Late Mesozoic and Cenozoic tectonics and magmatism, Northern England

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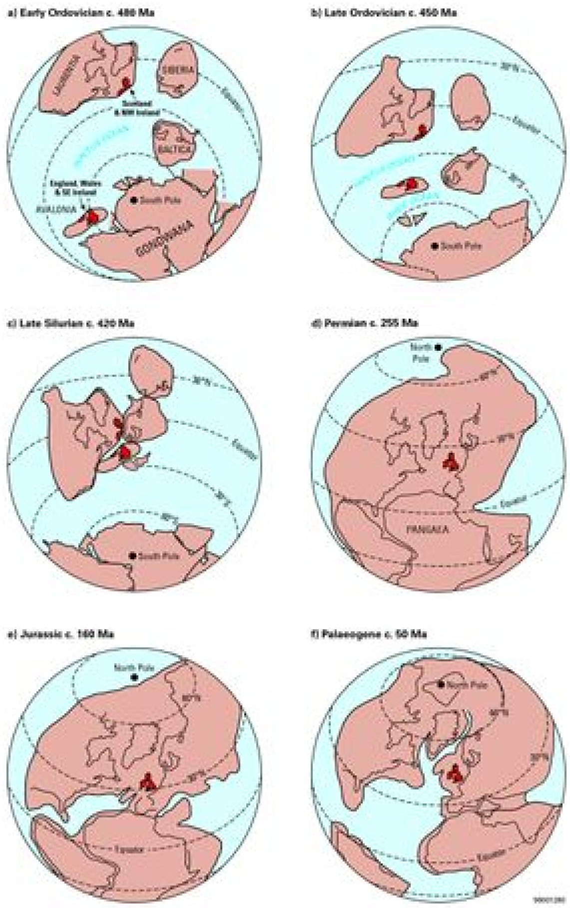
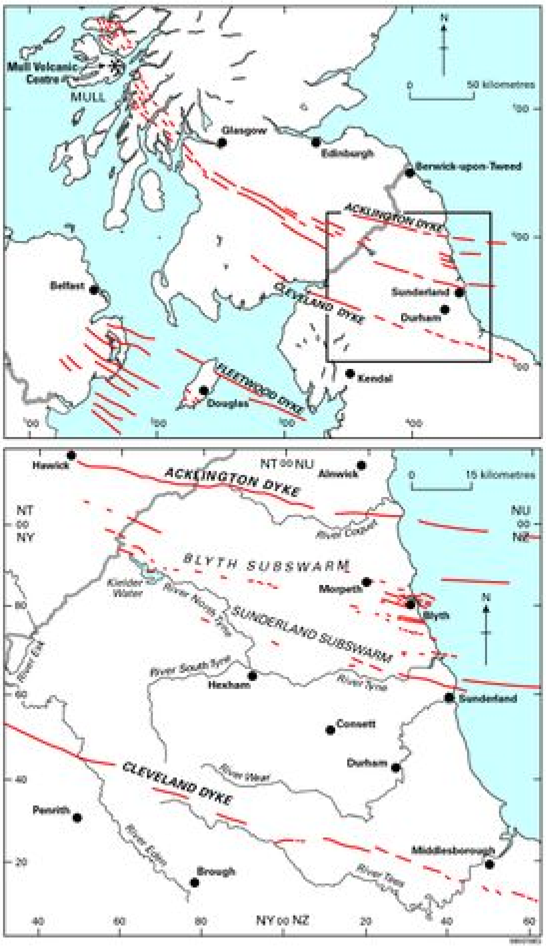
Introduction



Series of palaeogeographical reconstructions showing continental movements from the Ordovician to the

Palaeogene (after Woodcock and Strachan, 2000). P916033.



Distribution of Palaeogene dyke swarms across northern England and the surrounding regions. P916087.

Dolerite of the Cleveland Dyke exposed in the River Eden at Armathwaite [NY 5035 4538]; the dyke is here intruded into Permian strata of the Penrith Sandstone Formation, Appleby Group. (P221883).

Almost 190 million years elapsed between deposition of the youngest, Lias Group, rocks preserved in the Carlisle Basin and the onset of the Quaternary glacial episodes, yet the geological record in northern England now provides little evidence of the original distribution, lithology, thickness and stratigraphy of the deposits laid down during this time. It is widely agreed that Mesozoic rocks once covered much of the region, well beyond their present distributions in the Solway, Irish Sea and North Sea basins, whereas the nearest Cenozoic sedimentary sequences preserved are in Northern Ireland and in the southern parts of the Irish Sea and North Sea. Some knowledge of the events that occurred during this long interval is crucial to understanding how the region looks today. A broad picture can be pieced together by extrapolating stratigraphical and structural information from contiguous regions, and by deducing the burial history of the surviving rocks and hence the original thickness of the now-eroded cover. Techniques that address the latter problem include: studies of the variation in the physical properties of rocks with depth in boreholes, estimation of palaeotemperatures from the increasing reflectance of vitrinite particles and the colour of spore and conodont fossils (which darken with rising temperature), and from apatite fission-track analysis. The last method is based on the radiation damage suffered by individual crystals and the degree to which they have been annealed by rising temperature. The results have proved controversial, as these methods of investigating the burial history depend on assumptions that are not independently verifiable; a consensus on what is considered to be geologically reasonable has emerged only recently.

It is likely that the Jurassic sedimentation pattern that had been established in the Carlisle, Irish Sea and North Sea basins continued into Early Cretaceous time. However, around that time, areas such as the Lake District and Pennine blocks were eroded once again, as the widespread, late Cimmerian unconformity developed. Regional, post-rift shelf subsidence then dominated across the southern UK during Late Cretaceous times and probably extended to northern Britain, resulting in deposition of a relatively uniform Cretaceous sequence, dominantly of the Chalk Group. Maximum post-Variscan burial of the region is thought to have been attained towards the end of the Cretaceous Period, though in the Cleveland Basin, to the south-east of the region, maximum burial may have been attained a little later, in Oligo-Miocene times.

Northern England was affected by distant events of epic proportions during the Cenozoic Period. Regional uplift in Late Cretaceous to early Paleocene times established the region as land once again and triggered an episode of erosion that has continued, probably with little interruption, until the present day. The cause is believed to have been thermal uplift along the north-west margin of Europe as a precursor to the formation of new oceanic crust and opening of the North Atlantic Ocean. This was initiated by the impact of the proto-Icelandic mantle plume on the base of the lithosphere in a pre-Atlantic region that included the west coast of Scotland, Northern Ireland and eastern Greenland (P916033). This area became the focus of intense magmatism from about 60 to 55 Ma during which time immense volumes of basaltic magma were erupted from fissures and central volcanoes, with the accompanying intrusion of central-complexes, dyke swarms and sills. Swarms of tholeiitic basic dykes emanated from these main centres; some from Mull reached northern England, up to 420 km from their source, whilst dykes from Northern Ireland centres cross the Isle of Man and extend across Wales into the English Midlands.

Later, probably in Miocene times, a further major episode of uplift affected the Irish Sea and Carlisle sedimentary basins, probably as a distant effect of the Alpine Orogeny. This arose from the collision, away to the south, of the African and European plates. As a result of the two major tectonic uplift events in northern England during the last 65 million years, it is estimated that between 700 and 2500 m of strata have been removed by erosion, including the entire cover of Upper Jurassic and Cretaceous rocks.

Jurassic to early Cretaceous extension

Comparison with regions to the south and east, where the stratigraphical record of this interval is more complete, suggests that the extensional basins in and adjacent to, northern England continued to develop through normal faulting well into Early Cretaceous times. In west Cumbria, fault displacement demonstrably postdates the Sherwood Sandstone Group within the hanging-wall block of the Lake District Boundary Fault, whilst several faults in the Carlisle Basin displace Lias Group rocks. Moreover, up to one third of the total displacement on the Keys Fault in the western part of the East Irish Sea Basin has been estimated as due to post-Triassic movement, and thus, by analogy, significant throws may also have occurred at this time on other similarly orientated structures in the region, such as the Pennine and Lake District Boundary Fault zones. Supporting evidence for post-Triassic movements on the latter is provided by Early Jurassic to Early Cretaceous radiometric ages determined on minerals within fault gouge.

Palaeogene magmatism

Palaeogene dykes in northern England have a consistent east-south-east trend and have long been considered to originate from the Mull Centre (P916087). Detailed geochemical studies and a K-Ar radiometric age of 55.8 ± 0.9 Ma on the Cleveland Dyke confirm this connection. The orientation and petrography of the Palaeogene dykes readily distinguish them from the more west-to-east dykes associated with the earlier Whin Sill-swarm. Two conspicuous Palaeogene dyke arrays are present in northern England (P916087) and cause prominent aeromagnetic anomalies. The first is the Acklington Dyke, which intrudes Silurian to Carboniferous rocks from the Scottish Borders, through Northumberland into the North Sea. The second cuts Carboniferous to Jurassic rocks through the Vale of Eden, North Pennines and the North Yorkshire moors; it comprises a set of mostly vertical, en échelon segments that are collectively known as the Cleveland (or Armathwaite) Dyke (P221883). In addition, numerous other, similarly trending dykes of the Blythe and Sunderland subswarms are locally exposed in several parts of Northumberland and on the east coast between Blythe and Sunderland, with more encountered during coal mining in the Northumberland and Durham Coalfield. Locally, inclined lenticular and broadly concordant laccolith-like bodies are linked to the dykes.

Whereas most of the dykes are rarely more than 5 m wide, the Acklington and Cleveland dykes locally attain widths of 30 m, though the Cleveland Dyke is typically 22 to 28 m wide. Collectively these dykes derived from a huge volume of magma. For the Cleveland Dyke alone, this has been estimated to be at least 85 km3. Further, numerical modelling suggests that this dyke represents a single pulse of magma that spread laterally from a magma reservoir beneath Mull at a velocity of up to 18 km per hour, reaching its farthest extent in 1 to 5 days. Where magma rose vertically, en échelon dyke segments were produced.

The contact metamorphic aureoles adjacent to the dykes are typically very narrow and mining records show that coking of coal seams appears to have been much less than that associated with the earlier dykes of ‘Whin Sill’ affinity. During mining, some of the dykes were found to contain cavities up to 4 m by 7 m. These are thought to represent xenoliths of coal that were gasified after incorporation in the magma.

The dykes are dark grey or bluish grey, locally amygdaloidal, fine-grained to glassy basalt and basaltic andesite. Petrologically they are composed of essential plagioclase enclosed within pyroxene, with patches of microcrystalline or glassy mesostasis. Though the Acklington Dyke is not porphyritic, some of the others are conspicuously so. For example, the basaltic andesite Cleveland Dyke contains up to 4 per cent phenocrysts of plagioclase, with subordinate orthopyroxene and clinopyroxene but with no olivine, either as phenocrysts or in the groundmass. Minor olivine is present elsewhere, for example in some of the dykes exposed in the Bellingham area of Northumberland. The Tynemouth Dyke is characterised by conspicuous anorthite phenocrysts.

Throughout its length, the Cleveland Dyke is remarkably uniform geochemically, but chemical and petrographical data indicate a magmatic history that involved fractional crystallisation at several depths in the crust with minor amounts of crustal contamination of the magma. Locally, inclusions of gabbro and cumulate-textured plagioclase represent relicts that crystallised in the shallow magma chambers where the final composition prior to intrusion was produced. Ovoid inclusions of devitrified glassy material represent liquid remaining from the final crystallisation of the dyke.

Olivine dolerite dykes with an east-south-east trend are scattered throughout the Isle of Man and linear aeromagnetic anomalies show that the dyke swarm extends offshore. The dykes seem to be most abundant cutting the southern outcrop of Carboniferous rocks, but a 12 m wide dolerite dyke exposed in the northern part of the island forms a segment of the Fleetwood Dyke, which the aeromagnetic data suggests is one of the most prominent in the Manx region (P916087). It is not a single intrusion but a set of dykes, arranged en échelon and associated with inclined sheets, that was emplaced along a fault zone traversing eastsouth-east across the Irish Sea towards the Lancashire coast. The Palaeogene dykes of the Isle of Man appear to radiate from a centre in Northern Ireland.

Cenozoic uplift and basin inversion

Estimates of Cenozoic exhumation from apatite fission-track studies suggest that some 700 m of strata, mainly Late Cretaceous and possibly Permian and Triassic in age, were removed from the Scafell area of the central Lake District, whereas erosion of a more complex sequence of Carboniferous to Cretaceous rocks from the area around the West Newton Borehole, just to the north of the Maryport Fault in north Cumbria, amounted to about 1550 m. The difference in these figures approximates to the current difference in the elevation of the two localities above sea level.

Compressive uplift of the Carlisle Basin occurred probably during Miocene times. This process is referred to as inversion: pre-existing extensional faults are reactivated with a reverse sense and strata are folded. Up to about 2500 m of a mainly Jurassic and Cretaceous succession are thought to have been removed during basin inversion, with the Lias Group accounting for as much as 1500 m of this thickness within the depocentres, thinning to about 600 on the intervening saddle areas. Any overlying Middle Jurassic to Lower Cretaceous strata were either an originally thin sequence, or had been removed prior to deposition of 600–800 m of Upper Cretaceous Chalk Group rocks that are thought likely to have capped the succession. The Lower Jurassic strata in the outlier near Carlisle are situated on one of the saddle areas and have been preserved because they lie within an area that was less affected by inversion than the depocentres.

Palaeotemperatures inferred from conodont colours in the Lower Carboniferous rocks of north Northumberland and the Permian rocks of Durham suggest that Mesozoic cover in the area is unlikely to have been greater than about 2000 m. Farther south, the removal from the centre of the Cleveland Basin of about 2500 m of post-Middle Jurassic cover is required to explain the depth of burial inferred for this region; Palaeogene rocks may have accounted for up to 1000 m of this thickness. The Lake District and North Pennines may have been emergent throughout Palaeogene times, though it is possible that some strata were laid down on these block areas during Miocene basin inversion.

Inversion of the East Irish Sea basins was associated with the formation of hanging-wall anticlines during reversal of earlier normal faults. These effects are particularly well displayed by the Maryport and Lagman faults which form the margins of the south-west-trending Ramsey–Whitehaven Ridge, and by faults in the Coastal Plain Fault System to the west of the Lake District Boundary Fault Zone. Reverse displacement on faults within the Lake District Boundary

Fault Zone seems probable because apatite fission-track studies suggest that Cenozoic uplift of the East Irish Sea was some 500 m greater than that of the Lake District. Displacements on faults in other parts of the region at this time are also likely, notably in the Cheviot Hills, though convincing evidence is lacking.

Though other explanations are feasible, the tantalising prospect of Quaternary fault displacement is suggested by high-resolution seismic reflection data from Holmrook, southeast of Gosforth in west Cumbria. Small steps a few metres in height imaged at the interface between bedrock and the overlying superficial deposits are close to the inferred position of strands within the Lake District Boundary Fault Zone and would be consistent with Quaternary fault reactivation. Furthermore, the impressive Pennine Fault scarp is locally more than 500 m high and appears to be a geomorphologically young feature, as do fault scarps within, and bounding, the Cheviot Hills. Intermittent, small-magnitude earthquakes, felt particularly in the western half of the region, confirm that some faults remain active in northern England. The recently reactivated movement of certain faults in the Magnesian Limestone of eastern County Durham, due to rising groundwater in abandoned coal workings is discussed in Chapter 12.

No Cenozoic sediments are known to have survived in the region, though the products of pervasive weathering during this time may have been preserved locally. Possible examples are to be found around Buckbarrow in the south-west Lake District, in the Cheviot Hills and in the North Pennines. At Buckbarrow, rocks of the Borrowdale Volcanic Group are completely altered to a clay deposit up to at least 10 m thick. Both the Cheviot volcanic rocks and the Cheviot Granite are intensely altered and disintegrated in parts to depths of between 2 and 50 m; the residual sand and clay is referred to as saprolite. At Holwick Scars, in the North Pennines, the Great Whin Sill is rotted to a depth of up to 15 m. In all of these localities, the remarkable preservation of igneous and pyroclastic textures in the 'deposit' shows that transformation occurred in situ. Reminiscent of deeply weathered rock profiles seen in some present day humid tropical regions, formation of these deposits in early Cenozoic time would accord with the fact that this was globally one of the warmest episodes of Phanerozoic Earth history. Alternatively, the saprolite may have formed during warm, humid conditions later in Cenozoic times. A different origin seems more likely for the intense, argillic alteration of the Broad Oak Granodiorite in the southern part of its outcrop, contiguous with the Borrowdale Volcanic Group example above. There, the transformation may have been caused by circulating hydrothermal fluids and not by weathering processes.

The enigmatic palaeokarst clays of the Asby area, south-east of Shap, may also originate from this time, though deposition probably occurred during Quaternary ice movements. There, solution hollows in the karst surface of the Dinantian limestones are filled with a massive, tenacious red clay deposit containing sporadic striated pebbles and a flora that includes Carboniferous spores and long-ranging forms that are most likely Quaternary. Abundant leaf cuticle material was probably derived locally from a rich herbaceous flora, but abundant kaolinite and chlorite in the clay suggests that this component may have been derived from deeply weathered granite and volcanic rocks. Thus, these 'pocket deposits', which are also known from the karst of Derbyshire, may have been sourced from deeply weathered rocks in the Shap Fells and smeared into the karst surface by ice during Quaternary times.

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