Intrusive igneous rocks

Intrusive igneous rocks are those which have formed by being intruded (emplaced) as molten rock, or magma, into the surrounding rocks. They are distinguished from volcanic, or extrusive igneous, rocks by having crystallised and cooled at depth within the earth's crust. Such intrusions may take a number of forms, including widespread more or less horizontal sheets, known as sills; more or less vertical sheet-like bodies, known as dykes; and very large, often rather irregular, bodies known as batholiths. Intrusions may be of various geological ages. Intrusive igneous rocks, of a great variety, compositions, ages and forms are extremely common in parts of Great Britain.

Intrusive igneous rocks, which are exposed at the surface due to millions of years of erosion, give vital information on a great variety of geological processes which have operated deep within the earth's crust over many millions of years of earth history. A variety of sophisticated analytical techniques can be used to date the crystallisation of certain minerals within these rocks. These dates, when interpreted along with other geological evidence, provide an extremely valuable means of assigning accurate dates to key events in earth history.

Geological SSSIs

In GCR Block “Carboniferous — Permian Igneous"

SSSI Name/GCR Name/Grid Reference

Upper Teesdale/Whin Sill Exposures in Upper Tees [NY 880 225]

These include:

Cauldron Snout, Upper Teesdale [NY 815 286]

Force Garth Quarry (now known as Middleton Quarry), Upper Teesdale [NY 873 282]

High Force, Upper Teesdale [NY 880 283]

Low Force and Wynch Bridge, Teesdale [NY 905 279]

Falcon Clints, Upper Teesdale [NY 820 281] Cronkley Fell [NY 831 282]–[NY 854 282]

In addition, the following important exposures of Great Whin Sill lie within the Moorhouse–Upper Teesdale National Nature Reserve and the Appleby Fells SSSI:

Red Sike and Widdybank Fell, Upper Teesdale [NY 818 296]

Cow Green Reservoir, Upper Teesdale [NY 815 294]

Holwick and Crossthwaite Scars, Teesdale [NY 898 271]–[NY 927 253]

Durham County geological sites

Caledonian Minor Intrusions:

Cronkley Pencil Mill, Upper Teesdale [NY 848 296]

Great Whin Sill:

Greengates Quarry, Teesdale [NY 934 236]

Horsley Burn Waterfall, Eastgate [NY 975 384]

Killhope Burn, Copthill Quarry and Wear River at Burtreeford Bridge [NY 855 406]

Scoberry Bridge to Dine Holm Scar [NY 910 274]

Widdybank Fell [NY 820 290]

Wynch Bridge, Langdon Beck [NY 820 290]

Intrusive igneous rocks in County Durham

Outcrops of Intrusive Igneous rocks comprise approximately 2,523 hectares, or about 1%, of the surface area of County Durham (Figure 20).

Intrusive Igneous rocks of several ages and compositions occur within the county.

One major intrusion, the Weardale Granite, does not reach the surface and has been proved only in the Rookhope Borehole, but has been a major factor in the geological evolution of the north of England (see The Geological Evolution of County Durham). The term 'minor intrusion' is commonly applied to small bodies, or groups of small bodies, of intrusive igneous rock.

The intrusive igneous rocks of the area are reviewed briefly according to their ages of emplacement.

Caledonian intrusions

These rocks were emplaced during the long and complex series of earth movements which affected the area that was to become the UK, between roughly 500 and 390 million years ago. Within County Durham it is possible to recognise two groups of intrusive igneous rocks which date from this period.

The Weardale Granite

The pattern of mineralisation in the Northern Pennines, and comparisons with areas such as SW England, together with geophysical evidence, led to speculation that a concealed granite might be present at depth beneath the North Pennines. This hypothesis was tested in 1960–61 with the drilling of the Rookhope Borehole which proved granite at a depth of 390.5 metres. However, as the granite proved to have a weathered top, it was clearly much older than originally supposed. Radiometric dating of the granite gives it a geological age of crystallisation of 410 ± Ma, proving it to be a Caledonian intrusion.

Geophysical studies suggest that the Weardale Granite is part of a very large concealed batholith, which is likely to be some 60 by 25 kilometres in extent. These same studies suggest that the batholith has several high spots, or cupolas, on its upper surface which reach within a few hundred metres of the surface at such places as Rookhope, Rowlands Gill, Tynehead and Scordale.

Caledonian minor intrusions

Within County Durham, minor intrusions of Caledonian age are represented by the lamprophyre dykes which cut the Ordovician Skiddaw Group mudstones at Pencil Mill, near Cronkley in Upper Teesdale.

Permo-Carboniferous basic sills and dykes — the Whin Sill Suite

In late Carboniferous times and early Permian times, widespread earth movements beneath the area that eventually became Great Britain, caused fracturing and extensive stretching of the crust, allowing huge quantities of molten rock, or magma, to rise from deep within the Earth. In Northern England this magma did not reach the surface, but spread widely as sheets between the layers of pre-existing rocks, where it slowly cooled and crystallised to form the largest and most

extensive suite of intrusive igneous rocks in Northern England, collectively termed the Whin Sill or the Great Whin Sill.

The intrusion of such large volumes of molten rock, at temperatures in excess of 1000°C had profound effects upon the surrounding rocks, causing widespread intense alteration, or metamorphism, with the development of a range of distinctive metamorphic minerals and textures. A variety of hydrothermal minerals formed as joint fillings during the final cooling stages of emplacement of these intrusions.

The Great Whin Sill

This complex underlies much of North East England, including most of County Durham. It typically comprises an extensive series of sills with some associated dykes, and is composed of tholeiitic quartz-dolerite which exhibits a remarkable continuity in mineralogical and chemical composition across its extensive outcrop. By far the greater part of the complex consists of fine-to medium-grained dolerite, though fine-grained, chilled tachylitic contact rocks are common, and very coarse-grained dolerite pegmatite veins and segregations are common locally. Crude columnar joining is conspicuous in most exposures. The sill reaches its maximum known thickness of around 70 metres in Teesdale and in West Allendale, Northumberland, a short distance north of the county boundary.

Radiometric dating reveals an age of around 295 million years for the Whin Sill. Palaeomagnetic studies reveal that at the time of its crystallisation the area lay within tropical latitudes.

The Little Whin Sill

Over much of the county the Whin Sill exists as a single roughly horizontal sheet. However, in the Rookhope and Stanhope area of Weardale a much thinner upper leaf of the intrusion, known as the Little Whin Sill is present.

Both leaves of the sill were proved in the Rookhope Borehole. The Little Whin Sill typically comprises fine- to very fine-grained dolerite similar in composition to much of the Great Whin Sill. Unlike the main sill, the Little Whin Sill dolerite is distinguished by the presence of tiny phenocrysts of olivine, or pseudomorphs after olivine, within the lowest parts of the intrusion.

Dykes associated with the Whin Sill:

Several dykes are associated with the sill, some of which may have acted as feeders during its emplacement. Several of these have been given local names in the geological literature. These include:

The Greengates Dyke — This crops out on the north side of Lunedale, Lunedale [NY 933 234].

The Connypot Dyke — This crops out in the headwaters of the River Lune [NY 813 207].

The Hett Dyke — This can be traced intermittently for many miles from exposures in the Egglestone Burn [NY 985 258] to the Bowburn area [NZ 320 383]

The Wackerfield Dyke — This is exposed locally in the Wackerfield area [NZ 158 227]

The Brandon Dyke — This can be traced intermittently for several miles from near Quarry Hill, north of Brancepeth [NZ 212 389] to the neighbourhood of Shincliffe Colliery [NZ 304 401]. A second parallel dyke is present locally in the easternmost part of the outcrop.

The Ludworth Dyke — This is known, only from underground coal workings, to extend intermittently from south of Shincliffe [NZ 296 392] to the sub-marine coal workings in the Easington area [NZ 447 438].

Palaeogene intrusive rocks

During Palaeogene, or Tertiary, times, enormous earth movements associated with the opening of the Atlantic, resulted in extensive volcanic activity in the area we know today as the Hebrides and parts of Northern Ireland. In addition to the

huge thicknesses of lavas which were erupted in these areas, large bodies of intrusive igneous rocks were emplaced beneath the volcanic centres. Stresses in the earth's crust at this time caused cracking of rocks to extend in a radial pattern for many miles away from the volcanic areas. As they developed deep beneath the surface, these cracks were filled with basaltic magma, forming a series of extremely long dykes, which may be traced across much of Northern England.

Cleveland–Armathwaite Dyke

Within County Durham, the most extensive group of Palaeogene intrusions is the echelon of dykes collectively known as the Cleveland–Armathwaite Dyke, which derives its name from its outcrop across northern England, from the Cleveland Hills in East Yorkshire, to Armathwaite in the Vale of Eden in Cumbria, and which forms part of a group, or 'swarm', of dykes centred on the Island of Mull.

These dyke rocks are dolerites which may be readily distinguished from those of the Whin Sill by their porphyritic character, with small phenocrysts of feldspar and pyroxene set in a dark grey fine- grained matrix. A minimum age of around 55 Ma has been established for these rocks.

A small dyke up to about 5 metres wide, in the Bolam area, close to and parallel to the Cleveland- Armathwaite dyke, has been referred to as the Lough House Dyke.

Influence on the landscape

As it does not reach the surface the Weardale Granite has no direct affect on the landscape character of the county. However, its buoyancy effect within the basement rocks of the Northern Pennines has long influenced the geological history of the area throughout much of Carboniferous and later time. This continued buoyancy effect partly accounts for the upland nature of the western part of the county today.

The surface outcrop of the Caledonian minor intrusions is extremely limited and, apart from forming very small craggy exposures close to the river bank, their impact upon the landscape is very small.

Because of its hardness and resistance to erosion, the outcrops of the Great Whin Sill comprise some of the best known and most dramatic landscape features of Teesdale, in the west of the county. Most extensive of the natural exposures are the sombre cliffs of Crossthwaite, Holwick and Cronkley scars, as well as the waterfalls of High Force, Low Force and Cauldron Snout. Prominent crude columnar jointing is conspicuous in all of these natural exposures. It is also very well exposed in several large abandoned quarries along its outcrop on the southern side of Teesdale, and on the north side of the river at the long-abandoned High Force Quarry.

The outcrop of The Little Whin Sill is restricted to a small area of Weardale between Eastgate and Stanhope. The Little Whin Sill gives rise to low waterfalls in the Rookhope Burn at Turnwheel Linn, Rookhope and in Horsley Burn, near Stanhope. At Stanhope the River Wear flows through a narrow channel cut through the resistant dolerite of the Little Whin Sill. Between Eastgate and Stanhope the outcrop is marked by a low scarp feature, in which small exposures of columnar jointed dolerite are locally visible. Spectacular cliffs of columnar jointed dolerite are also present in the faces of the long- abandoned and flooded workings of Greenfoot Quarry, near Stanhope.

Dykes associated with the Whin Sill

The Greengates Dyke has been quarried on a significant scale at Greengates Quarry, Lunedale [NY 934 236], which now comprises a conspicuous landscape feature.

The course of the Hett Dyke may be traced in a series of old quarries, for example in the Eggleston [NY 9896 2610] and Hett [NZ 280 368] areas.

The Wackerfield Dyke locally forms a well- marked feature in the vicinity of Tunnelmire Plantation [NZ 1732 2325], and has been quarried north-east of Wackerfield village.

The course of the Brandon Dyke is marked by long-abandoned quarries in the High Houghall area [NZ 2749 3965] and [NZ 2722 3954].

The Ludworth Dyke does not crop out at the surface and thus has no impact upon the landscape.

The impact upon landscape of the Palaeogene dykes today derives mainly from their former working in quarries along their outcrops. Most conspicuous are the extensive deep quarries, resembling railway cuttings, excavated in the Cleveland–Armathwaite Dyke in the Cockfield area, though landfilling operations in recent years have destroyed some of the most spectacular exposures.

Outcrops of the Cleveland–Armathwaite Dyke in the Bolam area have also been extensively quarried, though landfilling here has obliterated most exposures.

The Lough House Dyke has little impact upon the landscape.

Influence on biodiversity

Where free, or almost free, of superficial deposits, the county's intrusive igneous rocks typically give rise to rather thin acid soils. These locally support populations of bell-heather, together with heather (ling), bilberry, cowberry and some bearberry. The Whin Sill block screes may locally host parsley fern. Fissures between larger blocks of Whin Sill dolerite provide refuges for trees such as aspen, rock whitebeam and juniper, which represent relics of former woodland. At higher altitudes these blocks may provide habitats for arctic-alpine herbs.

Tall cliffs of Whin Sill provide nesting sites for a number of birds as indicated by names such as Falcon Clints and Raven Scar.

Economic use

The Weardale Granite has only ever been sampled in the Rookhope Borehole and has never had any economic use, though its potential as a source of feldspar for the ceramics industry was contemplated at Cambokeels fluorspar mine in the 1980's.

The hardness and roughness of the dolerite of the Great Whin Sill, the Little Whin Sill, and associated dykes, makes these good sources of roadstone and aggregate which have been worked in numerous quarries. Most conspicuous are those in Teesdale. Several substantial abandoned quarries are conspicuous in the outcrop of this intrusion between Middleton and High Force, and in the Greengates Dyke at Greengates Quarry, Lunedale. The Whin Sill within the Burtreeford Disturbance was formerly quarried at Copthill Quarry, Cowshill, and the Little Whin Sill was also worked for roadstone at Greenfoot Quarry, Stanhope. Force Garth Quarry [NY 873 282], near High Force, is the sole remaining producer of Whin Sill dolerite in County Durham.

The Palaeogene dykes have been worked as sources of roadstone and aggregate at several localities. None is worked today and many of the largest and geologically most instructive exposures have been obliterated by landfilling.

Because of their hard, intractable nature, none of the county's intrusive igneous have ever been employed as building stones except locally in dry stone walling near accessible outcrops.

Future commercial interest

The extent of future working at Force Garth Quarry [NY 873 282] is dependent upon a range of commercial and planning considerations, though reserves of workable rock appear to be substantial.

At the time of writing no plans are known for any resumption of quarrying from abandoned quarries within the Whin Sill. Renewed working from these, or attempts to open quarries at virgin sites, seems unlikely.

Commercial interest in working of any of the county's other intrusive igneous rocks is extremely unlikely.

Working of the Weardale Granite, as discussed above, is extremely unlikely unless a revival of fluorspar mining led to working veins in the granite.

The Weardale Granite is known to be a 'high heat production' granite. Investigations into its potential as a source of geothermal energy in the 1980's did not result in commercial trials. However, interest in possible sources of sustainable, 'green', energy sources as part of long-term plans for after-use of the Eastgate Cement Works site have recently revived interest in the geothermal potential of the Weardale Granite, or sources of thermal groundwater known within the workings of Cambokeels fluorspar mine.

Threats

Natural exposures of intrusive igneous rocks are generally robust. However, abandoned quarries are at risk of becoming overgrown or degraded. Backfilling as landfill sites or as parts of other land reclamation schemes may threaten to damage or obliterate important sections. Haggerleases Quarry, Cockfield [NZ 1155 2549] and Bolam Quarry, Bolam [NZ 199 226] are good examples of sites damaged or obscured in this way. All abandoned quarries in these rocks may be perceived as 'at risk'.

Wider significance

The proving of the Weardale Granite in the Rookhope Borehole was a major contribution to understanding the geological structure of Northern England. The influence of the granite on the geological evolution of northern England extends far beyond County Durham. Its role in the formation of the metalliferous deposits of the Northern Pennines has contributed greatly to the development of hypotheses on ore genesis in this and similar orefields worldwide.

As it is regarded as the original sill of geological science, the Whin Sill may be regarded as one of the key natural heritage features within the county. It takes its name from the north of England quarryman's term 'sill' for any more or less horizontal body of rock, and 'whin' meaning a hard, intractable, black rock. The recognition, in the 19th century, of its intrusive origin, quickly led to the term 'sill' being adopted by geological science throughout the world for all concordant horizontal intrusive bodies of this sort.

The Whin Sill, and its associated intrusions, is one of the most studied geological formations within the county with a voluminous technical literature.

The Palaeogene dykes give important evidence of geological processes which operated far beyond County Durham.

Selected references

Hirst and Dunham, 1963; Hutton, 1831; Magraw, 1963; Pattison, 1986; Sedgwick, 1829; Smith, 1970, 1971, 1981, 1995, 1994; Smith and Francis, 1967, Smith et al. 1974; Smith et al. 1986.

(Photo 43) West Rigg Opencut, Westgate, Weardale. Worked out iron ore flats adjoining Slitt Vein. The vein remains as an unworked pillar in the centre of the quarry. B Young, BGS, ©NERC, 2004.

(Photo 44) Ankerite and galena-rich flat in Great Limestone. Wellheads Hush, Weardale. B Young, BGS, ©NERC, 2004.

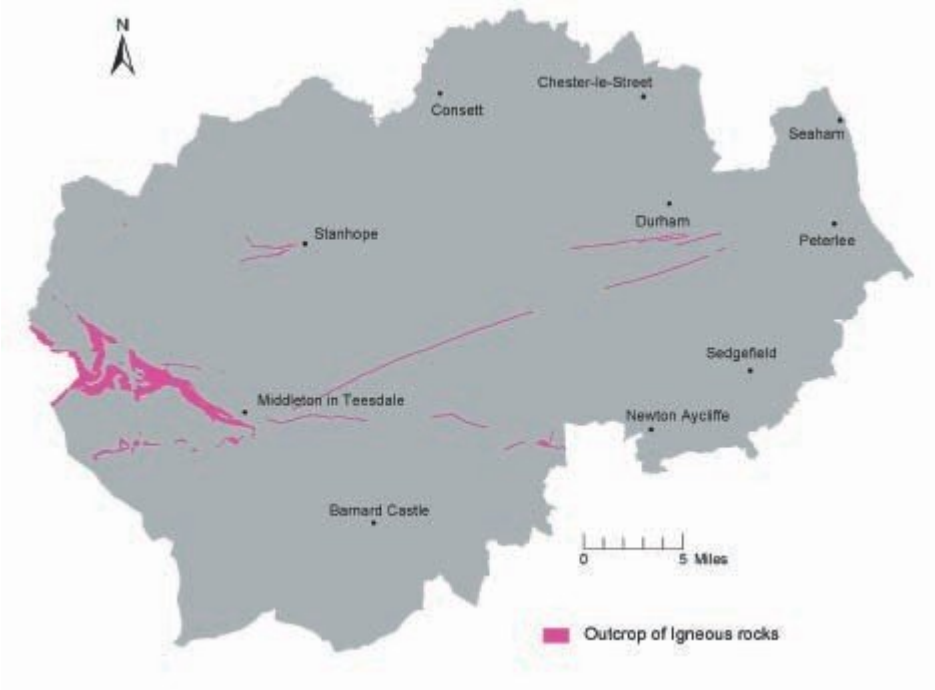
(Photo 45) Raisby Railway Cutting, Coxhoe. Exposure of copper mineralisation in Magnesian Limestone adjoining the Butterknowle fault. B Young, BGS, ©NERC, 2004.

(Photo 46) Queensberry Ironstone Workings,Cowshill, Weardale. Long-abandoned and overgrown workings in ironstone flats adjacent to the Burtreeford Disturbance. B Young, BGS, ©NERC, 2004.

(Photo 47) Groverake Mine, Rookhope. Surface plant and buildings of County Durham's last fluorite mine. B Young, BGS, ©NERC, 2004.

(Photo 48) Aerial view of Groverake Mine, Rookhope. The course of Groverake vein is marked at the surface by a line of large crown holes. Infoterra.

Full references



(Figure 20) Distribution of intrusive igneous rocks in County Durham.

(Photo 43) West Rigg Opencut, Westgate, Weardale. Worked out iron ore flats adjoining Slitt Vein. The vein remains as an unworked pillar in the centre of the quarry. B Young, BGS, ©NERC, 2004.

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