje (described as a doline) and there are small areas of limestone pavement. The significant scarp of Urswick Limestone is formed due to erosion of the Woodbine Shale and the presence of the spring and polje is also probably influenced by the relative impermeability of the Woodbine Shale |

## Fossils in the Urswick Limestone Formation

The Urswick Limestone is associated with sub-zone (h) of Garwood's (1912) zonal divisions of the Lower Carboniferous strata of North-West England, now recognised as the **Asbian** Age of the Carboniferous period. The sub-zone, identified by Garwood as '*Cyathophyllum murchisoni'* forms the lower part of the *'Dibunophyllum'* zone. Both of these diagnostic fossils are varieties of solitary rugose 'horn' coral, so-called because of their curved, conical shape. The Urswick Formation also contains abundant specimens of *Carcinophyllum* (another horn coral), *Siphonodendron martini* (formerly *Lithostrotion martini)* – a colonial rugose coral, and *Productus* cf. *maximus* (a large brachiopod). As noted earlier, and as illustrated below, a large fossil of *Rayonnocerous*, has been found near Silverdale, and Trowbarrow quarry reveals an abundance of *Thalassinoides* trace fossils: the casts of burrows preserved on the underside of vertically-tilted bedding planes.



Above Left: detail of colonial coral *(lithostrotion* sp.?) traversed by mineral viens at Jenny Brown's Point

Abve Right: Solitary rugose coral (*Siphonophyllia sp.*) and mineral viens at Jenny Brown's Point

Right: *Rayonnocerous:* an 'orthocone' (straight-shelled) Nautiloid seen at Heald Brow.

Below: *Thalassinoides* trace fossils: large-scale casts of burrows preserved on the underside of vertically-tilted beds in Trowbarrow Quarry (left) and on the upper surface of a bedding plane at Jenny Brown's point (right), where they are more accessible. The largest features at Trowbarrow are up to 10cm across and up to 2.5m in length

### *Alston Formation*

The Alston Formation comprises a highly variable unit of shales, mudstones, sandstones and limestones, deposited in varying depths of water, and marks a transition towards the deltaic sequences of the succeeding Namurian Millstone Grit series. Within the AONB, it only crops out directly to the north of Storrs Lane, to the east of Trowbarrow Quarry. Elsewhere, it underlies the peat beneath Leighton Moss and occurs beneath glacial till to the east of Millhead in the far south of the AONB. Its influence on the landscape, natural beauty and amenity of the area is therefore extremely limited.

### *Bowland Shale Formation, Pendle Grit and Millstone Grit*

The Bowland Shale Formation occurs only beneath glacial till to the east of Millhead in the far south of the AONB. Similarly, the Pendle Grit Member of the Pendleton Formation underlies Warton Marsh, and the mudstones, siltstones and sandstones of the Millstone Grit group occur beneath the outer part of Warton Marsh and the tidal flats of Morecambe Bay. None of these units crop out directly at the surface within the AONB, however, and therefore have no influence at all on the landscape or amenity of the area.

### *Triassic Mineralisation*

***Exploitation of the minerals within the AONB was never truly commercially successful. Nevertheless, mining formed part of the local landscape for many centuries and the minerals remain a potential valuable interest for raising awareness of the AONB's geodiversity to all ages***

Mineral veins exposed along the Silverdale Shoreline



| | |
|---|---|
| **AONB Landscape Character** | Not significant evidence of former mining to contribute to landscape character |
| **Soilscape England Soil Type** | N/A |
| **Agricultural Land Quality** | N/A |
| **Priority Habitat** | None identified |
| **Biological SSSIs** | None |
| **Geological SSSIs** | None |
| **LGS** | Arnside Foreshore, Far Arnside, including Blackstone Point, Silverdale Shore |

## Description, Occurrence and Typical Features

The formation and age of the minerals in the area is discussed in more detail in Chapter 2. Broadly, the minerals have been formed as a result of two processes:

- The metasomatic replacement of limestone which is the chemical alteration of rock associated with hydrothermal fluids, where the minerals that make up the rock are dissolved by the hot volcanic waters and as some gases are lost, particularly carbon-dioxide, new minerals are formed in their place; and,
- The deposition of minerals from water within the rock (formation water), as cavity infill, within existing caves and along existing faults.

The main minerals present in the AONB, grouped according to their associated element, are:

- Iron: **haematite, limonite, goethite** and **siderite**;
- Copper: **malachite** with some **chalcocite** and **chalcopyrite**;
- Calcium: **calcite** and **aragonite**; and,
- Magnesium: **dolomite**.

There are beautiful mineral veins, calcite crystals and red oxidised iron staining evident along the Silverdale shoreline, as well as associated dolomitised limestone and breccias. The breccias are not all formed by movement along a fault, but some by the action of the hydrothermal fluids, the hot and steaming water drawn into the voids and along the faults churning up fragments of rock.

Cavity infill within caves is also common, particularly on Warton Crag and at Red Rake, Silverdale. These mines are no longer accessible but were documented by cavers in the 1960s (Moseley, 2010).

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

Mining in the AONB was not extensive, and the landscape is not particularly marked by derelict mine buildings and large spoil heaps. There has therefore been no lasting adverse impact on the natural beauty of the area. However, former small mine entrances are common, such as on Warton Crag and a few exploratory mine workings along the Silverdale Coast. The red iron oxide staining in the cliff along the fault where the Red Rake mine at Silverdale Cove was worked is very evident. This mine was opencast at the entrance.

Other mine workings are found at Cringlebarrow, Yealand and Lindeth, with various trial workings also evident at White Creek, Heald Brow, Haweswater and Red Bridge.

There are also a few built features believed to relate to previous mine working, such as the chimney at Jenny Brown's Point, which is possibly from an 18$^{th}$ Century copper smelter and a structure believed to be an ore crusher on Warton Crag.

The mineralisation and former mine workings were not significant enough features within the landscape to have contributed to the Landscape Character Assessment completed by the AONB.

## Economic and Recreational Use, and Built Heritage

Mining in the AONB was not extensive and was mostly commercially unsuccessful. Nevertheless, it did form a part of the local landscape for several centuries. Evidence for copper mining prior to the mid-18th Century is poor. Evidence from maps and literature suggest that the Crag Foot mines on Warton Crag were initially worked for Copper in the mid-18th Century intermittently through to the early 19th Century. There is also some reference to copper mines around Arnside and Storth during the mid-18th Century, but no evidence for copper mining activity in this area remains.

Early accounts of the local iron industry are available from the monastic records. Wrought Iron was produced in small-scale technologically primitive ventures until early in the 18th Century. Subsequently, market demand and technological advances, together with the advent of the railway changed the nature of the industry. In the early 18th Century, Haematite from the Red Rake mine and the Cringlebarrow Workings were thought to be used - alongside a more plentiful supply from Furness - within the iron smelting works at Leighton Furnace. These works were located in Leighton, not because of the immediate availability of iron ore but because of the plentiful supply of peat as a substitute for charcoal (see page 103 below) and water.

The Crag Foot mines were the most significant of the area. As well as being worked for copper, they were also worked for haematite ore and soft red ochre through to the late 19th Century. Probably the most significant market for the mineral was as a pigment. The red ochreous haematite from the Crag Foot Mines (known locally as ’the paint mines’) was known in the trade as the ‘Warton Oxide of Iron’. Although the Carnforth iron works made use of the local sources of limestone as a flux, high-quality iron ore was required, and this was transported by rail from Furness.

Other mines on Warton Crag include Barrow Scout Mine, Warton Quarry Mine to the south and Three Brothers Shaft and Fairy Hole Shafts on the east of Warton Crag and some other smaller trials to the north of Warton. A detailed account of the various sources describing the mining history of the area is provided in Moseley (2010).

## Conservation of the Geodiversity

There are three LGS within the AONB that include the mining history or mineralisation as part of the interest, as detailed in Table 3.7, below.

**Table 3.7: Geological Sites which include Mineralisation or Mining History as part of the Interest**

| Site Name (County) | Status | Interest |
|---|---|---|
| Far Arnside, (Cumbria) | LGS | • Iron mineralisation evident in the cliffs. |
| Silverdale Shore (Lancashire) | LGS | • The mineralised veins of iron and copper, some mined, are within the Park Limestone Formation and evident along the Silverdale Shoreline as well as associated breccias. |
| Warton Crag (Lancashire) | LGS | • Historic mining interest at the Crag Foot Mines, the mines around Warton Crag Quarry and the mines along the east of Warton Crag. |

## *Glacial Till*

***The glacial till assists in creating the AONB's landscape mosaic by providing relatively acidic soils and habitats that intersperse with the calcareous soils and habitats formed over limestone. The glacial till has also contributed to the formation of the lowland raised peat bogs, shapes landscape character through the formation of the drumlin hills that border the AONB and provides evidence for past glacial environments.***

Shapely drumlin hills at Crooklands, just outside the AONB, east of Milnthorpe

Glacial till exposed as the River Bela cuts into a drumlin near Milnthorpe

| | |
|---|---|
| **AONB Landscape Character** | Underpins Type G: Drumlin Farmland and E: Inland Pasture and Farmland and supports Type C: Lowland Moss |
| **Soilscape Category** | No. 6, freely draining, slightly acid loamy soils |
| **Agricultural Land Quality** | Grade 3, Good to Moderate |
| **Priority Habitat** | **Not generally associated with priority habitats**. Some semi-improved grassland and coastal and floodplain grazing marsh with pockets of orchard and lowland meadows. Some overlap with the upland mixed ash woodland and lowland mixed deciduous woodland largely found on the limestone formations. Veteran trees are found within the Dallam Tower Estate. |
| **Biological SSSIs** | Thrang End and Yealand Hall Allotment, Gait Barrows |
| **Geological SSSIs** | Gait Barrows although it is the biodiversity that provides the interest |
| **LGS** | None |

## Description, Occurrence and Typical Features

The glacial till bordering the AONB to the east and south is probably lodgement till which is material deposited from beneath the ice and usually comprises sandy, silty clay with pebbles and boulders but can contain gravel-rich or laminated sand layers.

Much of the glacial till, especially on the east boundary of the AONB has been shaped into drumlins. Drumlins are subglacial features formed beneath ice and aligned to ice flow. Their development remains controversial and is argued could be due to differential deformation of the sediments by shear stresses imparted by the overlying ice or by sediment infill after large scale scouring by meltwater beneath the ice. The classic drumlin shape is a smooth, streamlined hill that resembles half an egg buried along its long axis. A number of drumlins tend to be found closely packed together as 'swarms' rather than as individual features. The drumlins on the boundary of the AONB form part of the wider drumlin swarm that extends from Kendal southwards. Drumlins may have a solid rock core, but are mostly made up of the poorly-sorted constituents of glacial till.

The shape of a drumlin shows the direction of ice streaming (flow) with the blunter end and highest point of the drumlin (stoss) being up-stream, with the gentle sloping pointed end (lee) of the drumlin hill being down-stream.

A large area of glacial till is also shown on the BGS map to the south of Warton Crag and around White, Hale and Thrang Mosses. Other smaller patches of glacial till are shown on the lower ground around Arnside, Silverdale, Hawes Water and Leighton Mosses including around Leighton Hall, with a further patch to the east of The Cove at Silverdale. One or two isolated drumlins are also identified in the valley drained by Leighton Beck at Cold Well Farm and between Brackenthwaite and Thrang End Farm.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

Drumlins form characteristic, egg-shaped hills, particularly along the A6 on the eastern edges of the AONB and within the Dallam Tower Deer Park, near Milnthorpe, where they contribute substantially to the area's natural beauty.

Just outside the AONB, within Milnthorpe itself and to the east of the A6, the drumlins form Landscape Character **G**: *Drumlin Farmland* - a landscape that is particularly valued for its gentle beauty. Within the AONB, the glacial till underpins Landscape Character **E**: *Inland Pasture and Parkland*, including both the Dallam Tower Estate and Leighton Hall Estate. Here the gently rolling landscape includes isolated drumlins but more generally is formed of glacial till draped over the limestone bedrock. The contrast between these areas of rolling pasture and the intervening wooded limestone hills adds considerably to the overall landscape mosaic of the AONB, which is a major aspect of its natural beauty.

The glacial till also adds support to Landscape Character **C**: *Lowland Moss* as it fringes and underlies the peat in many places – often providing a low permeability base on which peat could develop in waterlogged conditions. It may thus have contributed, along with lacustrine deposits, to the formation of many of the former lowland raised peat bogs including: Leighton Moss, those in the Hawes Water depression, Warton Moss and Hale Moss.

Where the glacial till is more permeable (due to a locally higher content of sand & gravel) or where it occurs on sloping ground, it creates the conditions for deeper, more acidic brown earth soils to form, described as 'freely draining slightly acid loamy soils'. These are more suited to agriculture than the soils developed over limestones, being of good to moderate quality.

The interplay of glacial till-derived soils and limestone-derived soils and the different plant communities supported by each is exemplified at Thrang End and Yealand Hall Allotment SSSI where 'tongues' of glacial till overlie the limestone pavement, creating a range of habitats. Acidic grassland, heather, bracken and hawthorn scrub are formed on the soils derived from glacial till. The glacial till at Gait Barrows SSSI has also lead to the development of a hazel-ash woodland with less lime-loving species than that developed on limestone pavements.

**Table 3.8: Biological SSSIs which include some overlap with Glacial Till**

| Site Name (County) | Status | Interest |
|---|---|---|
| Thrang End and Yealand Hall Allotment (Lancashire) | SSSI | • **Limestone habitats**, including calcareous and acidic grasslands, bracken, heather, hawthorn and hazel scrub and woodland.<br>• Both base-rich soils and areas of deeper, **more acidic superficial glacial deposits**. |
| Gait Barrows (Lancashire) | SSSI | • The periphery woodland is situated on limestone partly covered by superficial **glacial deposits** giving rise to soils varying from basic to moderately acidic and there is a lesser abundance of markedly lime-loving species than in the limestone pavement woodland. |

## Economic and Recreational Use, and Built Heritage

The more fertile gentle landscape underlain by glacial till provided the location for the development of the two main estates of the area: Dallam Tower and Leighton Hall which were developed in the 1600s with the current houses being built and the parkland laid out in the 1700s. The glacial till is widely used for pasture, both within these estates and along the A6.

## Conservation of the Geodiversity

The BRITICE map shows the extent of drumlins, albeit at a relatively small scale, and many of them are also identified on the BGS 1:50,000 scale superficial geology map. Additional drumlins, identified by the authors from aerial photographs and topographic maps, are included on **Map 6**, in chapter 2. No individual drumlins or glacial till deposits are designated for their geodiversity interest within the AONB.

## *Erratics*

***The erratics are localised but characteristic landscape features which make important contributions to overall landscape character of the AONB. They form isolated, discrete and distinctive features, scattered across fields and perched on limestone pavements. They add breadth to the geodiversity of the AONB by providing rocks of other ages and lithologies. They are important in determining the direction of flow and extent of former ice sheets.***

Right: One of the 'Three Brothers' - erratics of Urswick Limestone on Warton Crag.

Below left: A small lichen-covered greywacke erratic within a grike on Hale Fell Limestone Pavement.

Below right: An erratic of Shap Granite at Beetham Holiday homes, with a fresh piece of Shap Granite provided on top, enabling holiday residents to gain a better idea of its very different lithology.

**AONB Landscape Character:** Erratics are not associated with any single landscape character type but are found spread across the whole of the AONB as isolated, discrete features.

**Soilscape Category:** N/A

**Agricultural Land Quality:** N/A

**Priority Habitat:** None

**Biological SSSIs:** Several erratics are found within the protected limestone pavements.

**Geological SSSIs:** None

**LGS:** Several erratics are found along the shore within the Far Arnside LGS, Blackstone Point LGS and Arnside Foreshore LGS. The Three Brothers erratics are found within the Warton Crag LGS but are not included as part of the interest of the site.

## Description, Occurrence and Typical Features

An erratic is a rock (within the AONB ranging from pebble size to large boulder size) which has been transported and deposited by glacial ice and which is usually, but not always, of a different type (lithology) to the bedrock around it. Erratics are useful indicators of patterns of former ice flow and those within the AONB are all derived from rock outcrops to the north.

The erratics are predominately **greywackes**, a type of sandstone with poorly sorted angular grains in a fine clay matrix, sometimes with small rock fragments. The greywackes are of Silurian age and were formed by turbidity currents - underwater currents or 'avalanches' of rapidly moving sediment-laden water - flowing down steep slopes at the margins of continental shelves.

Other erratics include those of the Ordovician age **Borrowdale Volcanics Group**: extrusive igneous rocks formed when magma is forced to the surface, erupting as lava and ash, and of the Devonian age **Shap Granite**, an intrusive igneous rock, formed where magma cools more slowly beneath the surface.

Some erratics, such as the Three Brothers on Warton Crag are of more locally derived Carboniferous limestone but are nevertheless 'out of place' having been transported from their original outcrops by glacial ice.

The erratics generally form distinctive, isolated features within local fields. They are also found along the shoreline and on limestone pavements, where they are sometimes found on a 'pedestal' of limestone (the pedestal having been protected from rainfall and associated dissolution by the boulder itself). Smaller erratic cobbles can also be found lodged within the grikes on limestone pavements.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

Erratics are found scattered across the whole of the AONB but do not have any influence on the overall form of the landscape. They contribute localised interest rather than natural beauty and do not support any particular landscape character type.

The greywacke erratics, in particular, support the growth of lichen more readily than the surrounding limestone. This is particularly evident walking along the shoreline from Arnside to Blackstone Point. The smaller erratics within the grikes on limestone pavements contribute to the particular microclimate and biodiversity of these niche habitats, by adding extra shade and creating a damp surface.

## Economic and Recreational Use, and Built Heritage

Many erratics were cleared from fields and used in drystone walls. The 'Rent Stone' at Beetham is an erratic of Shap Granite. It is understood that medieval rents were paid here.

At Beetham Holiday Park two erratics, one of Greywacke, one of Shap Granite - whilst in their original setting are not in their original placement - have a particular interest to the site and caravan owners.

The Bowk Stone at Challan Hall and the Three Brothers on Warton Crag - all larger limestone erratics on pedestals - are also particular features of some appeal within the AONB.

## Conservation of the Geodiversity

The erratics add breadth to the geodiversity of the AONB, by providing rocks of other ages and lithologies. No erratics are specifically designated for their geological interest, although those perched on and within the limestone pavements are protected. The 'Three Brothers' limestone erratics are situated within the Warton Crag LGS but are not described as part of the interest of the site.

Erratics of Shap Granite are particularly important in helping to indicate the directions of ice flow during the Quaternary glaciations. The outcrop of this rock, with its very distinctive large pink feldspar crystal (see photograph on page 15), is found in just one discrete location in the UK, adjacent to the M6 motorway on the eastern side of the Lake District. This makes it possible to know exactly how far and in which direction the erratics sourced from this outcrop have travelled. The location of the Shap Granite erratics is shown in the Atlas and Guide to the Rocks and Soils of the Arnside and Silverdale AONB[29] and visitors are asked to be in touch with the author of that report with more finds.

[29]Standing, P (2015) *An Atlas and Guide to the Rocks and Soils of the Arnside and Silverdale AONB*, Bittern Countryside Community Interest Company, p14

## *Glaciofluvial Deposits*

**Glaciofluvial deposits can include landforms (kames, kettle holes and eskers) which add interest to the landscape and also provide evidence for past glacial environments.**

Kames creating a gently-undulating landscape within fields near Carnforth

Circular kettle hole and surrounding kame features near Carnforth

| | |
|---|---|
| **AONB Landscape Character** | Type H is described as 'low coastal drumlins', but more accurately is shaped by the subtle glaciofluvial landforms, also supports Type C: Lowland Moss |
| **Soilscape Category** | No. 6, freely draining, slightly acid loamy soils |
| **Agricultural Land Quality** | Grade 3, Good to Moderate |
| **Priority Habitat** | **Not generally associated with priority habitats**. Some coastal and floodplain grazing marsh. |
| **Biological SSSIs** | None |
| **Geological SSSIs** | None |
| **LGS** | None |

## Description, Occurrence and Typical Features

Glaciofluvial deposits are stratified materials deposited in layers by ice meltwater. The glaciofluvial deposits may form wide outwash plains but may also form landforms such as: eskers, kames and kettle holes, which are described below.

Glaciofluvial deposits are shown in association with glacial till at the eastern and southern margins of the AONB.

A number of eskers are shown on the BGS map and BRITICE just outside the AONB near to Carnforth. *Eskers* are effectively the 'casts' of sub-glacial tunnels – the sediments laid down by glacial meltwater flowing in tunnels beneath the ice. When the ice melts, these deposits become preserved as sinuous, upstanding ridges, usually parallel to the former direction of ice flow. However, on examination, the rather more random orientation and discontinuous nature of the ridges near Carnforth, together with their association with a number of peat-filled depressions (identified on the BGS map as small 'blobs') mean that many of the landforms here should more correctly be interpreted as kames and kettle holes. *Kames* are discrete mounds of sediment which originated by deposition within hollows within or on the surface of, stationary ice. *Kettle holes* are subsidence hollows created within previously continuous depositional surfaces in glacio-fluvial sediments, formed by the melting of underlying blocks of ice. The resulting depressions commonly fill with water and subsequently accumulate thin lacustrine sediments and/or Holocene peat deposits.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

Within the AONB itself, the limited areas of glaciofluvial sediment are not associated with any distinctive landforms and therefore do not contribute significantly to natural beauty. Rather, they are subsumed within Landscape Character **H**, which, more generally, relates to 'low coastal drumlins'. As noted above, subtle glaciofluvial landforms (kames, kettle holes and possible eskers) do occur directly adjacent to the AONB, around Carnforth, but again do not make a great mark on the wider landscape.

Like the glacial till, the glaciofluvial deposits are found in association with some of the mosses, particularly Warton Moss and Hale, White and Thrang Moss and therefore support AONB Landscape Character **C**: Lowland Moss. The glaciofluvial deposits also create the conditions for deeper, freely draining acidic brown earth soils to form which are of a better quality for agriculture. The peat within kettle holes creates particular niche soils and habitats.

## Economic and Recreational Use, and Built Heritage

Sand and gravel from the glaciofluvial deposits has been worked for use as a construction aggregate. Areas restored to open water have been created into holiday parks.

## Conservation of the Geodiversity

Whilst the glaciofluvial deposits only occur along the boundaries of the AONB, they are significant in determining the past glacial environments of the area. None of the glaciofluvial deposits or landforms is designated for their geodiversity interest within the AONB.

## *Talus (Scree)*

***The steep, scree-covered slopes below the Park Limestone outcrop on Arnside Knott form a distinctive feature within the hills of the AONB, which are otherwise dominated by the steps, scarps and limestone pavements of the Urswick Limestone Formation.***

**Arnside Knott**

Scree Slope

**Arnside Knott**

Scree Detail: cemented scree in the foreground (dislodged from an outcrop further up the slope) surrounded by loose gravel scree.

| | |
|---|---|
| **AONB Landscape Character** | Subsumed within Type F: Wooded Limestone Hills and Pavements |
| **Soilscape Category** | Not distinguished at the small-scale level of mapping |
| **Agricultural Land Quality** | N/A |
| **Priority Habitat** | The talus on Arnside Knott supports inland rock outcrop / scree and upland mixed ash woodland with some lowland calcareous grassland and lowland meadows. |
| **Biological SSSIs** | Arnside Knott |
| **Geological SSSIs** | None |
| **LGS** | None |

## Description, Occurrence and Typical Features

Talus is identified on the BGS map only on the lower south-east slope of Arnside Knott but smaller occurrences are found elsewhere, more commonly on slopes underlain by heavily jointed Park Limestone, including Middlebarrow Hill and some of the lower slopes of Warton Crag.

Freeze-thaw action, which creates scree by breaking-up the rock, is an ongoing process but would have been most prevalent during former cold climatic periods such as the Devensian glaciation, following the retreat of the ice sheets and glaciers, and during the subsequent 'Younger Dryas'. As explained in Chapter 2, at those times this area would have been subject to intense 'periglacial' conditions, comparable to those seen in higher latitudes and higher mountains today. On Arnside Knott, lime-rich waters subsequently flowed through the screes as the climate warmed in the Holocene, precipitating calcium carbonate which cemented some of the scree and intermingled 'loess' material together.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The steeply-angled, scree-covered slopes below the Park Limestone outcrop on the southern side of Arnside Knott form a distinctive feature within the AONB's inland hills, which are otherwise dominated by the steps, scarps, slacks and limestone pavement topography of the Urswick Limestone Formation. They provide a significant contribution to the natural beauty of this hill and (because of its prominence), to the surrounding areas as well. However, the scree slopes do not warrant a separate Landscape Character type and are subsumed within Type **F**: *Wooded Limestone Hills and Pavements*.

Very little true soil forms on the scree-covered slopes. However, trees do grow in the material, benefitting, perhaps, from the presence of co-mingled loess deposits trapped within the scree, and their suspended roots remain as the scree surface is periodically lowered by erosion, with some of the trees eventually dying from lack of nutrients.

The scree slopes on Arnside Knott lie within the Arnside Knott SSSI although the geological interest is not described in the SSSI citation.

**Table 3.9: Biological Sites which include Talus (Scree)**

| Site Name (County) | Status | Interest |
|---|---|---|
| Arnside Knott (Cumbria) | SSSI | • The scree slopes on Arnside Knott lie within the SSSI, but they are not described as part of the interest within the SSSI citation. |

## Economic and Recreational Use, and Built Heritage

The scree slopes on Arnside Knott were locally known as the Shilla Beds, Shilla being a word found in the English Dialect Dictionary meaning 'small pebbly stones, shingle or gravel'. These shilla beds were used as a cheap alternative to quarried rock in the construction of local lanes.

As part of the Leighton Moss Natural Legacy Discovery project[30], a recording was made of gentlemen retelling their childhood days playing on the scree-slopes.

## Conservation of the Geodiversity

The scree slopes are not designated for the geological interest, although the cemented scree is particularly interesting as an example of a more recent geomorphological process.

## *Loess*

***Loess provides opportunities for dating events in the Quaternary Period (using Optically-Stimulated Luminescence) and improves the quality of calcareous soils.***

| | |
|---|---|
| **AONB Landscape Character** | The small pockets of loess do not contribute to shaping landform and do not form a significant input to landscape character |
| **Soilscape Category** | Not distinguished at the small-scale level of mapping, although pockets of loess are known to create the conditions for deeper, more acidic loamy soils to form that are of good quality. |
| **Agricultural Land Quality** | N/A |
| **Priority Habitat** | Lowland heath develops on loess but is very limited in extent within the AONB |
| **Biological SSSIs** | Warton Crag, Arnside Knott |
| **Geological SSSIs** | None |
| **LGS** | Deepdale Doline within the Warton Dolines LGS |

## Description, Occurrence and Typical Features

Loess is a ubiquitous windblown deposit consisting of silt and was formed from the extensive glaciofluvial outwash plains, particularly after the ice retreated at the end of the Devensian glaciation. The glacially ground up silt was most easily transported by the wind. The Loess is not shown as outcropping on the BGS map, but it is known to occur as a surface veneer within some of the dolines, such as Deepdale Pond, and as pockets within the terraces on the limestone hills and within grikes on the limestone pavements.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

Loess has no particular direct impact on the landscape or natural beauty. However, it creates the conditions for deeper, more acidic loamy soils to develop. These contrast with the base-rich soils formed directly on limestone. This is particularly evident on Arnside Knott and Warton Crag where different plant communities are supported by the different soils. The loess supports more acidic heathland, contrasting with the calcareous grassland formed in areas where it is absent.

[30] The Legacy Project is a collection of photos and recordings of stories and memories that make Leighton Moss and the surrounding area special, photos: http://heritagephotoarchive.co.uk/f312620238 and map with links: https://ww2.rspb.org.uk/community/placestovisit/leightonmoss/b/leightonmoss-blog/archive/2014/04/11/the-natural-legacy-discovery-project.aspx

**Table 3.10: Biological Sites which include Loess**

| Site Name (County) | Status | Interest |
|---|---|---|
| Arnside Knott (Cumbria) | SSSI | • On the western slopes of Arnside Knott, the loess has led to the development of limestone heath. |
| Warton Crag (Lancashire) | SSSI | • The terraces are covered by loess and support neutral grassland and limestone heath dominated by scrub. |

## Economic and Recreational Use, and Built Heritage

Where loess overlies or is mixed with the calcareous soils, this helps to create deeper soils of a much better quality for farming. Loess has had no influence at all on built heritage.

## Conservation of the Geodiversity

Loess deposits provide opportunities for dating events in the recent geological past (the Late-Glacial and early Holocene) using Optically-Stimulated Luminescence (OSL) techniques.

Whilst Loess is not described as a specific interest feature within any of the sites designated for their geological interest, it is known to line Deepdale Pond.

**Table 3.11: Geological Sites which include Loess**

| Site Name (County | Status | Interest |
|---|---|---|
| Deepdale, part of Warton Dolines (Lancashire) | LGS | • Deepdale Pond is lined with loess. |

## *Lacustrine Deposits*

***Lacustrine deposits supported the development of lowland raised peat mosses inland and the lacustrine carbonate deposits (shelly marl) provide a sensitive palaeo-environmental record of the recent geological past.***

Shelly Marl at **Hawes Water**

**Lambert's Field**, adjacent to Burton Well, a polje-like depression which is very flat - indicative of a former lake - and underlain by lacustrine deposits

| | |
|---|---|
| **AONB Landscape Character** | Supports Type C: Lowland Moss |
| **Soilscape Category** | Not distinguished at the small-scale level of mapping |
| **Agricultural Land Quality** | Not distinguished at the small-scale level of mapping |
| **Priority Habitat** | Semi-improved grassland, lowland fen, coastal and floodplain grazing marsh |
| **Biological SSSIs** | Hawes Water, Cringlebarrow and Deepdale |
| **Geological SSSIs** | None, but Hawes Water is a GCR Site |
| **LGS** | Burton Well, Warton Dolines |

## Description, Occurrence and Typical Features

Lacustrine deposits, as mapped by the BGS across the UK, typically comprise thin layers of clay, silt and sand. Limited occurrences of lacustrine deposits are shown on **Map 6** bordering Warton Moss and Hale, Thrang and White Mosses, where they are also likely to underlie the peat. Localised pockets are also found within polje-like depressions, such as Lambert's Pasture in Silverdale and the wetland nature area within Beetham Holiday Homes, as well as within the centre of the Deepdale Pond doline. Other areas of lacustrine deposits are found along Park Road and Bottoms Lane in Silverdale and more extensively within the valley of Leighton Beck and along Storth Road, to the north of Hazelslack.

Some lacustrine deposits within the AONB are of shelly marl, associated with existing and former carbonate lakes which formed in areas of impeded drainage on lower ground following the retreat of the ice at the end of the Devensian glaciation. Shelly marl, a mixture of clay and calcium carbonate (a lime mud, known as micrite) and containing the shells of the freshwater invertebrates that inhabited the lake, precipitated from calcium-rich water draining into the lakes from the surrounding limestone hills. The best-known example is Hawes Water (see page 38), but similar deposits are also known to occur at Thrang Moss and may also be present in association with some of the other lacustrine deposits mapped by the BGS (see **Map 6**).

The geological structural controls appear significant, with springs above the Woodbine Shale or along faults possibly contributing to the formation of lakes and the subsequent remaining lacustrine deposits.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

Lacustrine deposits (including those concealed by peat) contribute to natural beauty by virtue of creating areas of flat ground in inland areas which contrast with, and provide a natural setting for, the adjoining limestone hills. The deposits have contributed - as a less permeable layer - to the development of reedbed, fen and ultimately the peat mosses of Hawes Water Moss and most probably Warton Moss, White Moss, Thrang Moss and Hale Moss.

Whilst the mosses have largely been worked and cultivated, the flat, low-lying wetland fens are still a very distinctive part of the AONB landscape, as shown on **Map 7**. The lacustrine deposits therefore support AONB Landscape Character **C**: *Lowland Moss*.

The lacustrine deposits at Hawes Water and Lambert's Field are a priority habitat for Lowland Fen. The smaller areas of lacustrine deposits at Hale, White and Thrang Mosses and Warton Moss are included with a larger area of priority habitat for Coastal and Floodplain Grazing Marsh. Other areas of lacustrine deposits include some priority habitat for semi-improved grassland.

Hawes Water, although now more limited in extent than the early-Holocene maximum, remains to this day as a marl lake and is designated a SSSI for the biological interest. It is the best example of a lowland hard water lake with low to moderate nutrients (an oligo-mesotrophic lake) in England. Whilst Hawes Water itself is highly calcareous, it is low in other plant nutrients as these are precipitated and locked up in the calcareous marl sediment. This results in a rather different mix of species that include rooted higher aquatic plants and rich bottom-living lake invertebrates particularly several types of snail.

| **Table 3.12: Biological Sites within the Lacustrine Deposits** | | |
|---|---|---|
| **Site Name (County)** | **Status** | **Interest** |
| Hawes Water (Lancashire) | SSSI | • **Limestone Habitats**: including a nationally important example of a **marl lake**;<br>• Plant and animal **species which are notably scarce** both in Lancashire and at a national level. |
| Cringlebarrow and Deepdale (Lancashire) | SSSI | • Deepdale Pond used to contain water but now is occupied by wetland vegetation. |

## Economic and Recreational Use, and Built Heritage

Marl can have value as a naturally occurring agricultural lime, but there is no record of the deposits being utilised for this purpose within the AONB – not least, perhaps, because of the predominance of limestone bedrock, the former availability of lime from kilns, and the relatively limited extent of acidic soil types. Instead, the deposits at Hawes Water have long been recognised for their much greater value to biodiversity and palaeo-environmental research. Many of the wetland areas underlain by lacustrine deposits are enjoyed, particularly by local residents, for quiet recreation, including walking and wildlife-watching. This includes Hawes Water, Lambert's Field, Deepdale Pond and the depression at Beetham Holiday homes, where some attempt has been made to re-establish a lake in the depression to add further appeal. None of the lacustrine sediments has had any influence on built heritage.

## Conservation of the Geodiversity

The uninterrupted deposition of lacustrine sediments at Hawes Water from the end of the last glacial period (the Devensian) to the mid-Holocene (our current geological period), together with the sensitivity to climate change that is recorded within carbonate sediments, is important for understanding both vegetation history and environmental change. Research by Frank Oldfield on the sediment and pollen records at Hawes Water contributed to the first late-glacial profiles of Northern Britain and ongoing research[31] at the site is constantly updating our understanding of the most geologically recent past inland environments of the area.

Hawes Water is a Geological Conservation Review (GCR) Site for the importance of this uninterrupted late glacial to mid-Holocene sedimentary record, but is not notified as a SSSI. Burton Well LGS includes a description of the elongated, structurally-controlled depression within which the lacustrine deposits occur as one of the interest features.

| **Table 3.13: Geological Sites within the Lacustrine Deposits** | | |
|---|---|---|
| **Site Name (County)** | **Status** | **Interest** |
| Burton Well (Lancashire) | LGS | • The elongated structurally-controlled closed depression is described as a doline but more typically presents as a polje. |
| Warton Dolines (Lancashire) | LGS | • A number of karstic depressions (not all of which are dolines or at Warton) including Hawes Water and Little Hawes Water lakes, and Deepdale Pond which are associated with lacustrine deposits. |

[31] Further information within: Huddart, D. and Glasser, N.F., (2002), Quaternary of Northern England, *Geological Conservation Review Series*, **25**, 745pp, particularly Chapter 6 The Late Glacial Record of Northern England, Site - Hawes Water GCR ID: 2880

## *Raised Marine Deposits*

***Raised marine deposits provide evidence for geologically recent former sea levels and supported the development of lowland raised peat mosses near the coast.***

**Silverdale Moss**

Marine incursions onto lower ground between the hills created coastal inlets when sea levels were higher in the early Holocene. A clayey, silty marine deposit was left behind after sea levels dropped, over which the peat of Leighton Moss and Silverdale Moss was able to form.

**Leighton Moss**

| | |
|---|---|
| **AONB Landscape Character** | Support Type C: Lowland Moss |
| **Soilscape Category** | No. 23: Loamy and sandy soils with natural high groundwater and a peaty surface |
| **Agricultural Land Quality** | Grade 4, Poor |
| **Priority Habitat** | Coastal and floodplain grazing marsh, some lowland fen and reedbeds |
| **Biological SSSIs** | None |
| **Geological SSSIs** | None |
| **LGS** | None |

## Description, Occurrence and Typical Features

Marine incursions over lower ground in the early Holocene formed deposits of clay, silt and sand in very shallow water within coastal inlets or embayments along the River Kent estuary. As the sea retreated, clayey raised marine deposits remained and are found within the AONB at New Barns and around and underlying Leighton, Silverdale and Arnside Mosses. There is evidence at Silverdale moss of the development of freshwater silts and peats, prior to marine incursion.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

As with the lacustrine deposits inland, the raised marine sediments contribute to the overall natural beauty of the area by virtue of creating broad areas of flat ground which contrast with, and provide a natural setting for, the limestone hills. They also contribute – by providing a less permeable layer - to the development of reedbed, fen and ultimately the peat mosses of Leighton, Silverdale and Arnside Mosses.

Whilst the mosses have largely been worked and cultivated, the flat, low-lying wetland fens are still a very distinctive part of the AONB landscape. The raised marine deposits therefore support AONB Landscape Character **C**: *Lowland Moss* and aid the development of loamy and sandy soils with naturally high groundwater and a peaty surface. Whilst the soils are of a poor quality for agriculture, the areas of New Barns, Arnside and Silverdale Moss do provide a priority habitat for coastal and floodplain grazing marsh and some of the priority habitat of lowland fen at Silverdale Moss and lowland fen and reedbeds at Leighton Moss is underlain directly by the raised marine deposits.

## Economic and Recreational Use, and Built Heritage

The areas underlain by raised marine deposits are used predominantly as grazing land. Leighton Moss is an important national wildlife reserve receiving many visitors each year from outside the area.

## Conservation of the Geodiversity

Mapping the location of raised marine deposits helps to identify the extent of geologically recent past sea levels.

The raised marine deposits are not designated for their geological interest.

## Peat

***Only fen peat is now found in areas of former lowland raised bog, but this is nevertheless an important habitat in its own right, with the possibility in some areas for creating the conditions for ombrotrophic bog to be re-established.***

**Silverdale Moss**

Now predominantly reedbed, open water and woodland habitat, with some areas of lowland fen peat

**Hawes Water Moss**

Now predominantly fen and carr (wooded fen) habitat

| | |
|---|---|
| **AONB Landscape Character** | Underpins Type C: Lowland Moss |
| **Soilscape Category** | No. 26: Raised bog peat soils (misleading, as only fen peat currently remains) |
| **Agricultural Land Quality** | Grade 4, Poor and Grade 3, Good to Moderate |
| **Priority Habitat** | Lowland fen, reedbeds, coastal and floodplain grazing marsh, semi-improved grassland, wet woodland, oligotrophic and dystrophic lake, ponds, lowland mixed deciduous woodland, deciduous woodland, purple moor grass and rush pastures |
| **Biological SSSIs** | Leighton Moss, Hawes Water (includes Hawes Water Moss), the Little Hawes Water Unit of Gait Barrows, Hale Moss (Just outside the AONB) |
| **Geological SSSIs** | None |
| **LGS** | None |

## Description, Occurrence and Typical Features

Areas of peat are shown on the BGS map to remain at Leighton Moss, Warton Moss, Hawes Water, Little Hawes Water and Hawes Water Mosses, White, Hale and Thrang Mosses and part of Silverdale Moss (as shown on **Map 6**). Waterlogging is required to provide anaerobic conditions to slow down plant decomposition leading to peat accumulation. In the AONB, low permeability substrata of raised marine deposits, estuarine and lacustrine clays, together with glacial till, have formed the base over which peat formation has taken place.

The evidence from cores taken within the mosses points to their development being transitional from reed bed to fen and wooded fen (carr) to raised bog. These bogs would have been actively forming raised domes of sphagnum in nutrient-deficient, acidic water, cut off from the influence of groundwater and fed only by rainwater (known as 'ombrotrophic' bog). However, all the lowland raised peat bogs within the AONB have been cut (mainly in the 18$^{th}$ Century for fuel) and drained (mainly in the 19$^{th}$ Century, for agriculture).

Leighton Moss formed in a previously flooded inlet of Morecambe Bay over 'raised marine' clays and silts associated with higher former sea levels. Arnside Moss and Silverdale Moss similarly formed over raised marine clays and silts in a flooded inlet of the River Kent estuary and possibly a moss at New Barns formed in a smaller embayment.

At Little Haweswater, Hawes Water and Haweswater Moss, the two lakes are drained by Myers Dyke which flows into Leighton Moss. In these areas, peat developed over calcareous muds and shelly marls of a larger lake bed, underlain by glacial till. Only Hawes Water and the smaller Little Hawes Water remain today as open water bodies.

White Moss, Thrang Moss and Hale Moss form part of a wider group of mosses, in an area of glacial till and glaciofluvial sand and gravel, drained by Leighton Beck and Holme Beck into the River Bela. Evidence indicates that these mosses (or at least some part of them) also developed on calcareous muds and shell marls of a previous lake bed.

Warton Moss is also located in an area of glacial till and glaciofluvial sand and gravel around the River Keer. Again, the peat is likely to be underlain by lacustrine sediments, small outcrops of which are mapped by the BGS at the edge of the peat.

As a consequence of peat cutting and drainage in previous centuries, no areas of lowland raised bog priority habitat remain within the AONB. Only the lower layers of peat are preserved in these areas and these generally support fen, carr or reedbed habitat. Other areas are used as wetland grazing land. However, there are some areas of the AONB where the creation of conditions appropriate for the formation of ombrotrophic bogs may be possible. These are discussed below.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The remaining areas of flat, low-lying wetland fens and associated peat deposits contribute to the general contrast in landscapes associated with the raised marine or lacustrine deposits which underlie them (see previous sections). They also contribute more directly to natural beauty by virtue of their distinctive vegetation types. Although not strictly speaking mosses any more, they are still a very distinctive part of the AONB landscape and exclusively underpin the

AONB Landscape Character **C**: *Lowland Moss* as shown on **Map 7**. They are also associated with the soil type incorrectly described in the Soilscape classification as 'raised bog peat soils' at Leighton Moss, Hale, Thrang and White Mosses and Warton Moss. More detail is provided on **Map 6**, where peat is also shown around Hawes Water and within parts of Silverdale Moss.

There are a variety of priority habitats mapped within the AONB on areas of former peat moss, as shown on **Map 8** and include in particular: lowland fen at Silverdale Moss, Hawes Water, Little Hawes Water and Hawes Water Moss, White Moss and some small parts of Hale Moss; reedbeds at Hawes Water Moss and over the majority of Leighton Moss; purple moor grass and rush pastures at White Moss and wet woodland at Hawes Water, Little Hawes Water and Hawes Water Moss. Other areas of former peat moss predominantly support priority habitat of coastal and floodplain grazing marsh.

Leighton Moss is of significant importance for the wetland habitats and ornithological interest and is designated a SSSI, SPA and Ramsar site, as well as being part of a larger RSPB Nature Reserve. Several of the other former mosses are designated as SSSIs for their biological importance.

**Table 3.14: Biological Sites within the Peat**

| Site Name (County) | Status | Interest |
|---|---|---|
| Leighton Moss (Lancashire) | SSSI, SPA, Ramsar | • Outstanding **ornithological importance**<br>• Reedbed and other **fen** habitat including open water and woodland.<br>• Rarer animal species including: Otters, Red Squirrel, Roe and Red Deer |
| Hawes Water including Hawes Water Moss (Lancashire) | SSSI | • Fen Habitats: including two nationally restricted types of woodland; fen, carr and grassland habitats, including three rare plant communities.<br>• An extensive reedbed which is of high ornithological importance. |
| Little Hawes Water Unit of Gait Barrows (Lancashire) | SSSI | • Little Hawes Water surrounded by fen, alder carr and wet meadow |
| Hale Moss (just outside and adjacent to the AONB boundary) (Cumbria) | SSSI | • Floor of a former fresh water lake. Consists of a southern area of base-rich fen and a northern area of mixed woodland.<br>• The fen supports a nationally rare community dominated by the black bog-rush. |

## Economic and Recreational Use, and Built Heritage

During the 18th Century, the peat was cut and the dried turf used as an alternative to charcoal as a fuel in local iron smelting. The majority of the peat removed from Arnside Moss and Silverdale Moss was probably used in this way to supply the Leighton Iron Works. The cut peat was also used as a domestic fuel and as a fuel within the salt-making industry. There is evidence that the moss from Warton Moss was probably used in this way.

Subsequent to the peat cutting, many of the lowland raised peat mosses were drained for use as fertile farmland.

Leighton Moss is an important national wildlife reserve and receives many visitors from outside the area each year.

Conservation of the Geodiversity

As ombrotrophic lowland raised peat bogs receive all their moisture and nutrient input from rainfall, they therefore contain a more sensitive record of past climate than other types of peat that are in connection with groundwater. Lowland raised peat therefore contains an important palaeo-environmental record of the recent geological past. However, as much of the peat was cut, that record has been largely lost. There are no SSSIs or LGS designated for geological interest within the peat, although Hawes Water is a GCR site and is recognised as one of the most important sites in the UK for Quaternary research.

Areas of lowland fen, particularly at Little Hawes Water, Silverdale Moss, Hale Moss and Thrang Moss form the greatest potential for the re-establishment of a hydrological regime appropriate for lowland raised peat bog to form. The re-establishment of ombrotrophic bog is important not just for habitat creation, but with their direct connection to the atmosphere, they form a stronger carbon sink than other types of peat.

## *Alluvium and River Terrace Deposits*

Alluvium underlies the floodplains of present-day streams and rivers. River Terraces represent older river floodplains, abandoned at slightly higher elevations as the rivers have cut down into them. Both are generally composed of clay and silt underlain at greater depth by sand and gravel. Both types of deposit are limited, within the AONB, to small occurrences alongside the River Bela and do not greatly influence the area's landscape or amenity.

## Saltmarsh Deposits and Shingle Beaches

***Dynamic geomorphological processes create an important but continuously changing ecosystem.***

Warton Saltmarsh

Channels within the sandbanks at Sandside becoming colonised by saltmarsh vegetation

Shingle beach behind accreting saltmarsh at White Creek Bay

| | |
|---|---|
| **AONB Seascape Character** | Type B: Bay Saltmarshes and Lagoons |
| **Soilscape Category** | No. 1: Saltmarsh Soils |
| **Agricultural Land Quality** | N/A |
| **Priority Habitat** | Coastal Saltmarsh |
| **Biological SSSIs** | The saltmarshes and shingle beaches are not separately designated but are included within the Morecambe Bay SSSI, SAC, SPA and Ramsar site |
| **Geological SSSIs** | None |
| **LGS** | Silverdale Shore |

## Description, Occurrence and Typical Features

Coastal saltmarsh deposits comprise clay, silt and peat and their maximum surface elevation corresponds to that of the highest tides. Tidal creeks within the sediments drain into the main channel of the River Kent, the sinuous position of which is continuously changing within the estuary. It is a dynamic geomorphological process. Over a period of decades, the main channel shifts from being near the northern side of the estuary (near the coast at Grange) to being near the southern side (near the coast of the AONB). Accordingly, on either side of the estuary there is an irregular alternation between periods of saltmarsh growth (accretion) when the main channel is far away and erosion, when the channel is closer to the shoreline. For this reason, although the Silverdale Saltmarsh has been lost in recent years, saltmarsh has been growing on the opposite side of the estuary at Grange. Warton Marsh and Hazelslack Marsh are currently the largest areas of saltmarsh in the AONB, although saltmarsh is also colonising the sands in the vicinity of Sandside and White Creek Bay.

Shingle beaches are recognised as a characteristic feature of the Silverdale Shore coastline. In places, the lower parts of the shingle beaches are alternately buried and re-exposed with the episodic deposition and erosion of saltmarsh. Elsewhere, as seen in the storm beach at White Creek Bay, the shingle extends above the height of the saltmarsh.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The green saltmarsh areas, continually changing in their location and extent, provide natural beauty in their contrast with the different colours and textures of the tidal flats beyond. They naturally form part of Seascape Character Type **B**: *Bay Saltmarshes and Lagoons*, though in practice, only Warton Marsh is identified as such - the other saltmarsh areas falling within Seascape Character Type **A**: *Intertidal Flats*. This is not because they are different; it is simply because those areas of saltmarsh have grown over the intertidal flats since the character maps were produced. This is a clear indication of the dynamic nature of both features.

The natural ongoing geomorphological processes which are responsible for this dynamic character also create the conditions for significant biodiversity along the coastline. Saltmarsh is important for roosting and nesting waders, waterfowl and other seabirds. The saltmarsh supports rare and uncommon plants and invertebrates, including beetles.

Warton Marsh and Hazelslack Marsh, the remaining saltmarsh at Silverdale, parts of Milnthorpe Sands, White Creek Marsh and the saltmarsh at New Barns Bay are all identified as priority habitats for coastal saltmarsh. White Creek Marsh is not identified on the current OS Map. However, the area is identified as saltmarsh on the most recent BGS map. Once again, these differences are a function of the dynamic nature of both the saltmarshes and intertidal flats.

| **Table 3.15: Biological Sites within the Saltmarsh Deposits** | | |
|---|---|---|
| **Site Name (County)** | **Status** | **Interest** |
| Morecambe Bay (Cumbria and Lancashire) | SSSI, SAC, SPA and Ramsar site | • Significance of the estuarine complex – intertidal flats and saltmarshes – for its ornithological importance, particularly wintering wading birds.<br>• Saltmarsh vegetation and associated invertebrates, particularly beetles. |

## Economic and Recreational Use, and Built Heritage

The saltmarshes form areas of grazing land for sheep and the cut saltmarsh turf around Morecambe Bay is of a quality suitable to be used in the sodding of bowling greens.

## Conservation of the Geodiversity

The natural ongoing geomorphological processes give rise to accretion and attrition of land that can be observed within a human lifetime. Dr. Ada Pringle, of the University of Lancaster, has been monitoring in some detail the erosion and growth of saltmarsh with the AONB and at Grange for the last four decades and this provides an invaluable record of recent change and some indication of how change may occur in the future[32]. Observation of the deepening of channels in one area and the silting up and associated growth of saltmarsh vegetation in others, together with the dendritic pattern of channels provides a good opportunity for small scale study of fluvial geomorphological processes. These same processes operate on a larger scale in more major river basins.

The more recently exposed shingle beaches are one of many interest features of the Silverdale Shore LGS.

| **Table 3.16: Geological Sites which include Shingle Beaches** | | |
|---|---|---|
| **Site Name (County)** | **Status** | **Interest** |
| Silverdale Shore (Lancashire) | LGS | • Limestone shingle beaches, revealed by recent saltmarsh erosion. |

[32] 'Pringle, A. W (1995) Erosion of a Cyclic Saltmarsh in Morecambe Bay, North-West England, *Earth Surface Processes and Landforms*, **20**, 387-405 and more recent articles in 'Keer to Kent' magazine.

## *Intertidal Flat Deposits*

***Dynamic geomorphological processes maintain an internationally important, continually changing ecosystem.***

Above: Evening light shining on the Intertidal Flats of Morecambe Bay

Right: Signs warning of rapidly rising tides emphasise the dangers associated with the active coastal geomorphological processes in operation


| | |
|---|---|
| **AONB Seascape Character** | Type A: Intertidal Flats |
| **Soilscape Category** | N/A |
| **Agricultural Land Quality** | N/A |
| **Priority Habitat** | Intertidal flats throughout Morecambe Bay and the Kent Estuary |
| **Biological SSSIs** | The Intertidal Flats are an essential part of the Morecambe Bay SSSI, SAC, SPA and Ramsar site. |
| **Geological SSSIs** | None |
| **LGS** | None |

## Description, Occurrence and Typical Features

Morecambe Bay is at the confluence of four main estuaries: the Leven, Kent, Lune and Wyre and includes other smaller rivers such as the Keer. These rivers bring sediment into the bay, but most of the mud and sand making up the tidal flats is brought into the estuary from the sea. The tidal range is very large (up to 10.5m on High Spring Tides) and this, combined with the extremely shallow gradients of the channels, sandbanks and mudflats, means that the tide rushes in and out of the estuary at considerable speed. A further consequence of the strong tidal currents is that the positions of the channels are constantly changing, as are the locations of dangerous mudflats and areas of quicksand. Signs warning of these dangers provide a clear indicator of the active geomorphological processes continually at work.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The intertidal flats contribute substantially to the natural beauty of the AONB, by virtue of the expansive, ever-changing views across them seen from the shoreline and hilltops, which also promote a good sense of wellbeing.

The intertidal flats priority habitat corresponds with Seascape Character **A**: *Intertidal Flats*. Collectively, the 5 estuaries form the largest single area of continuous intertidal mudflats and sandflats in the UK. Morecambe Bay is designated a SSSI, SAC, SPA and Ramsar.

The intertidal flats support huge numbers of invertebrates and an associated wide diversity of birds which feed on this plentiful resource.

**Table 3.17: Biological Sites within the Intertidal Flat Deposits**

| Site Name (County) | Status | Interest |
|---|---|---|
| Morecambe Bay (Cumbria and Lancashire) | SSSI, SAC, SPA and Ramsar site | • Significance of the estuarine complex – intertidal flats and saltmarshes – for its ornithological importance, particularly for wintering wading birds. |

## Economic and Recreational Use, and Built Heritage

Crossing the Sands by carriage from Arnside used to be the quickest route to the Lake District. Since 1501 there have been official guides to promote safe crossings of Morecambe Bay. These are now completed on foot. The current Queen’s Guide has contributed to raising millions as these crossings are often completed as charity walks.

When stocks are reasonable, commercial cockle picking and mussel harvesting are permitted in Morecambe Bay.

The tidal bore within the Kent estuary is, after the Severn Estuary, one of the best in the UK and canoeing is enjoyed.

## Conservation of the Geodiversity

The dynamic coastal geomorphological processes are indirectly protected through Morecambe Bay’s status as a SSSI for the biological interest and as a SPA, SAC and Ramsar site. Perhaps one way to promote the contribution which the dynamic geomorphological processes make to the internationally recognised biodiversity would be by holding Morecambe Bay Walks across the sands to raise funds for the conservation of geodiversity (as the Cumbria Wildlife Trust did for the conservation of biodiversity in 2018). This idea and others are discussed in more detail in Chapter 5.

## *Anthropocene - Slag Deposits*

***The slag deposits show a number of cooling features that are also observed within extrusive volcanic lava flows.***

An octagonal slag 'pudding' by the side of the River Keer, comprising low-temperature slag deposits which chilled rapidly against the sides of the slag boxes to produce material very similar to volcanic glass (© D. Woodcock)

Slag dribbles, resembling the 'pahoehoe' structures commonly seen on the surface of basaltic lava flows (© D. Woodcock)

'Spiniflex' textures formed by bladed olivine crystals within some of the more recent, higher-temperature slag deposits. The structures are comparable to those seen within very low silica volcanic lavas known as komatiites (© D. Woodcock)

| | |
|---|---|
| **AONB Seascape Character** | Within Type B: Bay Saltmarshes and Lagoons |
| **Soilscape Category** | Not distinguished at the small-scale level of mapping |
| **Agricultural Land Quality** | Not distinguished at the small-scale level of mapping |
| **Priority Habitat** | Within an area of priority habitat for coastal saltmarsh |
| **Biological SSSIs** | Within (but not forming part of the interest) of Morecambe Bay SSSI, SAC, SPA and Ramsar |
| **Geological SSSIs** | None |
| **LGS** | None |

## Description, Occurrence and Typical Features

The slag deposits of calcium silicate are the waste products from the former Carnforth Ironworks and other local furnaces and are identified as 'made ground' on the BGS map. These deposits interestingly show a number of cooling features that are also observed within extrusive volcanic lava flows including:

- **Slag dribbles**, resembling a pahoehoe, ropy lava flow which is formed when slow flowing liquid lava drags a still-plastic, but drying, surface crust into folds and wrinkles;
- **Glassy looking margins** with **conchoidal fracturing** - smoothly curving surface of materials which have no surfaces of internal weakness - typical of rocks that have cooled very quickly;
- **Spherical vesicles** or 'bubbles'; and,
- **Analogous komatiite spinifex texture**. Komatiite is a rock that formed from lava from very ancient geological times, in the early Archean Eon. The chemical composition of the earth's mantle and resultant lava was very different to that observed today and would have been runnier and cooled more quickly. The mineral 'olivine' cooled to form spiky shapes like the grass 'spinifex' found in Australia. Whilst the slag shows a similar spinifex texture, this is only an analogue of komatiite as the olivine minerals are different.

## Influence on Natural Beauty, Landscape, Soils and Biodiversity

The slag heaps alongside the River Keer can be seen across Warton Marsh and form bizarre shapes in the otherwise flat, saltmarsh landscape. They contribute interest, rather than beauty, and do not form a separate landscape character type. They are located within Seascape Type **B**: *Bay Saltmarshes and Lagoons*. The site is within the Morecambe Bay SSSI, SAC and Ramsar but the slag deposits themselves are not designated for their biological interest.

Other slag deposits are reported to occur within the AONB, in association with the former Leighton Furnace, but are not described here.

## Economic and Recreational Use, and Built Heritage

The slag heaps were placed to form part of the sea defence embankments in an attempt to reclaim land between Warton Marsh and Jenny Brown's Point. That scheme was subsequently abandoned. Much of the slag has, in the past, been re-worked and used as a secondary aggregate forming the base layer of local major roads, though it is no longer utilised in this way.

Conservation of the Geodiversity

The slag deposits are not designated for their geological interest. However, fieldtrips have been conducted to the site to study the lava-like deposits[33]. These include: The Open University, the U3A and the Westmorland Geological Society.

The cooling features of the slag deposits could also be of wider interest, particularly to undergraduate geologists from local universities studying volcanism and extrusive geological deposits.

## *Summary - Geological Controls on the Natural Environment and Landscape*

A summary of the assessment provided in this chapter of the way in which each geological formation, sediment or erosional feature influences the shaping of the **natural environment**, including landscape character, soil type and quality and habitat creation, together with the number and type of biological and geological designations is given Table 3.18 on the following four pages.

The links between each geological formation or sediment and the **built environment**, industrial heritage, culture, amenity and wellbeing described in this chapter are not included in this table. Instead, they are considered in more detail in the following chapter within the context of a full ecosystem services assessment (see Table 4.1 in Chapter 4).

[33] More information within: Woodcock, D (2014) Anthropocene volcano-analogue deposits near Carnforth, Lancashire: An Introduction and Field Guide, *Open University Geological Society Journal* **35**(1-2), 99-103 and Boulter, C. (2017) *Volcanic Lessons from the River Keer Slag*, *Warton Sands*, Unpublished Notes for a U3A Field Trip;

**Table 3.18: Geological Controls on the Natural Environment and Landscape** (page 1 of 4)

| **Geological Name and Description** | **Influence on Natural Beauty and Landscape Character** (referring to the AONB's Landscape and Seascape Character Types A-H) | **Influence on Soils** (referring to Soilscape Categories and Agricultural Land Classification) | **Biodiversity Designations and Priority Habitats** | **Geodiversity Designations** |
|---|---|---|---|---|
| **Furnace Waste from the Carnforth Ironworks**<br>Slag (Calcium Silicate) | The slag heaps form bizarre shapes in the otherwise flat, saltmarsh landscape. They contribute interest, rather than beauty, and do not form a separate landscape or seascape character type. | Not distinguished at the small-scale level of mapping. | Within (but replacing) an area of priority habitat for Coastal saltmarsh.<br>Within (but not forming part of the interest) of the Morecambe Bay SSSI, SAC, SPA and Ramsar site | None |
| **Intertidal Flat Deposits**<br>Sand and Mud | The tidal flats contribute substantially to the natural beauty of the AONB, by virtue of the expansive, ever-changing views across them seen from the shoreline and hilltops. **Underpins Type A**: Intertidal Flats | Not applicable | All intertidal mudflats are a priority habitat for **intertidal mudflats**.<br>The Intertidal Flats are included within the Morecambe Bay SSSI, SAC, SPA and Ramsar site. | None |
| **Saltmarsh Deposits**<br>Clay, Silt, Sand and Peat<br><br>**Shingle Beaches**<br>Gravel and Cobbles | The green saltmarsh areas, continually changing in their location and extent, provide natural beauty in their contrast with the different colours and textures of the tidal flats beyond. Only Warton Marsh is within **Type B**: Bay Saltmarshes and Lagoons – other saltmarsh is subsumed within Type A | Saltmarsh Soils,<br>- **Soilscape No. 1** | All saltmarsh is a priority habitat for **Coastal saltmarsh**.<br>The saltmarshes are not separately designated but are included within the Morecambe Bay SSSI, SAC, SPA and Ramsar site. | Many of the shingle beaches exposed by erosion of the saltmarsh are within the Silverdale Shore LGS. |
| **Peat Deposits**<br>Fen Peat | Peat deposits reinforce the landscape contrasts associated with the raised marine or lacustrine deposits which underlie them (see below) and contribute more directly to natural beauty by virtue of their distinctive vegetation types. They exclusively **underpin Type C:** Lowland Moss | In some areas, peat deposits are incorrectly associated with 'raised bog peat soils' - **Soilscape No. 26**. Elsewhere, they are generally associated with **Soilscape No. 23** - soils with high groundwater and a peaty surface. | Priority habitats: **Lowland fen, reedbeds, coastal and floodplain grazing marsh, semi-improved grassland, wet woodland, oligotrophic and dystrophic lake, ponds, lowland mixed deciduous woodland, deciduous woodland, purple moor grass and rush pastures**<br>Leighton Moss SSSI, SPA & Ramsar site; Hawes Water including Hawes Water Moss SSSI; Little Hawes Water Unit of Gait Barrows SSSI; and Hale Moss SSSI (just outside and adjacent to the AONB) | None |
| **Raised Marine Deposits**<br>Clay, Silt and Sand | The raised marine sediments contribute to the overall natural beauty of the area by virtue of creating broad areas of flat ground which contrast with, and provide a natural setting for, the limestone hills. They **support Type C:** Lowland Moss | Loamy and sandy soils with natural high groundwater and a peaty surface, **Soilscape No. 23**<br>**ALC Grade 4**, Poor | Priority habitat: **coastal and floodplain grazing marsh**, some lowland fen and reedbeds<br>Raised marine deposits underlie Holocene peat deposits within the Leighton Moss SSSI | None |

**Table 3.18: Geological Controls on the Natural Environment and Landscape** (page 2 of 4)

| **Geological Name and Description** | **Influence on Natural Beauty and Landscape Character** (referring to the AONB's Landscape and Seascape Character Types A-H) | **Influence on Soils** (referring to Soilscape Categories and Agricultural Land Classification) | **Biodiversity Designations and Priority Habitats** | **Geodiversity Designations** |
|---|---|---|---|---|
| **Lacustrine Deposits**<br>Clay, Silt and Sand and shelly marl | Lacustrine deposits contribute to natural beauty by virtue of creating areas of flat ground in inland areas, which contrast with, and provide a natural setting for, the adjoining limestone hills. They **support Type C:** Lowland Moss | Not distinguished at the small-scale level of mapping | Priority habitat: Semi-improved grassland, lowland fen, coastal and floodplain grazing marsh<br>SSSIs: Hawes Water, Cringlebarrow and Deepdale | Hawes Water GCR Site<br>Burton Well LGS<br>Warton Dolines LGS |
| **Loess**<br>Wind Blown Silt | Small pockets and veneers of loess are found across the AONB but have no influence at all on either landform or natural beauty. They are not associated with any particular landscape character type. | Not distinguished at the small-scale level of mapping, although pockets of loess create the conditions for deeper, more acidic loamy soils to form that are of good quality. | Within the AONB, loess deposits are not mapped and therefore cannot be associated with any particular habitat type. Deposits are known to occur, incidentally, within Warton Crag and Arnside Knott SSSIs where limestone heath has developed. | None |
| **Talus**<br>Scree material | The prominent scree slopes on Arnside Knott provide a significant contribution to the natural beauty of the area. They are **subsumed within Type F**: Wooded Limestone Hills and Pavements. | Not distinguished at the small-scale level of mapping, although the scree slopes do not really support the development of soil. | The talus within the Arnside Knott SSSI supports priority habitats of inland rock outcrop / scree and upland mixed ash woodland with some lowland calcareous grassland and lowland meadows. | None |
| **Glaciofluvial Deposits**<br>Sand and Gravel, locally with lenses of silt, clay and organic material | Glaciofluvial deposits are not associated with any distinctive landforms (within the AONB) and make little contribution to natural beauty. They are **subsumed within Landscape Type H**, which relates to 'low coastal drumlins'. The deposits **support Landscape Type C**: Lowland Moss and **Type E**: Inland Pasture and Farmland. | Freely draining, slightly acid loamy soils, **Soilscape No. 6**<br>**ALC Grade 3**, Good to Moderate | **Not generally associated with priority habitats**. Some coastal and floodplain grazing marsh. | None |

**Table 3.18: Geological Controls on the Natural Environment and Landscape** (page 3 of 4)

| **Geological Name and Description** | **Influence on Natural Beauty and Landscape Character** (referring to the AONB's Landscape and Seascape Character Types A-H) | **Influence on Soils** (referring to Soilscape Categories and Agricultural Land Classification) | **Biodiversity Designations and Priority Habitats** | **Geodiversity Designations** |
|---|---|---|---|---|
| **Glacial Till**<br>Usually sandy, silty clay with pebbles and boulders but can contain gravel-rich or laminated sand layers. | Glacial till provides natural beauty by virtue of its associated drumlin landforms and by the contrast between its rolling pastures and intervening wooded limestone hills. The deposits **Underpin Type G**: Drumlin Farmland and **Type E**: Inland Pasture and Farmland. They also **support Type C**: Lowland Moss. | Freely draining, slightly acid loamy soils, **Soilscape No. 6**<br>**ALC Grade 3**, Good to Moderate | **Not generally associated with priority habitats**. Some semi-improved grassland and coastal and floodplain grazing marsh with pockets of orchard and lowland meadows. Veteran trees are found within the Dallam Tower Estate.<br>Lowland Acidic Grassland and Lowland Heathland are known to occur within the Thrang End and Yealand Hall Allotment SSSI. Gait Barrows SSSI also has less lime-loving species in the woodland due to the presence of glacial till. | No Drumlins are designated<br>Gait Barrows SSSI – although for the biodiversity interest not the geodiversity |
| **Erratics** - varying lithologies including Silurian Greywackes, Ordovician Borrowdale Volcanics, Devonian Shap Granite and Carboniferous Urswick Limestone. | The erratics are found scattered across the whole of the AONB. They contribute localised interest rather than natural beauty and do not support any particular landscape character type. | Not applicable | Erratics are found within a number of biological SSSIs, particularly the limestone pavements, although they do not form part of the biodiversity interest. | Erratics are found within Far Arnside LGS, Blackstone Point LGS and the Arnside Foreshore LGS. In addition, the 'Three Brothers' erratics are within the Warton Crag LGS. |

**Table 3.18: Geological Controls on the Natural Environment and Landscape** (page 4 of 4)

| **Geological Name and Description** | **Influence on Natural Beauty and Landscape Character** (referring to the AONB's Landscape and Seascape Character Types A-H) | **Influence on Soils** (referring to Soilscape Categories and Agricultural Land Classification) | **Biodiversity Designations and Priority Habitats** | **Geodiversity Designations** |
|---|---|---|---|---|
| **Urswick Limestone Formation including the Woodbine Shale**<br>Thickly bedded limestone with palaeokarst surfaces, macrofossils and a thick layer of shale (the Woodbine Shale) within the lower part of the sequence | The Urswick Limestone caps almost all of the hills within the AONB and accounts for virtually all areas of limestone pavement. It therefore has a very **dominant influence** on the overall natural beauty of the area, as well as on individual beauty spots such as the Fairy Steps and Deepdale Pond and the coastal cliffs at Jack Scout. The formation clearly **underpins Type F**: Wooded Limestone Hill and Pavements | Thin, freely draining, slightly acidic but base-rich soils, **Soilscape No. 7**<br>**ALC Grade 5**, Very Poor | Priority habitat: predominantly **deciduous woodland or lowland mixed deciduous woodlands, upland mixed ash woodland and lowland calcareous grassland, inland rock outcrop / scree and limestone pavement** with maritime cliff, semi-improved grassland, lowland meadows and smaller patches of wet woodland, lowland heath and wood pasture parkland.<br>12 SSSIs: Cringlebarrow & Deepdale, Gait Barrows, Marble Quarry & Hale Fell, Middlebarrow, Thrang Wood, Thrang End &Yealand Hall Allotment, Thrang Wood, Underlaid Wood, Warton Crag, Coldwell Farm Pasture, Jack Scout and Silverdale Golf Course. | Trowbarrow SSSI, Hale Moss Caves SSSI, Gait Barrows SSSI and NNR, Far Arnside LGS, Blackstone Point LGS, Throughs Lane part of the Sandside Cutting and Throughs Lane LGS, Silverdale Shore LGS, Warton Dolines LGS, Warton Crag LGS, and Burton Well LGS |
| **Park Limestone Formation**<br>Poorly bedded, more consistent limestone with fossil fragments | The Park Limestone tends to form areas of gentle, rolling pasture rather than hills and pavements, though it does form the majority of Arnside Knott. It **shapes the majority of Landscape Type C**: Coastal Limestone Pasture and also **contributes** to **Type E**: Inland Pasture and Parkland. On Arnside Knott (only), The formation **supports Type F**: Wooded Limestone Hills and Pavements. | Thin, freely draining, slightly acidic but base-rich soils, **Soilscape No. 7**<br>**ALC Grade 5**, Very Poor | Priority habitat: predominantly **deciduous woodland or lowland mixed deciduous woodlands, upland mixed ash woodland and lowland calcareous grassland** with some inland rock outcrop / scree, limestone pavement, maritime cliff and slope, semi-improved grassland and patches of traditional orchard, lowland heath, lowland meadow and wood pasture parkland.<br>Nesting birds (particularly ravens and peregrine falcons) in former and active quarries | Far Arnside LGS<br>Blackstone Point LGS<br>Silverdale Shore LGS<br>Warton Crag LGS<br>Warton Crag LNR |
| **Dalton Formation**<br>Alternating beds of shale and limestone with macrofossils and dolomitisation near the top of the sequence | The Dalton Limestone generally has a subdued influence on natural beauty, except along the Arnside foreshore where it forms low cliffs and a narrow wave-cut platform. It **supports Type C**: Coastal Limestone Pasture and **Type E**: Inland Pasture and Parkland. Within Frith Wood, the Dalton Formation forms part of **Type F**: Wooded Limestone Hills and Pavements | Thin, freely draining, slightly acidic but base-rich soils, **Soilscape No. 7**<br>**ALC Grade 5**, Very Poor | Priority habitat: predominantly **deciduous woodland** or **lowland mixed deciduous woodland** and **upland mixed ash woodland** with some lowland calcareous grassland or lowland meadows and smaller patches of inland rock outcrop / scree, limestone pavement, traditional orchard, lowland grazing marsh and lowland fen.<br>Frith Wood Unit of the Arnside Knott SSSI | Sandside Cutting part of the Sandside Cutting and Throughs Lane LGS<br>Arnside Foreshore LGS<br>Far Arnside LGS<br>Blackstone Point LGS |

# 4. Ecosystem Services

*Ecosystem services are those aspects of the natural world which have value to the health and well-being of people. This chapter identifies the ecosystem services provided by the geological and geomorphological assets of the AONB – part of the area's 'natural capital' – and goes some way to considering their resilience to future impacts, including climate change.*

## *The Ecosystems Approach*

The Ecosystems Approach is a concept for promoting and delivering sustainable development which originated following the 1992 Earth Summit in Rio de Janeiro. It is defined, under the Convention for Biological Diversity (CBD)[34] as: *"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way."*

In the UK, Defra has taken the CBD's original definition and broadened its application by shifting emphasis onto maintaining and enhancing the health of ecosystems as well as the sustainable human use of the natural environment[35]. This is reflected in Defra's long-term aim for the ecosystems approach, which is: *"to embed an ecosystems approach to conserving, managing and enhancing the natural environment across policy-making and delivery."*

Adopting such an approach means looking at whole ecosystems during decision-making and valuing the 'ecosystem services' which they provide (see below). An **ecosystem**, in this context, is defined in the Millennium Ecosystem Assessment MA (2005) as: *"a dynamic complex of plant animal and micro-organism communities and their non-living environment interacting as a functional unit".*

## *Natural Capital and Ecosystem Services*

Natural capital can be defined as the Earth's naturally occurring stocks or assets – both physical and biological. It is from these **natural capital assets** that humans derive a wide range of what are called '**ecosystem services**' - those aspects of an ecosystem that have value to the health and well-being of people and which make human life possible[36]. The assets are not just ecological; they also encompass such things as water, mineral and soil resources and the landscape itself, together with ongoing biological, physical and chemical processes (including geological and geomorphological processes).

Many assessments of natural capital focus on the economic value of benefits. However, more recent research, including that by Natural England[37] gives greater consideration to the

[34] http://cbd.int/ecosystem

[35] Defra (2007) *Action Plan for Embedding an Ecosystems Approach*

[36] See: Natural Capital Forum, https://naturalcapitalforum.com/about/

[37] Lusardi, J., Rice, P. Waters, R.D. & Craven, J. (2018) *Natural Capital Indicators: for Defining and Measuring Change in Natural Capital*, Natural England Research Report 076

ecological and environmental properties that provide the natural capital assets, through the development of **indicators that measure change**. Our own development of indicators, designed more specifically to measure geodiversity aspects of landscape change, are a development of this concept and are discussed in Chapter 6.

An understanding of the links between natural capital assets and the ecosystem services they provide is crucial and these are discussed next.

Ecosystem services are typically grouped into four main categories [38]:

- **Provisioning services**: natural products that can be obtained from ecosystems including food, freshwater, wood and fibre, fuel and minerals and land that is suitable for various forms of development;
- **Supporting services**: natural processes necessary for the production of all other ecosystem services. These include, *inter-alia*, soil formation and geological and geomorphological processes;
- **Regulating services**: material benefits obtained from the regulation of natural processes to the benefit of people, including climate, flood, and disease regulation, water purification and the re-establishment of diverse ecosystems; and,
- **Cultural services**: non-material benefits to people including aesthetic, educational, recreational and spiritual benefits particularly the qualities within the landscape that are appreciated, such as 'natural beauty' and 'sense of place'.

Geodiversity - as a Natural Capital asset - underpins many of these services, either directly or indirectly (Gray, 2011, 2012, 2013; Gray *et al*, 2013; Gordon & Barron, 2012; Gordon *et al*, 2013). This is acknowledged in the Natural Character Area (NCA) Profile for the Morecambe Bay area[39] which notes that '*Biodiversity and geodiversity are crucial in supporting the full range of ecosystem services provided by this landscape*'. It is also acknowledged within the AONB's statutory management plan[40] and development plan document[41].

Geodiversity is a fundamental component of the 'supporting' ecosystem services, but also contributes to each of the other three categories. The extraction of minerals, for example, is a provisioning service, whilst the type of bedrock and the presence or absence of saltmarsh can provide regulating services in the context of flood management and coastal erosion, respectively. Similarly, the way in which rocks, sediments and active geomorphological processes shape the physical character of the landscape can contribute to cultural services by creating a distinctive 'sense of place'.

## *Geological Ecosystem Services within the AONB*

Comprehensive ecosystem services assessments have previously been completed for the AONB, most notably within the NCA Profile and within the AONB's statutory management plan. However, those assessments consider 'geodiversity' and 'mineral resources' as very

[38] See: United Nations Millennium Ecosystem Assessment (MA), initiated in 2001, https://www.millenniumassessment.org/en/About.htm

[39] Natural England's *Natural Area Character Profile* (2015) **20**: Morecambe Bay Limestones

[40] Arnside and Silverdale Statutory Management Plan (2014-2019)

[41] Lancaster City Council, South Lakeland District Council, Arnside and Silverdale AONB Development Plan Document (2017)

broad services, rather than considering the way in which the various formations, sediments and geomorphological processes contribute individually.

In order to address this issue, Table 4.1 at the end of this chapter provides a matrix which describes the Ecosystem Services associated with each of the Natural Capital assets represented by the various geological formations, sediments and active geomorphological processes within the AONB, listed in reverse chronological order (i.e. youngest first). The table also notes which of the supporting services – particularly those associated with natural habitats and active geomorphological processes – are most likely to be sensitive to the impacts of future climate change.

It is clear from Table 4.1 that a wide range of provisioning and cultural services, in particular, are provided by virtually all of the geological formations and deposits within the AONB, with the **Urswick Limestone Formation** providing the greatest number and range of services in both of these categories. Most of the assets also provide a range of supporting services, primarily through their influence on **soil formation**, or their association with **active geomorphological processes**, whilst only a few of the formations – primarily the coastal sediments and the bedrock formations – provide any kind of beneficial regulating services. The following text examines each of these groups in turn, drawing-out observations that are pertinent to future management of the resources.

In terms of provisioning services, the geology of the AONB has historically provided sources of **building materials**, **fuel**, **metalliferous minerals** and **water resources**, as well as providing soil types and landscapes which are suitable for **pastoral agriculture**, and thus the provision of food. Whilst quarrying activity continues at Sandside, it has ceased elsewhere in the AONB, and it is most unlikely to recommence in future at any other location within the area, because of the high-level protection afforded to AONB landscapes in both the National Planning Policy Framework and Local Plan policies. Similarly, fuel production (from both charcoal and peat) and mining activities have long-since ceased, and very little use is now made of groundwater resources within the Carboniferous Limestone. Pastoral farming continues, however, and provides an important aspect of land management which helps to preserve the character and quality of the rural landscape.

Supporting services should, perhaps, be the most important focus for active future management, since it is these which underpin all other ecosystem services. Moreover, as noted in Natural England's Climate Change Adaptation Manual[42], it is the supporting services which are most likely to be affected directly, and most immediately, by future climate change, before the effects are cascaded on to the services which they support. **Supporting services should therefore be a major focus in considering the resilience of each asset to the effects of predicted climate change scenarios**.

In this regard, the Adaptation Manual explains the relative sensitivity of each priority habitat to the various different aspects of climate change. Generally speaking, it notes that some of the **high sensitivity habitats** are those whose existence is dependent to a large extent on active, **ongoing processes**. These clearly include the active geomorphological processes

[42]Natural England and RSPB, **Climate Change Adaptation Manual**: Evidence to support Nature Conservation in a Changing Climate (2014)

responsible for sediment dynamics, erosion and deposition within the estuary, and it is the rapidly changing features of the tidal flats and saltmarshes, as well as the continually changing exposure of coastal rock outcrops and shingle beaches, which are therefore amongst the geodiversity features most susceptible to climate change. The manual also notes, however, that, being a component of dynamic coastal systems, **tidal flats and saltmarshes also have considerable ability to adapt to changes in sea level, provided that sufficient space is available and that the natural processes involved are not artificially constrained**. These are important points with regard to future management of the AONB.

High sensitivity habitats also include areas of lowland fen and reedbed. In these cases, the sensitivity derives not so much from active processes as from the intrinsic vulnerability (limited tolerance) of the habitats to imposed change.

Relatively **low sensitivity habitats** are often those where active processes – such as weathering or limestone dissolution – are relatively slow, and where the **underlying geology and/or geomorphological features formed in the geological past** plays a larger part in the ecosystem services being provided. This applies, for example to limestone pavements, calcareous grasslands and large-scale landforms such as drumlins. In such cases, the underlying geology plays a more fundamental role in maintaining the associated habitats than changing climate.

Understanding more about how the supporting ecosystem services are likely to respond to a changing climate also assists in identifying the **resilience of the AONB landscape** itself, as discussed in more detail in Chapter 6, below. Again, the limestones and drumlins are intrinsically more resilient in this respect, whilst the lowland wetland areas and particularly the coastal saltmarshes and mudflats are potentially less resilient.

Cultural services within the AONB include various **aesthetic**, **educational**, **recreational** and **spiritual** benefits, including benefits derived from both the natural and built heritage of the area. **Geotourism** is an important element within this category, combining both educational and recreational benefits, and there are numerous opportunities for the AONB to build upon this potential, highlighting further the links between landscape, culture, heritage and the underlying geology.

Finally, in terms of regulating services, the limestones (by virtue of their permeability) and lowland floodplains and coastal areas (by virtue of their capacity for surface water storage), already provide natural flood regulation services. Similarly, dynamic **coastal processes** and their associated mudflats and saltmarshes help to regulate the threat of coastal erosion. In each case there are risks of losing these important benefits if the assets are not adequately managed and protected, but there are also opportunities for enhancement if the services are properly recognised in the AONB's Management Plan. In this regard, the possibility of **re-creating conditions for the development of lowland raised peat bog** in certain areas, and thereby restoring services that have previously been lost through mis-management, represents a major opportunity.

## *Beneficiaries of the AONB's Ecosystem Services*

The various ecosystem services identified in Table 4.1 provide benefits to both people and wildlife, as well as to the natural environment itself. The main beneficiaries associated with each geological asset are indicated in the first column in the table and are summarised below.

Benefits to people, including local residents, visitors and those who obtain products originating within the AONB, can be both **direct** (e.g. through purchasing aggregate from Sandside Quarry, by learning from the observation of natural or man-made exposures, or by experiencing the area's natural beauty at first hand), or they can be **indirect** (e.g. through experiencing the consequential benefits of supporting services in maintaining or enhancing the area's habitats and wildlife).

Benefits to wildlife and to the quality and diversity of the natural environment itself are directly related to the geological and geomorphological assets, but in many cases, they depend on people to ensure that those assets, and the ecosystem services that are derived from them, are adequately maintained or (where possible) enhanced, through conservation initiatives. That responsibility falls partly on the AONB's Management Team, but ultimately rests on local planning authorities, conservation bodies, farmers, land-owners, visitors and tourist boards.

Overall, it is clear that **geodiversity is a key natural capital asset within the AONB** and that many public benefits (ecosystem services) flow directly or indirectly from it. It is therefore essential that the geodiversity itself is protected and enhanced, so as to optimise these benefits for future generations.

Recommendations with regard to future management are set out in the following chapter.

## Table 4.1: Arnside and Silverdale AONB: Geological Ecosystems Services Assessment Matrix (page 1 of 5)

| | **Ecosystems Services Assessment** | | | |
|---|---|---|---|---|
| **Natural Capital – the Geological Assets, by Name and Type**<br><br>*(and main beneficiaries)* | **Provisioning Services**<br>**Natural products** such as food, fresh water, wood, fibre, fuel and minerals.<br>contributes to the built environment, industrial heritage, local economy and landscape character. | **Supporting Services**<br>**Natural Processes** that are necessary for the production of all other ecosystem services**.**<br>includes soil formation and geological and geomorphological processes. | **Regulating Services**<br>**Material benefits** obtained from harnessing geomorphological, climate and ecological processes. Includes climate, flood, and disease regulation, water purification, re-establishment of diverse ecosystems. | **Cultural Services**<br>**Non-material benefits** to people<br>The aesthetic, educational, recreational and spiritual benefits, including 'sense of place' 'sense of history' and other qualities within the landscape that are appreciated. |
| **Furnace Waste from the Carnforth Ironworks**<br>- Slag (calcium silicate)<br>*(Benefits to lifelong learners and undergraduate geology students)* | Potential for re-use as a **secondary aggregate** in local major road construction (has previously been used for this purpose, but not currently) | No supporting services identified. | No regulating services identified. | **Educational**: The slag deposits show a number of cooling features that are also observed within extrusive volcanic lava flows, some of which are not seen naturally within the UK.<br>**Sense of History**: The waste tips provide a direct record of historical industrial heritage from the 18th to early 20th Centuries |
| **Intertidal Flat Deposits** – Sand and Mud<br>*(Benefits to local communities, future generations, habitats & species)* | Historically the intertidal flats formed a **natural byway** into Cumbria.<br>The intertidal flats support a vast number of marine invertebrates and **commercial cockle picking and mussel harvesting** is permitted when stocks allow. | Shoreline management plan policies highlight the importance of **natural coastal geomorphological processes** in maintaining the condition of designated sites and supporting associated wildlife. These natural processes are the **basis for the wealth of biodiversity** for which Morecambe Bay is designated a SSSI, SAC, SPA and Ramsar site<br>The shoreline management plan also seeks to balance the **conservation of the natural cliff types**, including some of geological importance, with the maintenance and protection of property, avoiding artificial structures where possible and maintaining natural processes where possible.<br>**The relative sensitivity of coastal saltmarsh habitat to climate change is high**, although the scope for natural adaptation is also high, provided that sufficient space is kept available and that natural processes are not constrained by inappropriate management or built development. | Within the shoreline management plan, policies of no active intervention have been proposed to **enhance and create areas of wetland habitat** within or adjacent to designated conservation sites.<br>Coastal saltmarsh provides a natural **buffer against flooding and coastal erosion**. However, its attrition and accretion vary greatly and the AONB coastline has lost much saltmarsh in recent years, simply as a consequence of natural sediment dynamics in the estuary; for the estuary as a whole there has probably been a balance of erosion and attrition.<br>Both the coastal saltmarsh and intertidal flat deposits are **carbon sinks**, thereby contributing to **climate regulation**. | **Recreational**: Morecambe Bay Walks with the Queen's Guide and canoeing on the Arnside tidal bore.<br>**Aesthetic and Spiritual**: The constantly changing light over the open and wide expanse of the intertidal flats gives a good sense of tranquillity and wellbeing. |
| **Saltmarsh Deposits** – Clay, Silt, Sand and Peat<br>**Shingle Beaches** – Gravel and Cobbles<br>*(Benefits to local communities, future generations, habitats & species)* | The coastal saltmarsh provides **natural grazing land** for sheep and is of a suitable quality to be used as **sodding turf** in bowling greens. | | | **Educational**: Observation of the shifting channel patterns within the estuary; the deepening of channels in one area and the silting up and associated growth of saltmarsh vegetation in others; and the development of dendritic drainage patterns within new mudflat areas all provide good opportunities for small-scale study of fluvial and estuarine geomorphological processes.<br>**Sense of History**: changes in coastline positions on successive Ordnance Survey maps provide a record of landscape change over the last two or more centuries. |

**Table 4.1: Arnside and Silverdale AONB: Geological Ecosystems Services Assessment Matrix** (page 2 of 5)

| **Natural Capital – the Geological Assets, by Name and Type**<br><br>*(and main beneficiaries)* | **Ecosystems Services Assessment** | | | |
|---|---|---|---|---|
| | **Provisioning Services**<br>**Natural products** such as food, fresh water, wood, fibre, fuel and minerals.<br>contributes to the built environment, industrial heritage, local economy and landscape character. | **Supporting Services**<br>**Natural Processes** that are necessary for the production of all other ecosystem services**.**<br>includes soil formation and geological and geomorphological processes. | **Regulating Services**<br>**Material benefits** obtained from harnessing geomorphological, climate and ecological processes. Includes climate, flood, and disease regulation, water purification, re-establishment of diverse ecosystems. | **Cultural Services**<br>**Non-material benefits** to people<br>The aesthetic, educational, recreational and spiritual benefits, including 'sense of place' 'sense of history' and other qualities within the landscape that are appreciated. |
| **Peat**<br>*(Benefits to local communities – historically and current, future generations, visitors, habitats & species)* | The peat was used historically as a **domestic and industrial fuel** and might also have been harvested for use as a horticultural **soil conditioner**, as it still is in other parts of Cumbria, though none of these operations now take place within the AONB. | The peat was drained and used as fertile agricultural land, **supporting the provision of food**. The current habitats of lowland fen, reedbed, wet woodland and purple moor grass and rush pastures **support a rich biodiversity**.<br>At a National level, the relative sensitivity of lowland fen to climate change is high, whilst that for reedbed, wet woodland and purple moor grass and rush pastures habitat is medium. | Creation of water environment conditions to re-establish ombrotrophic bog would boost **carbon sequestration** and contribute to **habitat recreation**. The national relative sensitivity of Lowland Raised Bog to climate change is medium and therefore would potentially also be more resilient than the areas of lowland fen currently supported. | **Educational** and **Sense of History**: the peat provides a sensitive palaeo-environmental record of the recent geological past, overlapping with human occupation, although much of the original peat has been lost.<br>**Recreational**: Leighton Moss Nature Reserve, now reedbed habitat, has significant ornithological interest and receives many visitors each year. |
| **Raised Marine Deposits -** Clay, Silt and Sand<br>*(Benefits to local communities, future generations, habitats & species)* | No provisioning services identified. | Raised marine sediments provided a low permeability seal over limestone bedrock which supported the development of peat, including former areas of **lowland raised peat bog**. Such areas are now occupied by other priority habitats including lowland fen, reedbed and coastal & floodplain grazing marsh which, at a national level, has a medium sensitivity to climate change. | The areas of raised marine deposits help in **regulating coastal flooding** by infilling previously lower and more vulnerable ground. | **Educational**: The raised marine deposits provide evidence for geologically recent former sea levels. |
| **Lacustrine Deposits -** Clay, Silt and Sand and shelly marl.<br>*(Benefits to academic researchers, habitats & species)* | Marl can have value as a naturally occurring **agricultural lime** but has not been utilised for this purpose within the AONB – not least because of the predominance of limestone bedrock and the relatively limited extent of acidic soil types. | Lacustrine deposits within low-lying hollows have supported the accumulation of marl deposits and/or peat, including former areas of **lowland raised peat bog**.<br>In these and other areas, the deposits have also supported other priority habitats including coastal & floodplain grazing marsh which, at a national level, has a medium sensitivity to climate change. | No regulating services identified. | **Educational** and **Sense of History**: the lacustrine carbonate deposits (shelly marl) provide a sensitive palaeo-environmental record of the recent geological past, which has overlapped with human history.<br>**Recreational:** the areas are enjoyed for walking and provide wellbeing. |
| **Loess -** Wind Blown Sand<br>*(Benefits primarily to academics)* | No provisioning services identified. | Loess greatly **improves soil quality** for agricultural use. However, occurrences within the AONB are generally thin and patchy, so do not lend themselves to supporting particular Soilscape categories. | No regulating services identified. | **Educational**: The loess provides opportunities for dating events in the Quaternary Period (using Optically-Stimulated Luminescence). |
| **Talus -** Scree material<br>*(Benefits to local communities & visitors)* | Scree gravel has been used historically in **local minor road construction**, but the practice has long been discontinued. | The talus on Arnside Knott supports a number of priority habitats particularly inland rock outcrop / scree and upland mixed ash woodland which have a low or medium sensitivity to climate change. | No regulating services identified. | **Aesthetic Landscape**: The scree slopes on Arnside Knott provide a distinctive localised landscape interest feature. |

**Table 4.1: Arnside and Silverdale AONB: Geological Ecosystems Services Assessment Matrix** (page 3 of 5)

| **Natural Capital – the Geological Assets, by Name and Type**<br><br>*(and main beneficiaries)* | **Ecosystems Services Assessment**<br><br>**Provisioning Services**<br>**Natural products** such as food, fresh water, wood, fibre, fuel and minerals.<br>contributes to the built environment, industrial heritage, local economy and landscape character. | **Supporting Services**<br>**Natural Processes** that are necessary for the production of all other ecosystem services**.**<br>includes soil formation and geological and geomorphological processes. | **Regulating Services**<br>**Material benefits** obtained from harnessing geomorphological, climate and ecological processes. Includes climate, flood, and disease regulation, water purification, re-establishment of diverse ecosystems. | **Cultural Services**<br>**Non-material benefits** to people<br>The aesthetic, educational, recreational and spiritual benefits, including 'sense of place' 'sense of history' and other qualities within the landscape that are appreciated. |
|---|---|---|---|---|
| **Glaciofluvial Deposits**<br>- Sand and Gravel, locally with lenses of silt, clay and organic material<br>*(Benefits to minerals industry and customers)* | The glaciofluvial deposits have been worked for use as **a construction aggregate** just outside the AONB, to the north of Carnforth. Whilst the same potential exists for the more limited extent of such deposits within the AONB, it is unlikely that any future need for this would outweigh the statutory protection afforded to the AONB landscape. | Glaciofluvial deposits support the process of **soil formation**, enabling the development of deeper, freely draining slightly acid loamy soils that are more suited to agriculture than the thinner calcareous soils developed over limestone. | No regulating services identified. | **Aesthetic Landscape**: the subtle landforms (kames, kettle holes and eskers) provide localised landscape interest features, though generally not within the AONB.<br>**Educational**: Glaciofluvial deposits provide evidence for past glacial environments. |
| **Erratics** - Varying lithologies derived from outcrops to the north<br>*(Benefits to academics and lifelong learners)* | Some erratics have been used as a natural **building resource** within **local dry-stone walls**. | The erratics support the colonisation of different and more abundant **lichen species** than does the limestone. | No regulating services identified. | **Educational**: Erratics provide a wider range of rock types than can otherwise be seen within the AONB and, more especially, provide a means of demonstrating the directions of movement of former glaciers. |
| **Glacial Till** – mixtures of sandy, silty clay with pebbles and boulders of varying lithologies.<br>*(Benefits to local farming communities & their customers, and to habitats & species)* | Primarily used as pastoral farmland, therefore **contributing to food production**. | By creating a low-permeability seal over limestone bedrock, glacial till has, in some areas, supported the formation of lakes which, in turn, have enabled the accumulation of marl deposits and/or peat, including former areas of **lowland raised bog**.<br>More generally, glacial till supports the process of **soil formation**, enabling the development of deeper, freely draining slightly acid loamy soils. | No regulating services identified. | **Aesthetic Landscape**: the Drumlin hills are greatly appreciated for their natural beauty.<br>**Educational**: The glacial till provides evidence for past glacial environments and the drumlins, in particular, demonstrate the directions of former ice flow. |
| **Mineralisation** – particularly iron & copper minerals<br>*(Benefits, historically, to local communities & entrepreneurs, and now to academics and lifelong learners)* | Mining in the AONB was not extensive and was mostly commercially unsuccessful. Nevertheless, both **iron** and **copper** were worked, with the soft ochreous haematite being used as a **pigment in paint** and iron ore within the iron smelting works at Leighton Furnace being the main uses. | The weathered minerals contribute to **soil formation** together with the limestone. However, no niche habitats over particularly mineral-rich soil or spoil heaps appear evident within the AONB. | No regulating services identified. | **Geotourism:** The **mineral interest** could be better **promoted** as an educational and recreational use of the geodiversity that would appeal to all lifelong learners.<br>**Sense of History**: the mining legacy, though not evident to any great extent in the modern landscape, is nevertheless important and could be better-promoted |

**Table 4.1: Arnside and Silverdale AONB: Geological Ecosystems Services Assessment Matrix** (page 4 of 5)

| **Natural Capital – the Geological Assets, by Name and Type**<br><br>*(and main beneficiaries)* | **Ecosystems Services Assessment** | | | |
|---|---|---|---|---|
| | **Provisioning Services**<br>**Natural products** such as food, fresh water, wood, fibre, fuel and minerals.<br>contributes to the built environment, industrial heritage, local economy and landscape character. | **Supporting Services**<br>**Natural Processes** that are necessary for the production of all other ecosystem services**.**<br>includes soil formation and geological and geomorphological processes. | **Regulating Services**<br>**Material benefits** obtained from harnessing geomorphological, climate and ecological processes. Includes climate, flood, and disease regulation, water purification, re-establishment of diverse ecosystems. | **Cultural Services**<br>**Non-material benefits** to people<br>The aesthetic, educational, recreational and spiritual benefits, including 'sense of place' 'sense of history' and other qualities within the landscape that are appreciated. |
| **Urswick Limestone Formation including the Woodbine Shale**<br>Thickly bedded limestone with palaeokarst surfaces, macrofossils and a thick layer of shale (the Woodbine Shale) within the lower half of the sequence.<br>*(Benefits to habitats & species, to local communities, visitors, academics and lifelong learners, and historically to the minerals industry and its customers)* | Historically worked at Trowbarrow for tar-bound road surfacing and flooring products, in particular '**Quarrite**' – a bespoke variety of tarmacadam which was in demand nationally and had an international reputation.<br>Urswick Limestone from the uppermost benches at Sandside Quarry, as well as Trowbarrow, also supplied **building stone** and **industrial lime**. Locally, the limestone was burnt to make a **lime powder** for use in agricultural land improvement and within building mortar. Limestone was extracted at Jenny Brown's point for use in **local construction** of the quay.<br>Prior to their protection by Limestone Pavement Orders, several areas of limestone pavement provided decorative **water-worn limestone** used in gardens, water features and walls. These are still in evidence locally, as are the areas of permanently damaged pavement.<br>In terms of **groundwater storage and supply**, the Urswick Limestone is classed only as a moderately productive aquifer and is rarely utilised. Abstraction is currently licenced for private water supply at the Fell End Caravan Site, near Hale, and for agricultural use (only) at the Lakeland Wildlife Oasis, Hale.<br>The more impermeable nature of the Woodbine Shale assists the development of **springs** along its length which were formerly used a natural water supply during the development of Silverdale. Elsewhere, the trough or linear slack formed by erosion of the Woodbine Shale is locally utilised as a **natural byway**.<br>Historically, the Urswick Limestone hills provided good locations for the development of **hill forts**, such as the one on Warton Crag. | The Urswick Limestone supports **calcareous soil formation**, which in turn supports predominantly the development of lowland calcareous grassland, deciduous woodland and upland mixed ash woodland priority habitats. At a National level, the relative sensitivity of these habitats to climate change is low.<br>**Limestone pavements**, developed preferentially on the Urswick Limestone, directly support many areas of limestone pavement priority habitat.<br>Many of these areas within the AONB are protected by National and (in some cases) international designations, including SSSIs, SACs and Limestone Pavement Orders. The designated sites are generally in good condition | The natural permeability of limestone helps to reduce surface runoff and thereby assists greatly in **regulating flooding** (by comparison with areas underlain by less permeable strata).<br>Although the limestone in this area is not seen as a major aquifer, and is no longer utilised as an important source of drinking water, natural infiltration of rainwater through the limestone enhances the quality of surrounding watercourses and water bodies including the estuary, for the benefit of wildlife in general.<br>The thin or absent soils on limestone pavements do not provide a carbon sink, but the calcareous grassland and deciduous woodlands do. | **Aesthetic Landscape**: The limestone hills and pavements are much appreciated for their **natural beauty**.<br>**Sense of History**: historic buildings and drystone walls, constructed from local limestone, contribute to the area's **built heritage**<br>**Geotourism**: The **fossil interest** could be better **promoted** for its educational and recreational benefits that would appeal to lifelong learners of all ages.<br>The **Fairy Steps** location has been a well-known beauty spot since Victorian times.<br>The steadily growing series of **Geotrail booklets** promote interest in the geodiversity, history and ecology of several areas of Urswick Limestone and, just as importantly, the comparisons and contrasts between these and other outcrops.<br>**Recreational**: More generally, there is a good public rights of way network across the landscape shaped by the Urswick Limestone Formation providing the opportunity for cost-free days out with associated health benefits and a sense of wellbeing.<br>Certain outcrops - particularly at Trowbarrow LNR, the upper crags at Warton Crag LNR, on the coast at Jack Scout and around the Fairy Steps – provide a very good variety of all levels of **recreational climbing** routes. |

**Table 4.1: Arnside and Silverdale AONB: Geological Ecosystems Services Assessment Matrix** (page 5 of 5)

| **Natural Capital – the Geological Assets, by Name and Type**<br><br>*(and main beneficiaries)* | **Ecosystems Services Assessment** | | | |
|---|---|---|---|---|
| | **Provisioning Services**<br>**Natural products** such as food, fresh water, wood, fibre, fuel and minerals.<br>contributes to the built environment, industrial heritage, local economy and landscape character. | **Supporting Services**<br>**Natural Processes** that are necessary for the production of all other ecosystem services<br>includes soil formation and geological and geomorphological processes | **Regulating Services**<br>**Material benefits** obtained from harnessing geomorphological, climate and ecological processes. Includes climate, flood, and disease regulation, water purification, re-establishment of diverse ecosystems | **Cultural Services**<br>**Non-material benefits** to people<br>The aesthetic, educational, recreational and spiritual benefits, including 'sense of place' 'sense of history' and other qualities within the landscape that are appreciated. |
| **Park Limestone Formation**<br>Poorly bedded, more consistent limestone with fossil fragments<br>*(Benefits to habitats & species, to local communities, visitors, academics and lifelong learners, and to the minerals industry and its customers)* | The consistent nature of the Park Limestone Formation makes it the easiest limestone to extract commercially within the AONB. It was previously quarried at Warton Crag and Middlebarrow and is currently quarried at Sandside for use as a **construction aggregate**.<br>In terms of **groundwater storage and supply**, the Park Limestone is classed only as a moderately productive aquifer and is no longer utilised as drinking water or for agriculture. Abstraction is currently licenced at only one location, for the purposes of dust suppression and mineral washing (only) at Sandside Quarry. | The Park Limestone supports **calcareous soil formation**, which in turn supports in particular the development of lowland calcareous grassland, upland mixed ash woodland and deciduous woodland priority habitats. At a National level, the relative sensitivity of these habitats to climate change is low.<br>**Limestone pavements**, though primarily developed on the Urswick Limestone, are also found in some parts of the Park Limestone outcrop. Many of these areas are protected by National and (in some cases) international designations, including SSSIs, SACs and Limestone Pavement Orders. Locally, some of them support small areas of limestone pavement priority habitat. The designated sites are generally in good condition.<br>The process of quarrying – albeit man-made rather than natural – is intrinsically associated with the limestone and creates **habitats for nesting birds**, such as raven, jackdaws and peregrine falcons. | The natural permeability of limestone helps to reduce surface runoff and thereby assists greatly in **regulating flooding** (by comparison with areas underlain by less permeable strata). Although the limestone in this area is not seen as a major aquifer, natural infiltration also enhances the quality of surrounding watercourses and water bodies including the estuary.<br>The thin or absent soils on limestone pavements do not provide a carbon sink, but the calcareous grassland and deciduous woodlands do. | **Aesthetic Landscape**: The views from the summit of Arnside Knott are much appreciated for their **natural beauty**.<br>**Geotourism**: The Arnside Geotrail booklet, in particular, promotes interest in the geodiversity, history and ecology of this outcrop of Park Limestone as well as the comparisons and contrasts between this and the Dalton Formation.<br>**Recreational:** Some recreational climbing used to take place within Middlebarrow Quarry and still does within Warton Crag Quarry, though these locations are far less suitable than routes on Urswick Limestone outcrops in terms of both quality and stability |
| **Dalton Formation**<br>Alternating beds of shale and limestone with macrofossils and dolomitisation near the top of the sequence<br>*(Benefits to habitats & species, to local communities, visitors, academics and lifelong learners, and historically to the minerals industry and its customers)* | The Dalton Formation has been quarried in the past for use in **local construction** of quays and as a **flux** within the Carnforth Ironworks.<br>In terms of groundwater storage and supply, the Dalton Limestone is classed only as a moderately productive aquifer and is no longer utilised at all within the AONB. | The Dalton Limestone supports **calcareous soil formation**, which in turn supports the development, in particular of deciduous woodland and upland mixed ash woodland priority habitats in several areas. At a National level, the relative sensitivity of these habitats to climate change is low. One such area, inland from Blackstone Point, forms part of an SSSI designation.<br>**Limestone pavements** are not widely developed on the Dalton Formation outcrop within the AONB, but a small area to the north of Warton village is protected by a Limestone Pavement Order. | The natural permeability of limestone helps to reduce surface runoff and thereby assists greatly in **regulating flooding** (by comparison with areas underlain by less permeable strata). Natural infiltration also enhances the quality of surrounding watercourses and water bodies including the estuary.<br>The thin or absent soils on limestone pavements do not provide a carbon sink, but the deciduous woodlands do. | **Geotourism**: The Arnside Geotrail booklet, in particular, promotes interest in the geodiversity, history and ecology of this outcrop and explains the contrasts between this and the overlying Park Formation.<br>**Sense of History**: historic buildings and drystone walls, constructed from local limestone, contribute to the area's **built heritage**<br>The **fossil interest**, particularly along the Arnside shoreline to Blackstone Point, could be better **promoted** for its educational and recreational benefits that would appeal to lifelong learners of all ages. |

# 5. Guidelines for Conserving and Managing Geodiversity

*Suggested Guidelines for the conservation of the AONB's geodiversity, as set out in this chapter, take into consideration the geodiversity audit completed in developing the framework and the ecosystems services assessment. The recommendations are set out within the six guiding themes of the UK Geodiversity Action Plan (GAP), thereby providing a first consideration of some of the steps that have already been taken and those that could be completed in developing a GAP for the AONB.*

Each of the following sections provides a statement of current understanding and progress, followed by our recommendations under six headings which connect with the six themes within the UK GAP[43]. These are:

Theme 1. **Increase Understanding of the AONB's Geodiversity**;

Theme 2. **Influence Planning Policy, Legislation and Development Design**;

Theme 3. **Gather and Maintain Information on the AONB's Geodiversity**;

Theme 4. **Conserve and Manage the AONB's Geodiversity**;

Theme 5. **Promote and Care for the AONB's Geodiversity**; and,

Theme 6. **Sustain Activities within the AONB**.

In addition, Table 5.1 provides more detail on suggested initiatives that would further understanding or aid the promotion of geodiversity at specific sites and places. These include each of the sites within the AONB which are designated for their geodiversity interest, as well as a number of additional sites which provide opportunities for further promotion and enhancement.

## *Theme 1: Increase Understanding of the AONB's Geodiversity*

***To foster pure and applied geoscience research, to better understand the AONB's geodiversity and its role in understanding and managing our natural environment.***

Relatively little work on the geology of the Arnside – Silverdale area was published during the 20th Century, although this included the classic work of Garwood (1912) on the Carboniferous succession, and Oldfield (1960) on the Quaternary. More recently, however, there has been a renewed scientific interest in both, together with updated and more detailed geological mapping and the introduction of new, explanatory literature aimed at promoting the geodiversity of the area to both local people and visitors.

The Carboniferous Limestone succession including recognition of the 'fossil fauna of Arnside' was established more than 100 years ago by Garwood (1912) and the stratigraphical

[43] The UKGAP provides an agreed framework for geodiversity action across the UK and can be found at: http://www.ukgap.org.uk/

nomenclature is that first used by Rose and Dunham (1977) although their work concentrated on the haematite deposits of the Cartmel peninsula. There were regional references in Moseley (1972, 1978) but it wasn't until PhD research towards the end of the 20th Century - by Horbury (1987) on the Urswick Limestone Formation and Aziz (1989) on the Dalton Formation and Park Limestone Formation – that more recent understanding of the limestone sedimentation was developed. Useful summaries were developed by Adams, Horbury and Abdel Aziz (1990) and by Cossey *et al* (2004) in the Geological Conservation Review.

Detailed mapping of recently re-exposed coastal sections was completed by Balderstone and Dewey (2003) and the structural geology of the area, including topographical evidence for the erosion of the Woodbine Shale, has been much considered by Patrick (2010, unpublished). The recently published British Geological Survey 50k Digital Dataset v8 (2017) includes new mapping for Sheet 049 Kirkby Lonsdale which covers the AONB area. Printed copies of this map are not yet available, but the digital linework and pdf copies of the larger scale (1:10,000) 'Approval Proofs' can be purchased from the BGS and have been utilised in the preparation of this report. The four Carboniferous Limestone formations within the area (Dalton, Park, Urswick and Alston), along with the Woodbine Shale within the Urswick Formation are - for the first time - discretely mapped. This represents a very substantial improvement on previously published editions of the geological map, although the latest BGS interpretations (of structural features, in particular) sometimes differ from those of local experts.

Succinct but well-researched and considered overviews of the geological evolution of the area are provided by Gale (2000) and Moseley (2010), though again these interpretations do not always agree with local views and there is certainly scope for further research to improve and refine scientific understanding.

Such refinement has been clearly demonstrated in the ongoing research and publications relating to the Quaternary succession at Hawes Water, where multiple lines of evidence and new dating techniques have been brought together to refine the pioneering work of Frank Oldfield in the 1960s (Marshall et al 2002; Jones et al, 2004, 2011).

Dr Ada Pringle, University of Lancaster has been monitoring the erosion and growth of saltmarsh within the AONB and at Grange for the last four decades and other current work includes that by Dr Mark Hounslow from the University of Lancaster and colleagues from the University of Liverpool to determine a geomagnetic polarity for the geological record provided by the Dalton Formation, Park Limestone Formation and the Urswick Limestone Formation (together with limestone formations of an earlier and later age) as well as radiometric dates from volcanic ashes (the bentonite clays) to gain additional evidence for their ages of formation.

An important strand of recent work has been the publication of a series of 'Geotrail' guides by local landscape geographer, Peter Standing. These are aimed, not at pushing forward the boundaries of scientific discovery, but at encouraging non-specialists (including local people and visitors) to become interested in local geological features and the links between these, local history, ecology and landscape. Further details are given under Theme 5, below.

Theme 1 Recommendations

- The AONB would benefit from making and maintaining greater links with local universities, particularly the authors identified at (or retired from) the School of Earth and Environment at the University of Leeds, the School of Earth and Environmental Sciences at the University of Manchester, the University of Lancaster Environment Centre and the School of Earth, Ocean and Ecological Sciences at the University of Liverpool.

- There may be interest from local structural geologists in providing field checks to the recently issued BGS mapping (v8), particularly the evidence for and location of the Woodbine Shale and the linear features: faults, breaks in slope and their origin, and the axes of anticlines and synclines. This would perhaps be most usefully managed as a partnership project between the AONB and BGS.

- Other suggestions for research are given for individual sites in Table 5.1 below and include: research involving dating sediments and cave formations (speleothems) at Hale Moss Caves to better understand their formation; research on the role of faults in developing dolines and of the possible role of the Woodbine Shale in the development of poljes; and detailed research and field mapping to aid in understanding the potential complexities of the Silverdale Disturbance.

- The AONB, particularly due to the mosaic of habitats within a small area, also provides good opportunities for more applied research including exploring in more quantitative detail the role of geology and ongoing geomorphological process in contributing to ecosystem services, the resilience of landscapes and potential for habitat adaption.

## *Theme 2: Influence Planning Policy, Legislation and Development Design*

***Recognition in policy, relevance to sustainable development and advocate design that enhances geodiversity***

There is good recognition of geodiversity within the Arnside & Silverdale AONB Development Plan Document. Policy AS04 states: '*The high quality of the natural environment is a key feature of the AONB. New development will conserve and enhance the AONB's biodiversity and geodiversity, avoid the fragmentation and isolation of or disturbance to wildlife, habitats and species....*'

Generally, however, it is the links between the limestones and biodiversity that are more widely-recognised in strategic and policy documents rather than the role of the more recent Quaternary deposits and ongoing geomorphological processes. However, the NCA Profile has four Strategic Environmental Statements of Opportunity which between them cover the greater breadth of the AONB's geology. These statements relate to limestone habitats, the coastal zone, the wetland landscape and the wider landscape. Each statement whilst focussing on habitats and landscape makes a direct connection to the underlying geodiversity and the need to conserve, promote, enhance or restore this geodiversity as demonstrated by the excerpts below and the further detail provided in the document:

- From SE01: 'Protect and enhance the extensive mosaic of **high-quality limestone habitats**…to… maintain the strong relationship between the **landscape** and its **underlying geology**'
- From SE02: 'Ensure the long-term **sustainable management of the nationally and internationally designated coastal zone** by conserving and managing its habitats, including the **extensive sand flats, salt marshes, estuarine landscapes and limestone cliffs**…….'
- From SE03: 'Ensure the long-term **sustainable management of the nationally and internationally designated wetland landscape** ….by **conserving and restoring the lowland raised bogs** …'
- From SE04: '**Conserve and enhance the wider landscape** of the NCA as the supporting framework to its distinctive attributes, **including features of the drumlin landscape**….'

Theme 2 Recommendations

- **Recognition in Policy and Sustainable Development**: The NCA statements of opportunity, together with the information provided in the geological story, geological framework and ecosystems services assessment can be used within revisions of statutory and strategic documents to provide greater detail on the links between all aspects of the geodiversity and soils, habitats, landscape and built environment across the AONB.

- **Advocate Design that enhances Geodiversity**: There is an opportunity to include geodiversity interpretation boards at various sites across the AONB.

## *Theme 3: Gather and Maintain Information on the AONB's Geodiversity*

***To audit and document the geodiversity of the AONB, including sites, archives and collections***

The commissioned work which led to the production of this report included an audit of geological sites within the AONB, supported by an archive of digital photographs and GIS maps. The site audit forms are presented in Appendix A and the full photographic and GIS archives are held by the AONB office in Arnside.

Theme 3 Recommendations

- This report should be made publicly accessible via the AONB Website.

- The Geological Story, based on Chapter 2 of this report, should be published more widely as a freestanding, downloadable pdf document, and should be strongly promoted through links from other parts of the AONB and Natural England Websites. It would also be worth publishing in hard copy as a colour-printed A4 booklet, to be sold via information hubs, such as tourist information centres, the suggested 'geo-hub' at Arnside (see Theme 5, below) and the existing RSPB visitor centre at Leighton Moss. A slightly abbreviated version of 'The Story', written in plain English, has been provided by the authors for this purpose.

- Digital mapping, compiled as part of this project, could be developed into a publicly-accessible interactive GIS with limited functionality (such that the layers can be seen but not exported or modified). This would be an online resource, similar to the BGS 'Geology of Britain' viewer.

- An archive of digital photographs, including those produced as part of this study and those collated from earlier publications, could be made available to the public (subject to Copyright permissions) via the AONB Website. This would require the scanning of older photographs and the necessary software to be developed for viewing and downloading photographs. If possible, this could be made accessible via hyperlinks within the interactive GIS, but should also be accessible directly, as simple digital albums.

- Linkages between geodiversity, biodiversity and landscape, as identified in Chapter 3 of this report, and links with ecosystem services, as identified in Chapter 4, should be reinforced in revised documentation for each of the various non-geological designations within the area.

- A catalogued library of specific targeted research completed within the AONB, as identified in this report could usefully be kept, including both published and (with permission from the authors) unpublished material.

- An online and updated catalogue of the relevant documents relating to each geodiversity site should also be maintained. This could include the maps, photographs and site reports compiled as part of this project.

- It would be beneficial to have a record of Dr Ada Pringle's detailed survey work on the attrition and accretion of the saltmarsh, both for general interest in active geomorphological processes, but more importantly to assist in developing appropriate local plan and shoreline management plan policies and the coastal footpath.

- A collection of previously-collected fossil finds across the AONB could usefully be put together as part of a local 'geo hub' within Arnside (see Theme 5, below).

## *Theme 4: Conserve and Manage the AONB's Geodiversity*

***To conserve through sites and areas, to maintain and enhance through management and to share good practice***

**The AONB is already a highly designated area**. The sites designated primarily or jointly for their geological interest, including both SSSIs and LGSs, along with a number of other locations of geological interest, were visited as part of the fieldwork audit carried out at the beginning of this study. In each case, a site assessment form was used to record the Earth Science Conservation Classification of the site, key features of interest and the condition of these features, together with brief information on the identified usage of the site, access and land ownership, accessibility, health and safety, potential threats (including risks and vulnerabilities) and opportunities for education, enhancement and links to other sites. The site assessment forms are presented in Appendix A.

The fieldwork and evidence from the site condition forms demonstrate that, generally, the sites recognised for their geodiversity importance are in **favourable condition**. The main conservation issue is the need for carefully planned vegetation clearance at a number of exposure sites, including parts of Trowbarrow Quarry SSSI, the small quarry within the Arnside Foreshore LGS and possibly the natural outcrop of Whin Scar within which Fairy Steps is situated.

In this regard, careful consideration must also be given to biodiversity, ensuring that this is not harmed in the interests of improving access to the geology. In many cases, particularly but not only on the limestone pavements, the geodiversity and biodiversity interests go hand-in-hand, and the latter may be of equal if not greater importance. For this reason, further advice should be sought as appropriate before any vegetation clearance is undertaken within the limestone pavements and other designated sites. For SAC and SSSI designations, clearance of vegetation would be a 'notifiable operation' in law. Species which are causing both geologists and botanists concern, such as Cotoneaster spp. and red valerian (Centranthus ruber) at several limestone pavements and disused quarries should be specified. For example, there has recently been a supervised programme of cotoneaster removal from, among other locations, Sandside Railway Cutting and National Trust land holdings.

The other key issue was found to be that of **access**. Limited or no public access to certain sites restricts opportunities for enhancement, interpretation and promotion.

The greater need, however, is for the **interpretation** and **promotion** of the sites which are accessible and for **sharing good practice**, including making the links to the geodiversity within sites designated for their biodiversity. For example, along the coast, the deepening of channels in one area and the silting up and associated growth of saltmarsh vegetation in others, together with the dendritic pattern of channels provide good opportunities for small scale study of fluvial and coastal geomorphological processes. In addition, at several of the biological sites – particularly at Warton Crag SSSI and Thrang End and Yealand Hall Allotment SSSI – differences in geology and soils underpin the mosaics of habitats. These are all interactions which are worthy of being highlighted to a greater extent than they are at present.

Some other aspects of the geodiversity, such as the ongoing geomorphological processes within the estuary and bays, and features associated with the limestone pavements, are protected only indirectly, through the designation of those sites for their biodiversity interest.

## Theme 4 Recommendations

- There is a good network of geological sites, particularly regarding limestone outcrops and limestone geomorphological features. **More attention** could be given to **Quaternary geomorphological landforms**: drumlins, kames, kettle holes and eskers (although, with the exception of drumlins, these lie just outside the AONB boundary) and **ongoing coastal processes**.

- We do suggest two discrete LGSs for Sandside Cutting and Throughs Lane and **one LGS that encompasses the whole of the coastline from Arnside to Brown's Cottages**. The reasoning for these suggestions is discussed in Theme 5 below and in Table 5.1.

- Most importantly, we suggest that a **Local Geodiversity Action Plan** (LGAP) **should be developed and used to provide a framework for the conservation and enhancement of the AONB's geodiversity**. The LGAP process[44] can identify in a detailed way, and within a specified timescale, the actions that are required to manage and enhance the geodiversity at sites and places (including those designated for their biodiversity as well as those designated for their geodiversity), together with the people and funding that may be required to enable this to happen. The site assessment forms in Appendix A, together with the information summarised in Table 5.1, provide starting points for developing the more detailed action planning process that is needed.

## *Theme 5: Promote and Care for the AONB's Geodiversity*

***Make relevant to the wider world, use the arts to involve people and create resources to help integrate geodiversity into learning***

There is great **wealth of local interest** and **expertise**, both professional and amateur, within the AONB, and the Westmorland Geological Society is very active in promoting interest in local features, as well as contributing significantly to scientific understanding of the area. The Landscape Trust also provides an annual programme of events and a number of excellent geotrails have been produced by Peter Standing. Both the Arnside & Silverdale AONB Landscape Trust events and the geotrails make the links between geodiversity, biodiversity, landscape, history and the arts. To date, Peter has produced geotrails for:

- 'Storth',
- 'Gait Barrows to Trowbarrow',
- 'Beetham and Hale' and
- 'Arnside'

He also has plans to develop further trails for: 'The Yealands', 'Warton and the Keer' and 'Silverdale'.

There remains considerable scope to develop geo-diversity-related activities and resources that engage with visitors, families and school groups.

### Theme 5 Recommendations

Table 5.1, below, provides more detail on our specific recommendations for various sites and places within the AONB.

- In particular, we would recommend a single, revised LGS for the whole of the Coastline from Arnside round to the chimney at Brown's Cottages (encompassing the existing LGSs at Arnside Foreshore, Blackstone Point, Far Arnside, and the Silverdale Shore, as well as intervening areas). A great range of geodiversity is exposed along the whole of this coast, including geomorphological features of the cliffs, beaches, saltmarshes and

[44] Burek, C. & Potter, J. 2006. Local Geodiversity Action Plans - Setting the context for geological conservation. English Nature Research Reports, No 560

adjacent sandbanks and channels, as well as the rocks themselves. All of these aspects should be identified within the LGS citation.

- A GeoCaching GeoTour (see Table 5.1) could provide a way to promote the geological story of the AONB.

- Additionally, a 'Geo hub' could be created at Arnside, supported by trained volunteers in the busy months of the year to enthuse families, in particular, in observing and photographing (but not collecting) fossils and in learning more generally about the geodiversity of the AONB.

- Where Arnside and Silverdale is promoted as an area to find fossils it would be beneficial to work with partner organisations to accurately promote this interest, emphasising the benefits of observing and photographing, rather than collecting, fossil specimens.

- Trowbarrow, Gait Barrows and Warton Crag, which are already managed as local or national nature reserves and have outstanding geodiversity interest, would benefit from site-specific interpretation, including at Gait Barrows and Trowbarrow, the development of educational material suited to the national curriculum.

- Fairy Steps and Hale Fell are located on the route of the 'limestone link' and could be included as part of a developed geotrail for this pre-existing long distance walk and Beetham Holiday homes is ideally placed to develop the first geotrail for a caravan park.

- Other sites would benefit from further research as discussed in Theme 1 above and the slag deposits at Warton Marsh could provide a teaching resource for undergraduate geology students.

- More generally, it would be beneficial to put together sites/itineraries for school fieldtrips for geography and geology (A level and GCSE). This is something which the Earth Science Teachers' Association (ESTA) is already collating around the country.

- The Landscape Trust events include exploring the links between geodiversity and the arts through exhibitions with the Silverdale Art Trail[45] and they could continue to provide a forum for engagement with the arts, together with The Barn at Heron Corn Mill as a particular venue for children[46].

- The RSPB centre at Leighton Moss provides an excellent venue for finding out about the natural history of the wider area, attracting large numbers of visitors. It already helps to promote geodiversity to some extent by selling copies of Peter Standing's Geotrail booklets in the café upstairs, but it would be beneficial if these, and other aspects of geodiversity, could be given a higher profile within the main display area

[45] Silverdale and Arnside have a quality of light, range of land and seascapes, variety of terrain and protected flora and fauna, which inspire creativity in local people, who demonstrate this in the well-established art and craft trail: www.silverdalearttrail.co.uk

[46] Heron Barn is an arts, education and community facility, offering an ongoing programme of workshops, activities and events: http://www.heronmill.org/

downstairs, perhaps with interpretation boards and/or sales of a booklet version of The Geological Story of the AONB (as per the recommendation on page 132 above).

## *Theme 6: Sustain Geodiversity Activities within the AONB*

### ***Involve more people, increase financial support and encourage working together***

There is a substantial volunteer workforce within the AONB which is to be greatly applauded. Maintaining partnership working with the various local societies and groups is to be encouraged.

### Theme 6 Recommendations

- It is strongly recommended that ongoing contact should be maintained by the AONB Partnership with Geo Lancashire, Cumbria GeoConservation and the Westmorland Geological Society.

- More specifically, in developing a GAP for the AONB, the aspirations and engagement of these and other local groups should be sought. One way to encourage, active, on-the-ground partnership working, would be by co-ordinating bid-writing to obtain funding - through the Heritage Lottery Fund, for example - for a particular project (such as the suggested development of a GeoHub at Arnside).

- Holding a Morecambe Bay Walk across the sands to raise funds for the conservation of geodiversity (as the Cumbria Wildlife Trust did for the conservation of biodiversity in 2018) would be one way of both promoting the geodiversity of the AONB , gaining more support, and raising funds for conservation of the geodiversity at the same time.

- The promotion of and engagement with geodiversity at Sandside Cutting, which has included funding from and publicity for the local community shop, could be used as an example of good practice in using and gaining support for local geological sites. Other, site-specific suggestions for partnership-working are given in Table 5.1, below.

## **Table 5.1: Suggested Initiatives at Sites of Geodiversity Interest** (page 1 of 4)

| **Sites designated for their Geodiversity Interest and other sites visited** | **Opportunities, Motivators, Incentives** | **Suggested Geodiversity Initiative or Action** | **Suggested Partners** |
|---|---|---|---|
| **Trowbarrow Quarry** SSSI | The site is well-used by climbers, walkers and mountain bikers.<br>Recent report by Natural England (Evans, 2018) provides detailed information about a number of locations within the site and their current condition.<br>Site Ownership is with Lancaster City Council and management co-ordinated by the AONB Unit. | Trowbarrow would lend itself to a number of small interpretation panels explaining the geodiversity interest features, with QR codes for visitors who are interested in accessing more information, including text that is accessible and relevant to the curriculum for KS2 and KS3 school-age children, and promotion of the site for use by local schools. | Natural England<br>Lancaster City Council<br>Local users of the site represented by local community groups and the British Mountaineering Council.<br>Earth Science Teachers Association |
| **Gait Barrows** SSSI<br>**Hawes Water** GCR<br>Warton Dolines LGS: **Hawes Water and Little Hawes Water Lakes** | The current restoration work at Hawes Water includes renovation of an old building by the water (probably a gentlemen's after dinner smoking room). There is a possibility that this building could become a small interpretation centre.<br>The site is a National Nature Reserve and managed by Natural England. | Opportunity for post-graduate research that would provide further information on the development of the depression that contains Hawes Water, Little Hawes Water and Hawes Water Moss (to determine whether this is a polje or a composite doline) and the possible role of the Silverdale Disturbance and Woodbine Shale in its development.<br>An interpretation centre on site would provide an ideal place to promote the interest of the exceptional limestone pavement, marl lake and the significance of the site for palaeo-environmental research, particularly including resources that are accessible and relevant to the curriculum for KS2 and KS3 school-age children as the site appears to be underused by this age-group. | Natural England<br>Local Universities, PhD students<br>Earth Science Teachers Association |
| **Hale Moss Caves** SSSI | The SSSI citation states: '*Further study of the peaty sediments and cave formations (speleothems) will clarify their origin and provide valuable evidence of the development of the landscape of the Morecambe Bay area through the last Ice Age*'. | Opportunity for PhD or post-graduate research that would provide further information on the age and formation of the caves and Hale Moss. | Natural England<br>Local Universities, PhD students |
| **Sandside Cutting** part of Sandside Cutting and Throughs Lane LGS | Already well promoted by a Geodiversity Trail and an Interpretation board at Sandside Cutting. | Suggest two separate LGS, one for Sandside Cutting and one for Throughs Lane, as whilst both sites show evidence for the Silverdale disturbance, they are in discrete locations, with differing access, and within different formations.<br>The promotion and engagement at Sandside Cutting, including funding from and publicity for the local community shop, could be used as an example of good practice in using and gaining support for local geological sites. Both sites give evidence for the Silverdale Disturbance and, together with a number of other exposures across the AONB provide opportunities for further mapping and research which is needed to better understand the complex geological structures within the Sandside area. | Already well promoted by local partners and advertised on the AONB website.<br>Local Universities<br>Local geological experts in liaison with the British Geological Survey.<br>Cumbria GeoConservation |

**Table 5.1: Suggested Initiatives at Sites of Geodiversity Interest** (page 2 of 4)

| **Sites designated for their Geodiversity Interest and other sites visited** | **Opportunities, Motivators, Incentives** | **Suggested Geodiversity Initiative or Action** | **Suggested Partners** |
|---|---|---|---|
| **Arnside Foreshore** LGS extending further to include the full shoreline from Arnside through **New Barns Bay** to Blackstone Point<br><br>**Blackstone Point** LGS and the **Far Arnside** LGS together with intervening areas including **White Creek Marsh**<br><br>**Silverdale Shore** LGS including the coastline right around to the chimney at Brown's Cottages | Marine and Coastal Access Act 2009: The Act enables the creation of an England Coast Path, a continuous, signed and managed route around the coast plus areas of spreading room.<br>The NCA Profile has the statement: '*Providing a coastal access route that allows for improved access to, and understanding of, the coast while respecting the sensitive habitats and species of the coastal margin*.'<br>Promotion of the Arnside and Silverdale area for fossil hunting by the National Trust on their website (although this should be amended to promote observation and photography rather than physical collection). | **One LGS for the whole of the Coastline which is more widely promoted to provide an understanding of the Geological Story of the AONB** as there are good outcrops of the Dalton Formation, Park Limestone Formation and Urswick Limestone Formation together with structural, geomorphological and fossil interests. Specific features include: the contrasting lithologies and bedding characteristics of each limestone formation, the Far Arnside Fault, the Arnside Point Syncline, the faults and associated mineralisation within the Park Limestone, karst features within the limestones, including caves of phreatic origin, shingle beaches, cliff erosion and morphology, including the erosion of the Woodbine Shale at Cow's Mouth, fossils within the Dalton Formation, fossils and trace fossils within the Urswick Limestone Formation, and the dynamic changing conditions exhibited by the saltmarshes, intertidal flats and channels.<br>There is the potential for the creation of a 'Geo hub' at Arnside, perhaps within the disused quarry on the foreshore. There is an ongoing ability and educational value in being able to discover and observe (but not collect) numerous fossils on the shore and within the coastal exposures. Support from trained volunteers from the local conservation groups during the busy months of the year would help families and other individuals engage in valuing the geodiversity of AONB. Picnic tables and small interpretation boards with access to more information through QR codes could also be placed in the disused quarry.<br>The South Downs National Park has created the first GeoTour in the UK and there is a good opportunity for the AONB to create the second along the coastline. GeoCaching is an outdoor recreational activity using a Global Positioning System (GPS) mobile device to hide and seek containers, called 'caches', at specific locations all over the world marked by coordinates. Whilst there are a good number of geocaches already placed by various individuals within the AONB, a GeoTour would provide the opportunity for a more strategic official approach of a collection of geocaches that would serve as a self-guided themed tour. The AONB GeoTour could include a number of EarthCaches which are a special kind of 'geocache' enabling people to learn about the geology through a set of educational notes and a short quiz. This approach is supported by Cumbria GeoConservation. | Cumbria GeoConservation<br>GeoLancashire<br>with the<br>Westmorland Geological Society<br>National Trust including through accurate promotion on their website<br>Geocaching Association of Great Britain<br>Earth Science Teachers' Association |
| **Burton Well** LGS | | There is an opportunity for post-graduate research that would provide further information on the development of the depressions within the AONB and the role of the Woodbine Shale in their development (and specifically to determine whether or not any of these are poljes). This includes Lambert's Field adjacent to and within the Burton Well LGS. | GeoLancashire<br>Local Universities,<br>PhD students |

**Table 5.1: Suggested Initiatives at Sites of Geodiversity Interest** (page 3 of 4)

| Sites designated for their Geodiversity Interest and other sites visited | Opportunities, Motivators, Incentives | Suggested Geodiversity Initiative or Action | Suggested Partners |
|---|---|---|---|
| **Warton Crag** LGS<br><br>Warton Dolines LGS: **Three Brothers and NW Warton Crag** | The site has multiple landowners including Leighton Hall Estate, Lancaster City Council, Lancashire County Council and RSPB and a range of others including Scout Cragg Caravan Park. Lancashire Wildlife Trust manage a large part of the site leased from Leighton Hall Estate.<br><br>Part of the site is a Local Nature Reserve | Warton Crag provides an excellent and diverse location for educational school visits, which should be explored by the AONB and others in liaison with the Earth Science Teachers' Association (ESTA)<br><br>There is an opportunity for post-graduate research that would provide further information on the development of the dolines within the AONB and the possible role of faults in their development.<br><br>There is a great variety of geodiversity on Warton Crag, particularly features that provide the links between the geology and the wider environment. Some of these links are made within the Warton Crag leaflet but the location of features is not provided. Features that could be usefully identified, described and promoted within a **Geotrail** include: the use of the limestone hill as a non-defensive hilltop enclosure, possibly dating to the Late Bronze Age, mining for copper and haematite, the steps and scarps in the limestone, the limestone pavements, caves, erratics and dolines, the way the loess and limestone have contributed to habitat, and the development of Warton Village. | Leighton Hall Estate<br><br>Lancashire County Council<br><br>Lancaster City Council<br><br>Lancashire Wildlife Trust<br><br>GeoLancashire<br><br>RSPB<br><br>ESTA |
| **Heald Brow** | A Limestone Pavement Order is in place for Heald Brow and the site is managed by National Trust. | Keep the nautiloid fossil covered as is the case currently with interested parties shown the fossil on request. | National Trust |
| **Sandside Quarry** | A restoration plan for the quarry has been agreed. | Implement the agreed restoration plan, which has the aim of integrating the site into its local setting, including the retention of many faces for their geological interest and the provision of new habitat - particularly calcareous grassland - to promote biodiversity. | Tarmac, Cumbria County Council, Dallam Tower Estate. |
| **Middlebarrow Quarry** | The site could be a valuable research resource in liaison with the landowner | The quarry faces are high and unstable but provide an excellent insight into the structure and lithology of the Park Limestone Formation. The geodiversity interest is not accessible (other than views from the public footpath by the railway crossing), although palaeomagnetism research is being undertaken and further opportunities may be possible for professional/scientific geological research with close consultation and permission of the landowner and the former quarry operator (Hanson) for as long as they still have any responsibility for aftercare of the quarry. | Dallam Tower Estate<br><br>Hanson Aggregates<br><br>Local Geologists<br><br>Westmorland Geological Society |
| **Beetham Holiday Homes** | Site Owner with a genuine interest in promoting the biodiversity and geodiversity of the site and the wider AONB area. | Beetham Holiday Homes has a good range of geodiversity within a relatively small site which includes: limestone pavements with deep grikes, a limestone scarp indicating the line of a fault, a depression or doline feature and erratics. A site-specific small geotrail could be developed with a number of small discreet interpretation panels explaining the geodiversity interest features, with QR codes for site users who are interested in accessing more information. Information on the nearby limestone caves could also be provided. This geotrail could be used as an example of good practice with other caravan park owners within the AONB. | Beetham Holiday Homes<br><br>Cumbria GeoConservation<br><br>Local Geologists<br><br>Westmorland Geological Society |

**Table 5.1: Suggested Initiatives at Sites of Geodiversity Interest** (page 4 of 4)

| **Sites designated for their Geodiversity Interest and other sites visited** | **Opportunities, Motivators, Incentives** | **Suggested Geodiversity Initiative or Action** | **Suggested Partners** |
|---|---|---|---|
| **Fairy Steps and Hale Fell** | Limestone Link, a 13-mile long distance walk through the limestones of Cumbria which includes a traverse of the Fairy Steps and Hale Fell. | The current leaflet for the Limestone Link focusses on the biodiversity of the limestones with more limited information on the limestone pavements. However, the long-distance route is already in place, so gives opportunity to develop material that promotes the geodiversity within a GeoTrail.<br>The Fairy Steps is an iconic, well-known local landmark and could potentially benefit from some interpretation of the geology. There is an interpretation sign already at the site. Geology could be merged into this with QR for further information, following discussion with Dallam Estates. The site may benefit from some vegetation clearance. | South Lakeland District Council<br>Dallam Tower Estate<br>Natural England |
| **Slag Deposits within Warton Marsh** | Interest and explanation provided by local academic geologists. | The slag deposits show a number of cooling features that are also observed within extrusive volcanic lava flows, some of which are not available within natural rock exposures within the UK. Promote the interest features at the site for use by local universities. | Local Universities<br>Clive Boulter<br>Duncan Woodcock |
| **Hazelslack – Black Dyke area** | Observations and interpretations relating to the Silverdale Disturbance in these areas, reported by local geologist Colin Patrick in a note on a field excursion by the Westmorland Geological Society in April 2010. | Consider the identification of some of the features in this area as new **Local Geological Sites**, subject to discussion with the landowner (Dallam Tower Estate). | Dallam Tower Estate<br>Local Geologists<br>Westmorland Geological Society |
| **Leighton Moss** | RSPB Visitor Centre provides a well-used location at which geodiversity could be promoted more extensively than it does at present. | Geodiversity, and especially its links with landscape and habitat evolution at this site (and elsewhere in the AONB) could be given a higher profile within the main display area of the visitor centre, perhaps with interpretation boards and/or booklets based on The Geological Story from Chapter 2 of this report | RSPB<br>Cuesta |

# 6. Further Recommendations and Opportunities

*Whilst the key recommendations from this project are those relating directly to the conservation and management of the area's geodiversity, as discussed in the previous Chapter, the project was also required to provide recommendations on a range of other, related topics. These include:*

- *the identification of **key indicators** for monitoring future landscape change;*
- *the identification of opportunities for supporting future **landscape resilience**; and*
- *the provision of draft recommendations for **further research**.*

*This chapter deals with each of these topics in turn.*

## *Key Indicators for Monitoring Future Landscape Change*

One of the reasons for commissioning this work was to complement Natural England's emerging evidence base on the monitoring of landscape change, and its Framework for Monitoring Environmental Outcomes in Protected Landscapes, launched in 2014. As part of this, one of the output requirements for this work was the identification of key indicators for monitoring landscape change within the AONB.

As noted Poole *et al* (2010): *"An indicator refers to specific characteristics that can be monitored to provide a measurement of changes and trends, often towards a particular goal or target. An indicator quantifies and simplifies so that complex realities can be understood*". In this case, it is suggested that the selected indicators should be related directly to the ways in which geology and geodiversity influence the landscape, so that changes in these characteristics, and therefore the effectiveness of the AONB Management Plan in conserving and enhancing the area's natural environment, can be monitored over time.

Shifting tidal channels within the outer Kent Estuary

It is also suggested that the indicators should be explicitly linked to the ecosystem services with which they are associated, in order to emphasise the importance of geological and geomorphological factors in this context. Each category of service should be represented (provisioning, supporting, regulating and cultural), but with an emphasis on the importance of supporting services. As explained in Chapter 4, supporting services, which include active geomorphological processes and conservation of the assets which provide the services, are critical to all other categories of service and are particularly important in the context of maintaining landscape resilience to climate change.

One further, essential criterion is that all of the selected indicators should readily be capable of being quantitatively measured and monitored, to enable robust and consistent data series to be compiled over time. Only by ensuring consistency can reliable trends be established from the data collected. Bringing all of these ideas together, Table 6.1, below, sets out the suggested range of key indicators, grouped into a series of specific 'attributes' within each of the four ecosystem service categories or themes. The suggested indicators overlap, to some extent, with those used by Natural England in its work on monitoring environmental outcomes, but they are more specifically focused on the rather different purpose of this project.

**Table 6.1: Suggested Indicators for Monitoring Geodiversity Aspects of Landscape Change**

| Theme | Attributes | Key Indicators |
|---|---|---|
| **Provisioning Services** | Food Products | The annual output of **food products** sourced from farms within the AONB |
| | Mineral Products | The annual output of **mineral products** sourced from quarries within the AONB |
| **Supporting Services** | Geological Conservation | **Protection**: The total surface area of sites designated at International (SAC, SPA, Ramsar), National (SSSI, NNR, LPO) or Local (LNR, LGS) level, within the AONB, for which geological or geomorphological features or processes provide essential support, whether or not these are noted features of interest |
| | | **Protection**: The total surface area of sites designated at National (SSSI) or Local (LNR, LGS) level, within the AONB, where geology or geomorphology is explicitly cited as the main or joint conservation interest |
| | | **Condition**: The percentage of designated geological and geomorphological sites (as defined above) which are in favourable condition |
| | | **Enhancement**: The total number of geodiversity and biodiversity sites designated at International, National or Local level, where positive conservation management has been undertaken within the preceding five years to enhance geodiversity interests. |
| | Active Geomorphological Processes | **Channel Changes**: The position and minimum elevation of the floor of tidal channels within the outer Kent Estuary (as a measure of any systematic changes in morphology over time) |
| | | **Avoidance of Constraints**: The total length of shoreline protected by engineered sea defences (as a measure of the extent of human constraints on active coastal processes, which needs to be kept to a minimum) |
| | Soil Formation and Priority Habitats | The total surface area of **all priority habitats** within the AONB. This would need to use the latest available data as a baseline and then ensure that the same assessment criteria and survey techniques are utilised in all future surveys. |
| **Regulating Services** | Raised Bogs | The total surface area of land being managed for the re-instatement of **lowland raised bog** (as a measure of enhancement of Carbon sequestration) |
| | Saltmarsh | The total surface area and maximum elevation of **saltmarsh** within the AONB *and along the north coast of the Kent Estuary* (to monitor overall response to sea level rise) |
| **Cultural Services** | Natural Beauty: | The **quality of views** obtained from specific vantage points within the AONB |
| | Recreation: | The number of AONB '**Geotrail**' booklets sold in the preceding five-year period |
| | Education: | The number of **geodiversity information panels and/or QR codes** currently installed at points of geodiversity interest within the AONB |
| | Research: | The number of **academic research papers** relating to geological or geomorphological aspects of the AONB published in scientific journals during the preceding five-years. |

## *Opportunities for Supporting Landscape Resilience*

'Resilience' to climate change (or to any other external influence, including that of people), is not simply about the resistance of a system to physical or ecological change, or to changes in visual appearance, it is about '*the ability of the system to absorb disturbances while retaining the same basic ways of functioning, and retaining the capacity to adapt to stress and change*'[47].

Working at a **landscape scale**, rather than focusing exclusively on special sites or features of interest, is a key adaptation principle, as are the concepts of increasing **landscape connectivity** and **involving people**. All of these are recognised in Natural England's 'Conservation 21' strategy[48], which sets out its new approach to environmental conservation and management.

Leighton Moss and adjoining limestone hills

In the context of landscape change it must be recognised that **continuous evolution** is a natural part of the 'system' itself, and that the continuing operation of **natural processes**, is both inevitable and desirable. The key requirement is to ensure, not that the landscape remains static, but that it is able to adapt to the changes which occur in such a way as to maintain – or enhance – the overall level and balance of **ecosystem services** which it provides.

As noted in Chapter 4 of this report, **supporting services** are likely to be the most important in this respect, since it is these which are most likely to be affected directly, and most immediately, by the impacts of future climate change. It has also been shown, in Chapter 4, that **active geomorphological processes** – those responsible for the rapidly changing features of the tidal flats and saltmarshes, as well as the continually changing exposure of coastal rock

[47] Natural England and RSPB, 2014: Climate Change Adaptation Manual

[48] Natural England, 2016: Conservation 21 - Natural England's Conservation Strategy for the 21st Century

outcrops and shingle beaches, are amongst the geodiversity features most susceptible to climate change. Such processes also underpin some of the most sensitive natural habitats within the AONB which, in turn, are particularly vulnerable. It has also been noted, however, that tidal flats and saltmarshes also have considerable natural ability to adapt to changes in sea level, provided that sufficient space is available and provided that the natural processes involved are not artificially constrained (e.g. by engineered defences).

The Silverdale Shore, with its alternation of limestone cliffs, shingle beaches and eroding saltmarsh

To this extent, one of the main opportunities for supporting landscape resilience within the AONB will therefore be to ensure that the **continued operation of natural estuarine processes within Morecambe Bay and the Kent Estuary**, and the **overall extent of coastal saltmarsh habitats**, are not hampered by the desire to maintain coastal flood defences in the face of rising sea-levels. Space will be needed for saltmarsh areas to develop as the tidal channels continue to migrate. As noted in Chapter 2, this is currently achieved within the existing coastal boundaries, with the periodic loss of saltmarsh in some areas continuing to be compensated for by the accretion of new saltmarsh in other parts of the bay (future monitoring of which will require consideration of the entire Morecambe Bay / Kent estuary system, not just the areas within the AONB). In the longer term, however, as relative sea levels continue to rise (with increasing speed according to latest projections – see page 51, above), there is likely to be a need for previously reclaimed coastal lowlands to be allowed to flood. Such action – i.e. 'managed retreat' – will entail a trade-off between different types of ecosystem services: land that is currently utilised for agriculture, or valued for its reedbed or lowland fen habitats, for example, may need to be replaced by encroaching (or returning) saltmarsh. The choice will be one of the many dilemmas thrown-up by the desire to maintain or enhance overall landscape resilience and will need to be informed by a thorough analysis of the relative ecosystem service benefits of alternative scenarios.

Other aspects of the landscape that are especially sensitive to climate change are those which support habitats and species which have only **limited tolerance** to changing environmental conditions. As noted in Chapter 4, these include areas of **lowland fen** and **reedbed**. Given that these are precisely the kind of habitats which could well be 'squeezed' out of existence in some areas if saltmarsh is allowed to encroach inland, the choice will not be an easy one.

Egret fishing within reedbed habitat at Leighton Moss

However, although such habitats do not have the same capacity to adapt to climate change as do areas of saltmarsh, they can be assisted by human intervention and management. Water levels (for both lowland fen and reedbed) can be increased, for example, through the installation of sluice gates (as planned for Hawes Water); and *where appropriate,* water depths can be increased by dredging (as has been carried out at Leighton Moss, in the past).

Opportunities even exist for re-creating the conditions for the gradual reinstatement of **lowland raised bog** habitat in certain locations. As noted in Table 4.1, such habitat (once established) is likely to be more resilient than either lowland fen or reedbed habitats. Further, comprehensive, details of appropriate management techniques are given in the Wetlands Restoration Manual produced by the Wildlife Trusts[49].

As explained in Chapter 4, most other parts of the landscape – those where active geomorphological processes are relatively slow, and where the underlying geology and/or geomorphological features formed in the geological past play a larger part in the ecosystem services being provided – are likely to be **inherently more resilient** to future climate change. This applies, for example, to limestone hills and pavements, calcareous grasslands, quarry exposures, coastal cliffs which are cut into limestone bedrock, and large-scale landforms such dolines and drumlins.

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[49] Eades, P., Bardsley, L., Giles, N. and Crofts, A. 2003: The Wetland Restoration Manual. The Wildlife Trusts, Newark.

All of these, however, are still susceptible to the impact of other imposed changes; particularly those imposed by **human activity**. In this regard, the opportunities for supporting landscape resilience are primarily linked to the sensitive formulation of **land use planning policies** and appropriate implementation of **land management** regimes. Again, it is not a question of resisting change altogether: as with the natural environment, cultural aspects of the landscape have evolved over time though continual man-made changes which, to varying degrees, impart distinctive elements of character to the landscape, along with a 'sense of history'. It is right that this should continue, through well-managed future land use and appropriate development, guided, where possible, by the **Ecosystems Approach**.

Limestone Pavement preserved within a Storth Garden

## *Recommendations for further research*

Several recommendations for further work, leading on from this study, have already been made within Chapter 5 of this report. These range from **detailed geological investigations** to unravel the structural complexities in the northern part of the Silverdale Disturbance to **improved public access** to the data compiled within this study and to generally **maintaining good liaison** with academics at a number of University Departments as well as with local, professional and enthusiastic amateur geologists, and with Geo Lancashire and Cumbria Geoconservation.

Work is also needed to implement the **systematic monitoring of the indicators** suggested in Table 6.1, above. The first stage of this, working in liaison with Natural England, will be to specify more precisely the metrics to be recorded and, where necessary, to establish precise methodologies for undertaking surveys (e.g. for the extent of priority habitats), so that these can be applied consistently over time. In this way, recorded trends will hopefully reflect actual changes rather than differences in measurement techniques.

Perhaps the most important overall requirement is for a **Local Geodiversity Action Plan** (LGAP) to be developed for the area. This would provide a means of confirming and promoting the various actions needed to ensure that geological and geomorphological features contribute the core purpose of the AONB: conserving and enhancing the natural beauty of the area.

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