Section 2 Roots of our geological heritage

Evolution of the rocks and landscape of the district

Although the Earth is almost 4600 million years old, events from only about the last 440 million years are recorded in the rock record of the district. The following account sets the scene for the discussion of the region's geodiversity with a summary of the geological evolution and development of the landscape.

England's northern border coincides approximately with the Iapetus Suture, one of the fundamental geological boundaries in Britain.The suture is the trace of the junction between two ancient continents that were once separated by a vast ocean, known as the Iapetus Ocean, up to 1000 kilometres wide at its maximum extent in late Cambrian times, about 500 million years ago. The

Iapetus Suture has since been buried by more recent sediments but its shallow inclination northwards beneath northern England can be imaged from geophysical data. Renewed movements affecting the Suture have controlled the geological history of the area.

In early Palaeozoic times the continent of Laurentia lay to the north of the Iapetus Ocean. Forming part of the continent's south-eastern margin were Scotland and the northernmost part of England, together with the north and west of Ireland. At a latitude of about 60° south lay the rest of England and Wales, on the smaller continent of Avalonia, together with the south and east of Ireland, parts of mainland Europe and fragments of the maritime states of North America.

From late Cambrian times, plate tectonic processes gradually closed the Iapetus Ocean resulting in the convergence and ultimate collision of the two continents, Laurentia and Avalonia, and building the Caledonian mountain belt as a consequence. The eroded core of this belt can be traced today through Scandinavia, Scotland, Ireland, and on into Greenland and maritime North America. Continental collision began around 425 million years ago in mid-Silurian times and the leading edge of Avalonia was driven at a shallow angle northwards beneath Laurentia. The oldest rocks exposed at the surface today in the district comprise the Riccarton Group and date from this period. These rocks were deposited as marine muds and sands in the much diminished remains of the Iapetus Ocean.

A timescale and summary geological history

Geological time is divided into the Eras and Periods shown, with the ages before the present day given in millions of years. The colour bands in the chart indicate those periods of geological time represented in the district's rocks. Also included are events that occurred during the long periods of time for which no record remains; their presence has been inferred from evidence in adjoining areas.

The enormity of geological time may be appreciated by representing the whole of Earth history by a single day. On this scale, the oldest rocks in the National Park formed around 9.45 pm, the Carboniferous limestone and sandstone that make up most of the central and southern parts were laid down between 10.10 and 10.30 pm, and the Quaternary ice ages began less than one minute to midnight. Man first walked across the Northumberland moors at less than one second to midnight.

By early to mid-Devonian times the sediments that had accumulated on the shrinking Iapetus Ocean floor were compressed intensely between the colliding continents. This folded, cleaved and uplifted the rocks during an event termed the Caledonian Orogeny.

Towards the end of, or closely following, the Caledonian Orogeny, volcanoes formed in the area of the Cheviot Hills. These are thought to have been low-lying, shield- like structures formed by the amalgamation of many flows of magnesian- and iron-rich lava erupted from numerous vents, rather than the classic conical volcanoes typical of modern day western North and South America. A large mass of silica-rich magma was injected and solidified beneath the volcanoes to form the Cheviot Granite Pluton, locally baking and re-crystallising (metamorphosing) the surrounding volcanic rocks. Subsequently, the extinct volcanoes were eroded intensely by rivers. Relics of the alluvial fans of gravel deposited at the edge of the ancient upland by these rivers are preserved today as the lower Carboniferous Roddam Dene Conglomerate.

At around 410 million years ago, in the early Devonian Period, a similar body of granite to the Cheviot Pluton was intruded beneath what is today the North Pennines. Although this granite – the Weardale Granite (or North Pennines Batholith) – does not extend under the district, its presence was to have a significant affect on the district's subsequent geological evolution.

In early Carboniferous times global continental movements resulted in a general north-south extension of the Earth's crust beneath the area now occupied by northern Britain and neighbouring parts of the North Sea. Movement along a number of fractures, or faults, defined a pattern of 'basins' and 'blocks'; and caused the sea to flood much of the area that had been land at the end of the Devonian. In northern England, the crust overlying the Iapetus Suture subsided and broke along east-west fractures forming, amongst others, the Stublick–Ninety Fathom Faults. The presence of the Weardale Granite to the south of these faults kept this area 'buoyant' as granitic rocks are significantly less dense than most other rock types. Consequently, subsidence to the north of the Stublick–Ninety Fathom Faults, in the area that is now central Northumberland, was more rapid than that to the south, in the area that is now the Northern Pennines. A large 'hole', known today as the Northumberland Trough, developed in central Northumberland, and as a result a much greater thickness of Carboniferous rocks accumulated here than in the North Pennines. Initially, crustal stretching and subsidence within the Northumberland Trough were rapid enough to allow basaltic magma, generated in the underlying Earth's mantle, to reach the surface along fractures, and to erupt as lava. The remains of these eruptions are preserved in the district along the southwest margin of the Cheviot massif as the Cottonshope Volcanic Formation.

At the beginning of Carboniferous times, the area that was eventually to become northern England lay within equatorial latitudes. During the Carboniferous Period it drifted northwards across the Equator from 5° to 10° south to about 5° north. This movement took the region from the southern hemisphere tropical arid zone, through the much wetter equatorial zone during much of the Carboniferous, into the northern hemisphere tropical arid zone in latest Carboniferous times. Over millions of years of the Carboniferous Period, the whole region subsided beneath a wide, shallow, tropical sea in which an abundance of lime-secreting organisms gave rise to accumulations of limestone. Large and vast rivers, draining from upland areas to the north and north-east, in the region occupied today by the Southern Uplands, brought periodic influxes of sand, silt and mud and built wide deltas into the Carboniferous sea. Lush forests flourished on top of the deltas and peat accumulated on the swampy forest floors. As the deltaic sand, silt and mud became buried by successive layers of sediment, they compacted to form sandstones, siltstones and mudstones; the peat became preserved as thin coal seams. The cycle of marine limestone followed by deposition, in regular sequence, of muds, silts and sands, was repeated many times during the Carboniferous Period, giving rise to a highly distinctive repetition of limestone, mudstone, siltstone and sandstone. These sediments are preserved today in the rocks of the Yoredale Group. With the passage of time, influxes of deltaic sediment became more frequent and widespread, and the lush forests became more extensive. By the late Carboniferous Period the whole area had become a low-lying, deltaic swamp crossed by wide, meandering rivers. The numerous, extensive and thick coal seams of the Pennine Coal Measures record the periodic development and burial of vast volumes of swamp vegetation over very wide areas.

'Blocks' and 'basins' developed at the beginning of the Carboniferous Period in the region that was to become northern England

Granitic rocks had been intruded from below into the existing rocks prior to Carboniferous time. These consisted of batholiths – groups of more-or- less contiguous igneous intrusions that collectively formed large bodies, typically with steep sides and no visible floor, and plutons – high-level, cylindrical masses of igneous rock emplaced at low temperature in a near-solid state. These huge masses of granitic rock were less dense than the surrounding rocks and formed upstanding areas (blocks) in the early Carboniferous land surface.

About 295 million years ago, towards the end of Carboniferous times, Earth movements, related to a period of mountain building known as the Variscan Orogeny in what is now southern Europe, uplifted, tilted and locally folded the Carboniferous rocks and created an upland area across what was to become northern England. This event also stretched parts of the crust beneath northern England to allow huge volumes of magma to rise, spread out and solidify between the layers of sediment, forming the Whin Sills. The crystallised magma formed sheets of the hard black rock known as dolerite. The injection of magma at temperatures of at least 1100°C metamorphosed adjacent sediments; sandstone became much harder, mudstone was turned into hornfels (known locally as 'whetstone'), and limestone was turned into marble.

Soon after the intrusion of the Whin Sills, mineral-rich waters, warmed by the Weardale Granite beneath the North Pennines, began to circulate through cracks and faults in the rocks deep beneath the southern part of the district. As these solutions cooled, their dissolved minerals crystallised to form the veins found in the Haydon Bridge area; these veins form an outlying part of the Northern Pennine Orefield.

Evidence for most of the geological events affecting the region from this time until the ice ages of the Quaternary Period can be inferred only from outside the region as all traces of the succeeding succession of rocks have been removed by erosion. However, evidence for the development of the North Atlantic Ocean during Palaeogene times is present within the district. Significant stretching of the Earth's crust during the initial stages in the opening of the North Atlantic Ocean, approximately 60 to 55 million years ago, resulted in extensive volcanic activity centred in the Hebrides and Northern Ireland. Basaltic magma dykes, a distant expression of this volcanic activity, were intruded over much of the district. The Acklington Dyke is one such example. The opening of the ocean elevated much of northern Britain to begin a long period of erosion and landscape development during Cainozoic times.

The start of the Quaternary Period, about two million years ago, saw the beginning of a period of global cooling. Throughout Quaternary time the climate fluctuated rapidly over very short timescales, from warmer temperatures than those of today, to full glacial conditions. ice-sheets began to grow across the uplands of Britain and Ireland. As the ice-sheets thickened they flowed out of the uplands and extended southwards across much of Britain and the adjacent continental shelf.

The effects of these glaciations can be seen in the landscape and deposits of the whole of the district. Lowland areas are blanketed with thick sequences of till (boulder clay), testament to the massive erosive and transportational processes of the ice. Large boulders transported by the ice can be found all over the district. These are known as 'erratics' as their individual rock types do not match those of the underlying bedrock and show that they have travelled some distance, mostly from southern Scotland and northwestern England. Large areas supported very fast-flowing portions of the ice-sheet, called ice streams, and their effects can be seen in the streamlining of bedrock surfaces and the moulding of surface sediments. During warmer intervals, the ice retreated back into the neighbouring uplands. During the retreat, huge volumes of meltwater transported large amounts of sand and gravel both beneath and around the wasting glaciers. Great swathes of countryside were buried by this glaciofluvial material deposited in outwash deltas, such as that at Woodbridge, in vast lakes like the one that occupied the Milfield Plain during this time, or as chaotic deposits of mounds, hollows and abandoned river valleys such as those found near Roddam and Wooperton.

After the retreat of the last ice-sheets, around 15 000 years ago, the climate remained cold for some time, allowing deposits of peat to develop locally. After a final, 1000 year-long intensely cold period, the climate improved dramatically and the first pioneer forests, composed of birch, aspen and pine, colonised the district followed by a floral succession culminating in mixed deciduous woodland. Throughout this time alluvial silts and muds continued to accumulate, as they do today, along major rivers and streams.

The influence of geodiversity in the landscape

Geodiversity is intrinsically linked to many facets of the district's landscape, from its most obvious manifestation in the Whin Sill ridge to the more subtle relationship of plants to the soil and the human use of natural resources. Indeed, the landscape we see today has been modified to such an extent that it can be difficult to identify the fundamental contribution of geological processes to the physical landscape. Consequently, as a first step in the analysis of landscape character, it is necessary to produce an assessment of the physical landscape that is not strictly dictated by formally designated geological boundaries. The objective of this exercise is to obtain a 'feel' for the landscape, and for this it seems logical to devise a set of criteria by which the landscape could be interpreted in terms of its visual physical characteristics. As the broad physical landscape character of the district as a whole can be appreciated best by looking at it from the air, a computer-generated, photorealistic hillshade model was created from digital elevation data. This model shows landscape and landform features at a very high resolution. It can be used to delimit areas of similar featuring, and therefore geological style, on the basis of their broad visual character.

It is clear from the study that geological or geomorphological processes, rather than rock type or deposit, are the critical factors in determining the broad landscape character of the district: most notably the different processes involved in glaciation and deglaciation of the landscape. Even in those areas of the district where bedrock is at the surface, the broad physical landscape has resulted from the interaction between the rock and these geomorphological processes.

Two of the most impressive landscapes of the region, namely the Cheviot Hills in the north and the escarpment on which Hadrian's Wall stands in the south, are composed largely of igneous rocks.

The rocks are at, or very close to, the surface throughout the Cheviots, but the physical landscape shows dramatic variation as a result of the response of the rocks to different glacial processes. In the eastern Cheviot, the upland slopes are smooth and convex, often covered only by thin deposits of weathered material. Tors of granite and metamorphosed volcanic rocks characterise the hilltops. By contrast, the igneous rocks of the western Cheviot are covered in a thick layer of degraded and weathered rock in a landscape characterised by concave slopes and 'V-shaped' valley profiles, with large accumulations of weathered rock at their bases.

The striking north-facing escarpment of the highly resistant Whin Sill, with its bare rocky cliffs and long, gentle southerly slopes, provided the Roman civil engineers with a natural defensive site for the construction of Hadrian's Wall. Adjacent to the Whin Sill in the Wall country, where the Carboniferous sedimentary rocks have been tilted towards the south, differential erosion of the component rocks has produced a pronounced east-west orientated scarp and dip topography, which has been accentuated by the scouring action of eastward flowing ice during the last glacial period (p. 22).

The comparatively resistant limestones and sandstones typically form scarps or cuestas, often with small rocky scars along their crests, with the outcrops of the weaker mudstones and siltstones marked by lower lying, unexposed 'slack' ground or hollows between the scarps. This landscape, perhaps most strikingly seen when approaching Housesteads from the east in low-angled sunlight, or with a dusting of snow, is one of the most distinctive landscapes in northern England. Few areas of Britain demonstrate so clearly the essential relationship between landform and the underlying geology.

In a similar fashion, much of the central area around Otterburn is characterised by distinctive scarp and dip slopes formed by the differential weathering of Carboniferous sediments. Although, here the cuesta landscape has been partially blanketed by till and only particularly resistant sandstones form small craggy outcrops.

In north Northumberland the grits and sandstones of the Fell Sandstone form the long tiers of crags and bold escarpments that are so conspicuous, giving rise to the distinctive skyline at Simonside and the crags at Harbottle. Except for the breaks of the Aln and the Coquet rivers, the escarpment completely divides the Cheviot Hills from the sea and deflects all the drainage.

Much of the district is blanketed by glacial till. In lowland areas it commonly masks the bedrock topography. In other places the surface of the till has been smoothed or streamlined into long, linear features by fast-moving overriding ice. To the north of the Wall country, around Henshaw, Haughton and Thirlwall commons, the till has been shaped into elongate, commonly egg-shaped mounds (or drumlins).

Following deglaciation the moulded landscape provided suitable conditions for a wide variety of habitats to develop, such as the Roman Wall Loughs, Border Mires and areas of blanket bog that are important in the landscape today. However, in common with almost every part of Great Britain, the landscape today owes much to human intervention. Agriculture and a variety of industries, including mining and quarrying have all played a part in shaping it. A number of the district's past and present industries are a direct result of locally available mineral raw materials. The nature and properties of local stones have to a large extent determined the character of local buildings. Local materials have combined with the distinctive landscape they helped to shape to create a strong 'sense of place' – unique vistas that have provided an inspiration to writers, poets, musicians and artists throughout the centuries.

The particular influence of each element of geodiversity in the landscape is highlighted in the sections that follow.

Figures

(Figure 9) Hadrian’s Wall above a cliff in the Great Whin Sill, with Crag Lough behind. Milecastle 39 in the foreground © Graeme Peacock www.graeme-peacock.com.

(Figure 10) The approximate position of the buried Iapetus Suture, shown on a satellite image taken by the LANDSAT 5 Thematic sensor.

(Figure 11) Globe showing position of the Iapetus Ocean, approximately 500 million years ago and the areas that were to become present-day Great Britain and Ireland. A — Scotland and the north of Ireland B — England, Wales and the south of Ireland.

(Figure 12) A timescale and summary geological history.

(Figure 13) 'Blocks' and 'basins' developed at the beginning of the Carboniferous Period in the region that was to become northern England.

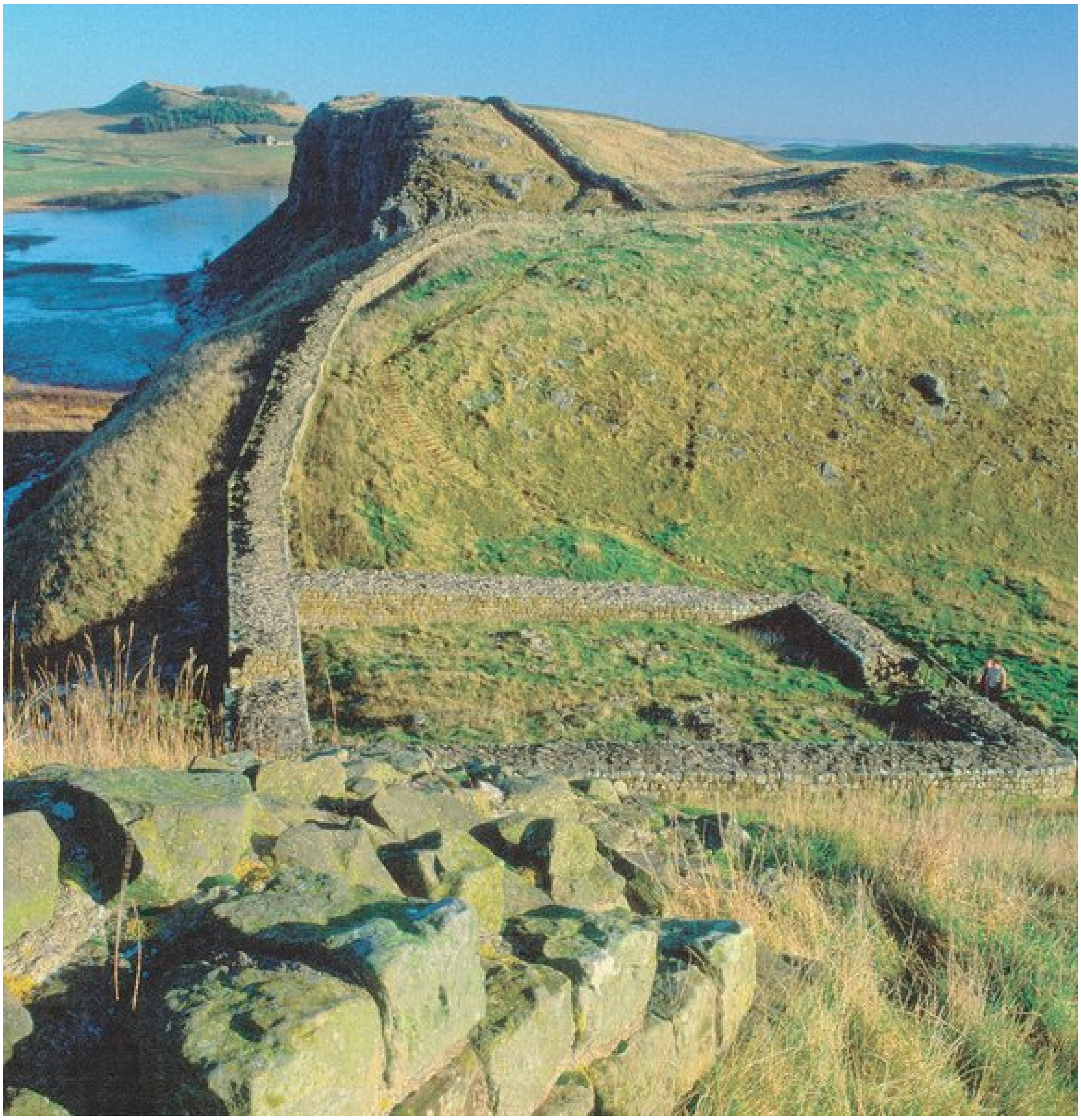
(Figure 14) The striking pattern of ridges formed by tilted Carboniferous rocks, which epitomises Hadrian’s Wall country, is most spectacularly seen from the air. In this view ridges of resistant sandstone and limestone are clearly seen, though most prominent is the scarp of the Great Whin Sill, which casts dark shadows on its northern side near Sewingshields (1). The Whin Sill crags can be followed westwards towards Housesteads (2) and Crag Lough (3), though their continuity is locally disrupted by several faults © AirFotos Ltd.

(Figure 15) Simplified geological map of the district.

(Figure 16) View south-east from Hedgehope Hill showing Long Crags, Housey Crags and Langlee Crags, tors of metamorphosed volcanic rock © Graeme Peacock www.graeme-peacock.com.

(Figure 17) A photorealistic hillshade model of the region, derived from the NEXTMap® digital elevation model (© Intermap Technologies Inc.) based on low-level radar survey of the ground surface.

(Figure 18) Squared blocks of sandstone in Hadrian’s Wall near Housesteads © Emma Amsden.



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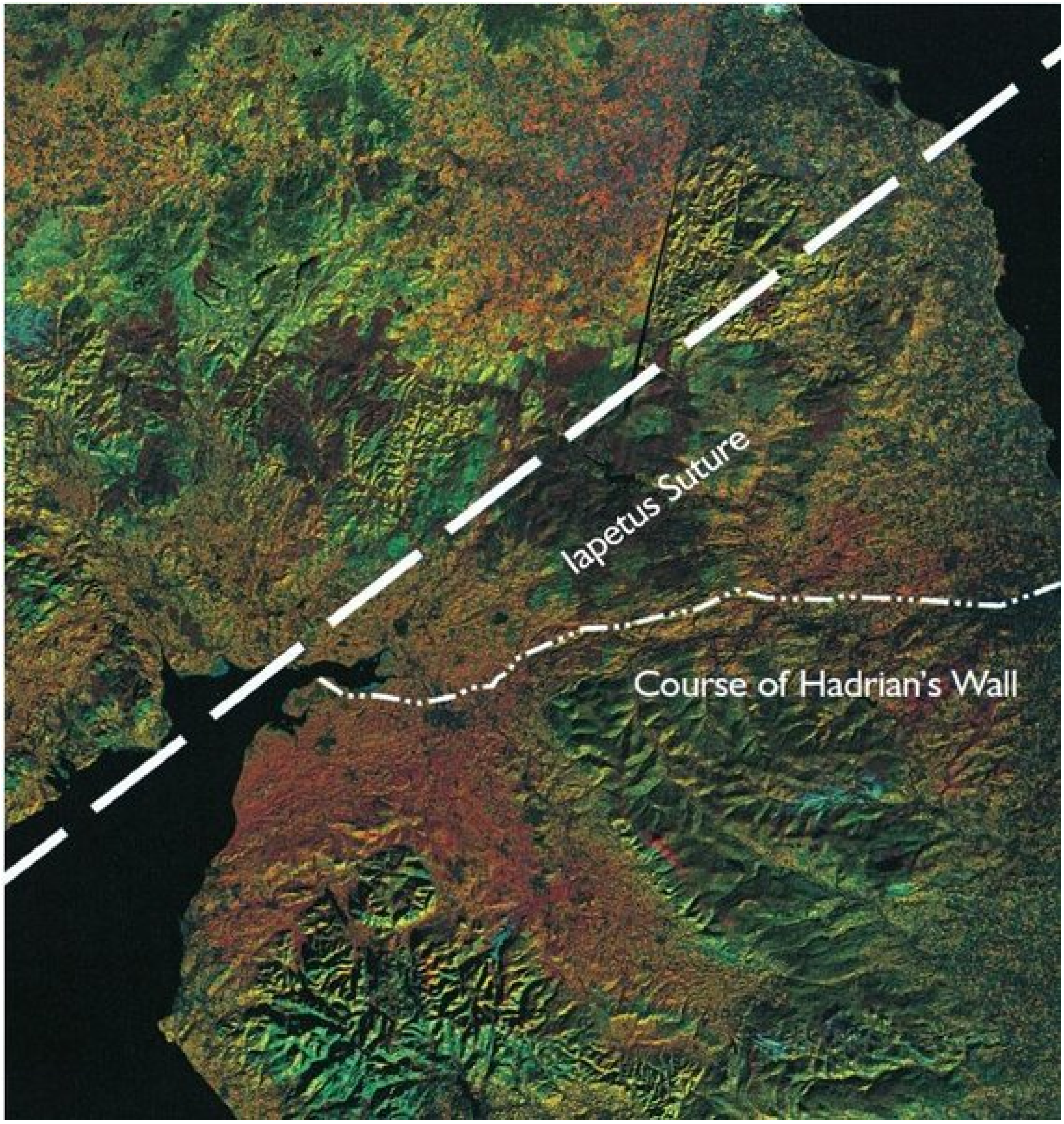

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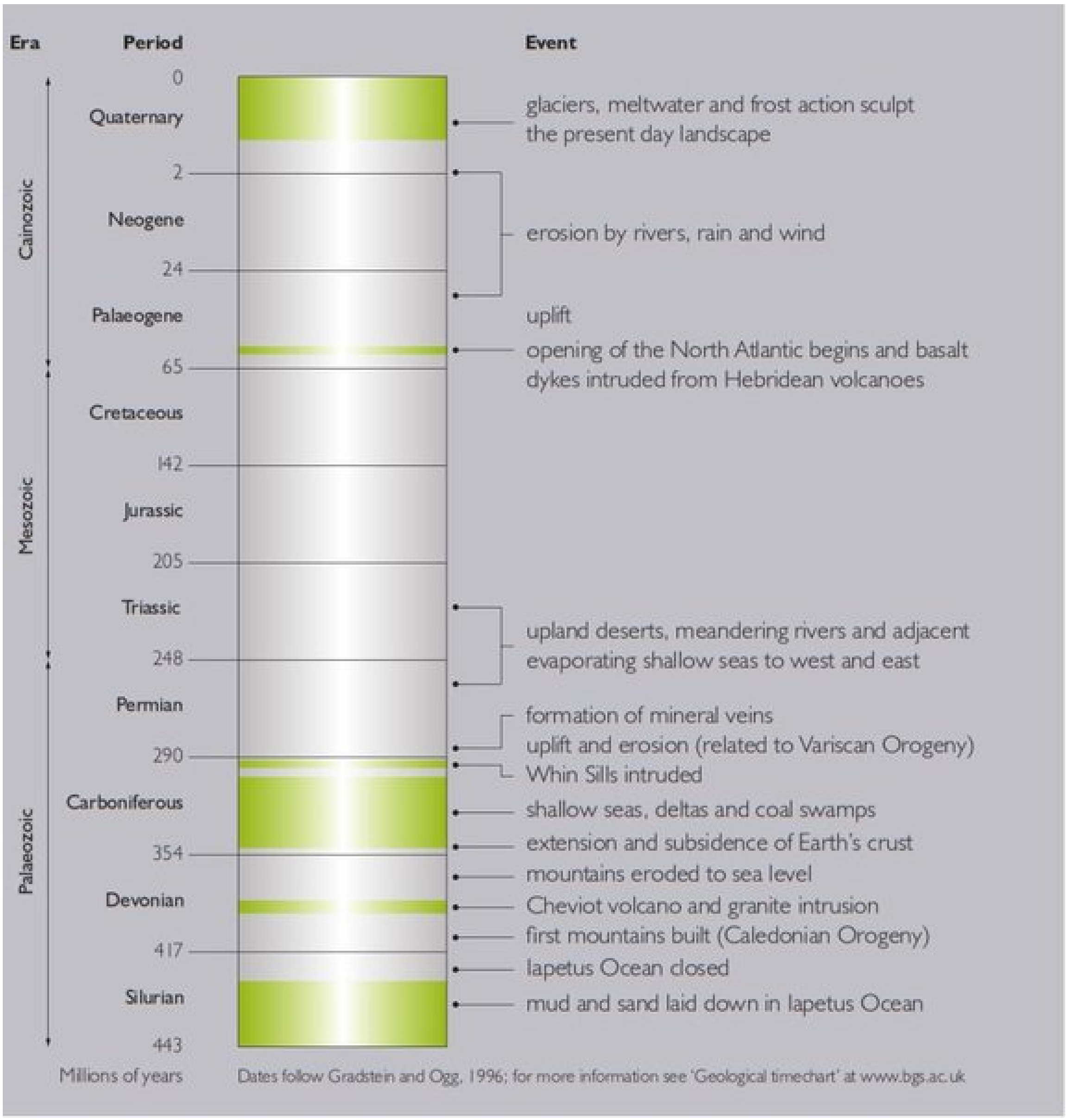

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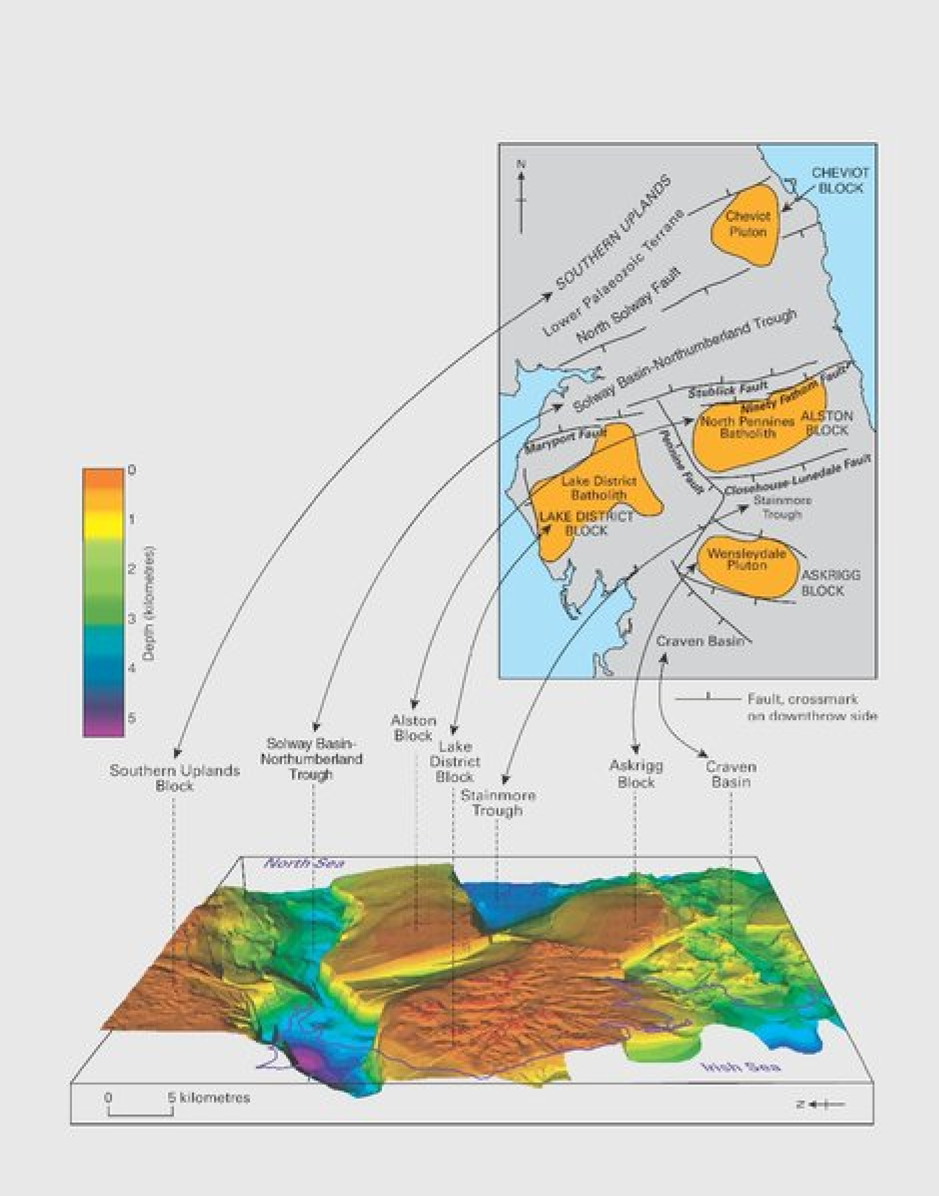

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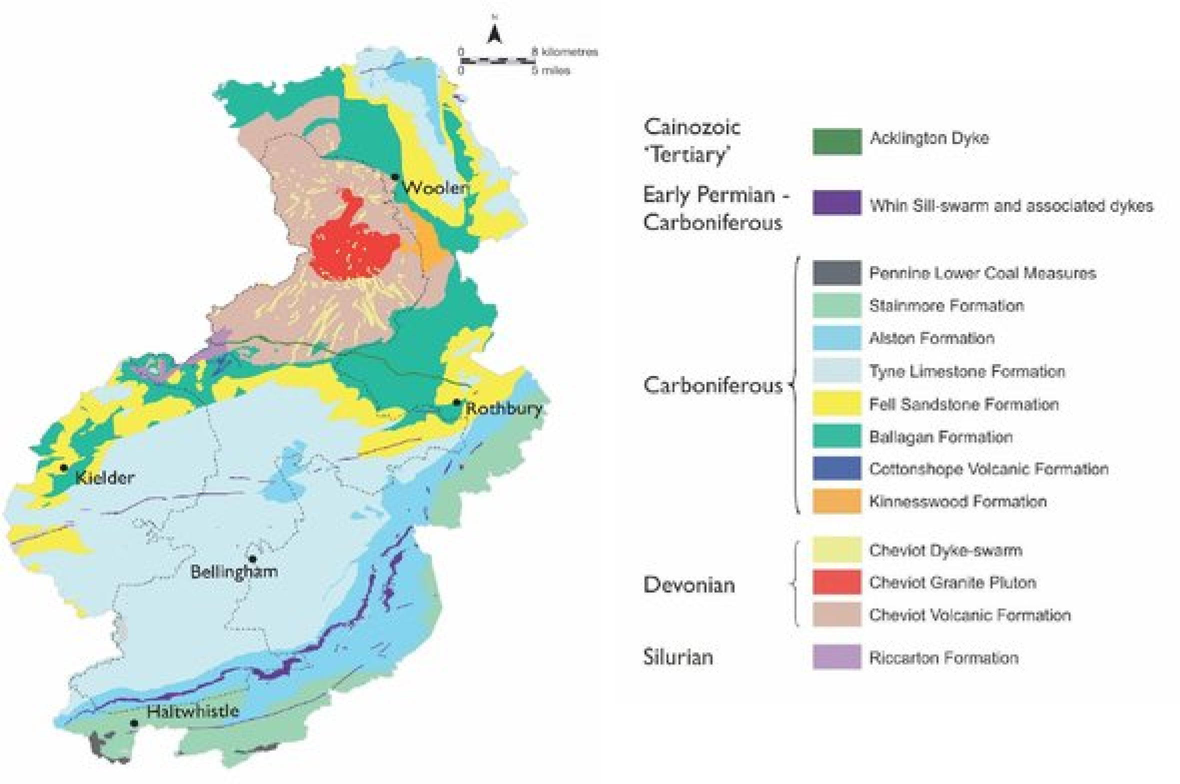

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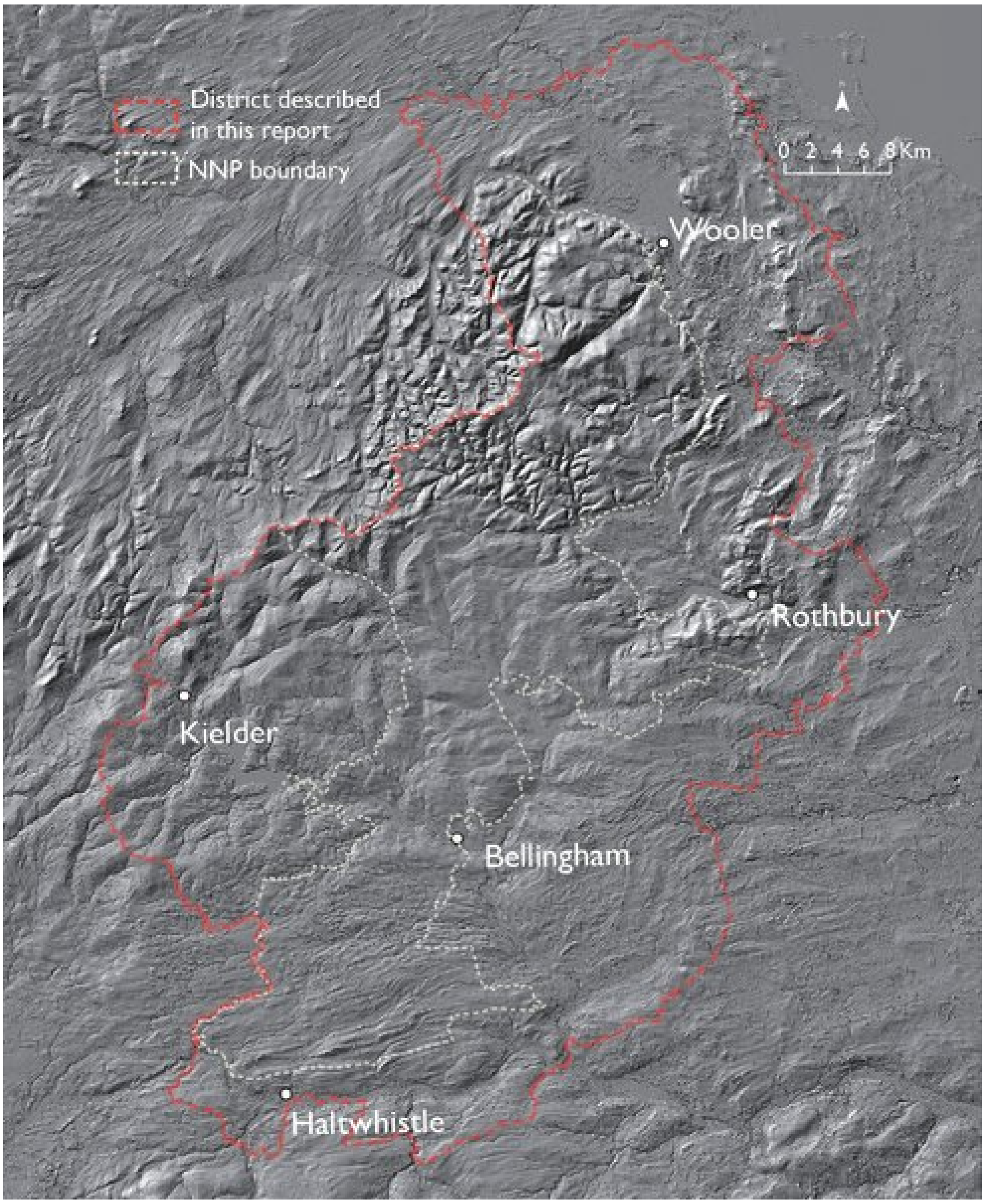

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