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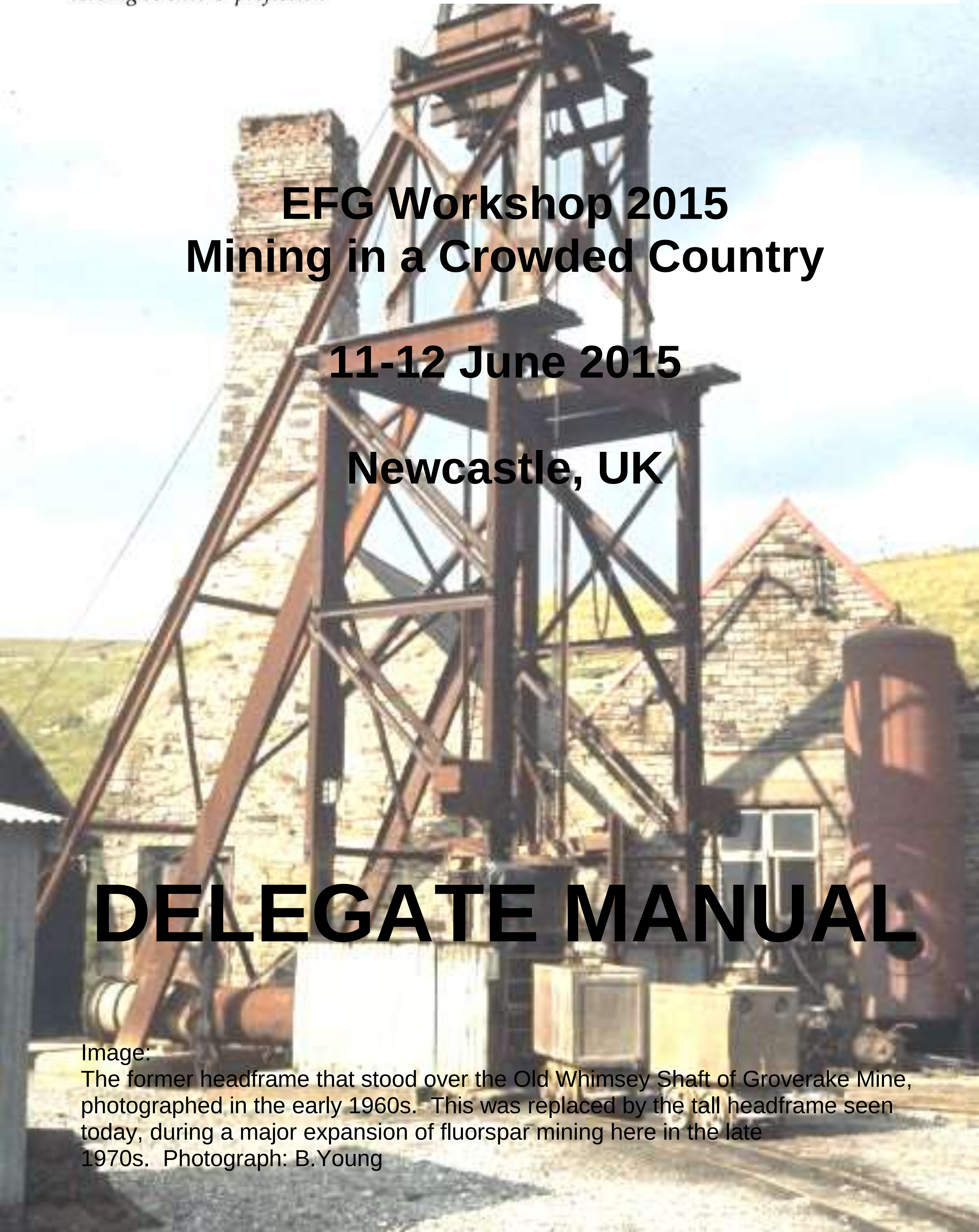

EFG Workshop 2015
Mining in a Crowded Country

11-12 June 2015

Newcastle, UK

DELEGATE MANUAL

Image:
The former headframe that stood over the Old Whimsey Shaft of Groverake Mine, photographed in the early 1960s. This was replaced by the tall headframe seen today, during a major expansion of fluorspar mining here in the late 1970s. Photograph: B.Young

Contents

We gratefully acknowledge the support of the following event organizing partners for making the workshop and field excursions possible:

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Workshop and Field Excursion Programme

Thursday 11 June 2015

09.00	*Registration*
09:10	***Welcome to the North of England Institute of Mining and Mechanical Engineers*** *Catherine Miller, President*
09.15	***Introduction: geology of a busy region*** *David Manning, Newcastle University/Geological Society of London*
09.30	***The future for coal*** *Paul Younger, University of Glasgow*
10.00	***Potash in a National Park*** *Graham Clarke, Sirius Minerals*
10.30	***Tea and coffee***
11.00	***Metals: new life in the North Pennines?*** *Rick Smith, FWS Consultants Ltd*
11.30	***Underwater mining (¡VAMOS!)*** *Stef Kapusniak, SMD Ltd*
12.00	***Discussion***
12.15	***Lunch***
13.00	***Depart for field excursion part 1***
18.00	***Return to Newcastle***
19.30	***Dinner – Blackfriars Restaurant, Newcastle***

Friday 12 June 2015

09.30	***Depart for field excursion part 2***
19.30	***Dinner – Centre of Britain, Haltwhistle***
23.00	***Return to Newcastle***

Field Excursion Information

DAY 1

11 June 2015

Field Excursion Part 1 - The Northumberland Coalfield 11 June 2015

Field excursion leader: David Manning

School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK

INTRODUCTION

The Northumberland Coalfield has a long history of mining bituminous coals, dating back over 200 years. Surface mines are still operating and new surface mines are being planned. Current mining provides an opportunity to correct earlier environmental damage caused by both underground and previous surface mining, leading to the creation of amenity as well as improved landscapes. Exposures of coal-bearing strata are excellent, both in working surface mines and in outcrops along the coast. This field excursion will give participants chance to see modern surface mining methods designed to minimize environmental harm, and to see key geological characteristics of the Westphalian coal-bearing strata.

Key reference:

Turner, B. R and Richardson, D (2004) Geological controls on the sulphur content of coal seams in the Northumberland Coalfield, Northeast England. International Journal of Coal Geology 60 (2004) 169-196.

GEOLOGICAL BACKGROUND

The Westphalian sequence in north-east England (Figure 1), described locally as 'Coal Measures', was deposited in a coastal alluvial plain environment, with rivers draining to the south and southwest and the development of deltas that extended into inter-distributary lakes (Turner and Richardson, 2004). Peat-forming vegetation developed on exposed surfaces; periodic flooding drowned the resulting peat mire with lake sediments. Overall, the succession is characterized by coarsening upward deltaic sequences of mudstone, siltstone and sandstone, each sequence being up to 15m thick. Vegetation developed on kaolinitic palaeosols, which are preserved as seat-earths. Sand-filled channels are frequently observed, their bases often containing rip-up clasts of mudstone and coal.

The 750m thick Coal Measure sequence dips gently east-southeast and is overlain unconformably in Newcastle (Tynemouth) by the Permian Yellow Sands (a dune sand complex) and the 'Marl Slate' (equivalent to the Kupferschiefer, but only 1m thick). Coastal exposures present a more-or-less continuous sequence extending north from Newcastle to near Warkworth. Coal-bearing rocks occur north of here within older Carboniferous strata, and were mined in the past. Large-scale industrial mining of coal is confined to the area of Coal Measures shown in Figure 1, in a triangle of land bounded by the River Tyne to the south, the sea to the east, and the subcrop of the Westphalian to the west. As shown in Figure 1, coal mining extended under the sea (until 2005); at present there are plans to exploit offshore coal through coal gasification (Five Quarter Energy Ltd). There are around 30 named coal seams in the coalfield, with varying lateral extent and thickness, and many more thin un-named seams that in some cases can be recovered through careful surface mining.

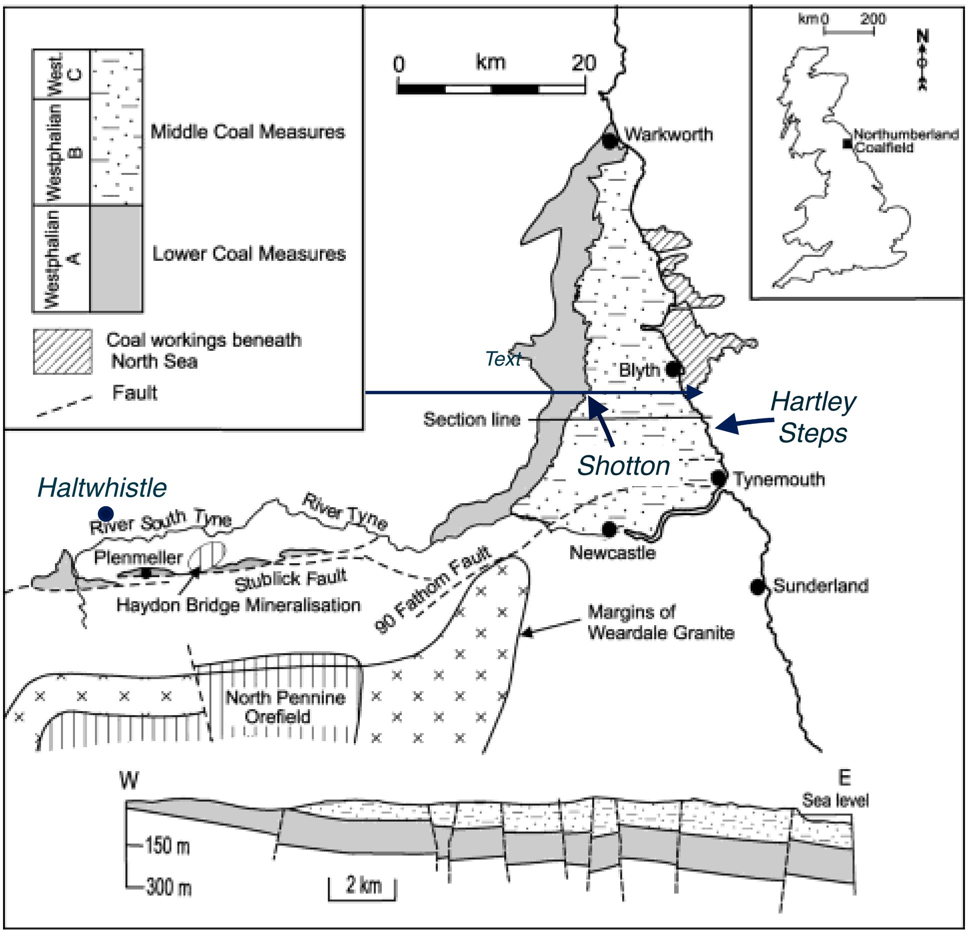

Figure 1.
General geological map of the Northumberland Coalfield (based on Turner and Richardson, 2004).

APPROXIMATE SCHEDULE

Part A: - Present day surface mining and its legacy (courtesy of The Banks Group).

a) 13:30 Shotton Surface Mine

b) 14:15 Northumberlandia

Part B: - 15:30 Coastal outcrops of Westphalian sequence (low water 18:10)

Part C: - 17:00 SMD tour

18:30 arrive back in Newcastle

THE EXCURSION ROUTE

Stops made will depend on a number of factors, including the weather and operational constraints at Shotton surface mine. Hartley Steps is tide dependent.

Stop 1.

SHOTTON SURFACE MINE

Operated by The Banks Group (www.banksgroup.co.uk) the excursion will be divided to enable participants to visit the mine in small groups.

One of a number of surface mines on the Blagdon Estate (the home of Matt Ridley, the 5th Viscount Ridley, author and journalist), Shotton Surface Mine is expected to produce 6 million tonnes of coal and a similar amount of brick clay, fireclay and stone from the 400 ha site until 2018, with progressive restoration that will continue after extraction. The site lies on the boundary between the Pennine Lower Coal Measures Formation and the Pennine Middle Coal Measures Formation, which is marked by the Vanderbeckei Marine Band (characterized by the goniatite Anthracoceratites vanderbeckei). It mines coal mainly from seams in the Lower Coal Measures. A typical vertical face from the adjacent Delhi surface mine (Figure 2) shows the occurrence of coal seams within the overall sequence of mudstones, siltstones and sandstones. Coal is carefully mined from seams exposed by the removal of overburden.

Adjacent to the surface mine, the Charles Jencks sculpted landform Northumberlandia (www.northumberlandia.com) has been constructed using materials derived from the mine. It is a permanent piece of public art, and is part of an overall land restoration plan that will bring a range of benefits once mining has stopped. A clear view of the coal storage area can be seen from Northumberlandia's forehead (Figure 3).

***Figure 2**.*

Coal Measures strata exposed in Delhi Surface Mine, Blagdon Estate, Northumberland (2005).

Figure 3.

Coal storage area at Shotton Surface Mine, from Northumberlandia.

NOTES:

Stop 2.

HARTLEY STEPS

Access to the shore is by a staircase with 77 steps, which must be climbed to return.

Hartley Steps provide access to excellent coastal exposures of the Middle Coal Measures sequence above and below the Low Main Seam, which are described in detail by Jones (1967). The apparent dip of the bedding is almost horizontal, and the Low Main Seam is clearly visible in section in the cliff. It is about 1.5 m thick, and overlies a 0.5m kaolinitic seat-earth (Figure 4). About 3 m above the Low Main Seam is a thin coal (the '5 inch seam' according to Jones, 1967) in the position of the Low Main Mussel Band (a marine band). The 5 inch coal represents a vegetated island, surrounded by the sea, at the time of deposition.

In addition to excellent exposures of the coal-bearing sequence and the sedimentary structures that this contains, the section shows significant faulting and associated minor folding (Figure 5).

To the north of Hartley Steps, the sequence is uninterrupted by faulting until reaching Crag Point. The Low Main Seam outcrops at the base of the cliff, and is underlain by prominent sandstones that form well-jointed wave cut platforms. In some places, joint-bounded blocks have been removed by mining to gain access to coals lower in the sequence. The northern limit of Hartley Bay is defined by Crag Point, where the Crag Point Fault, downthrowing 15m to the north, introduces a major sandstone (Figure 6).

Offshore, a tall tower is clearly visible in good weather. This is the NAREC (National Renewable Energy Centre) Offshore Anemometry Hub (NOAH). The ports of Newcastle (Port of Tyne) and Blyth, where NAREC is located, play a major role in the UK's offshore wind sector.

Key reference:

Jones, J. M. (1967) Geology of the coast section from Tynemouth to Seaton Sluice. Transactions of the Natural History Society of Northumberland, Durham and Newcastle upon Tyne, 16, 153-192. Available from www.nhsn.ncl.ac.uk.

***Figure 4**.*
Hartley Steps, with the Low Main Seam half way up the cliff, overlying a thin seatearth.

Figure 5.

Faulting south of Hartley Steps. The Low Main Seam, clearly visible on the right of the image, is downthrown to the left (south), by about 4m.

Figure 6.

The coast section north of Hartley Steps, with the Crag Point Fault at the end of the cliff introducing a massive sandstone.

NOTES:

Stop 3.

SOIL MACHINE DYNAMICS (SMD) LTD TOUR

(https://smd.co.uk)

Soil Machine Dynamics (SMD) Ltd manufactures a range of equipment designed for remote operation in extreme environments, including remote mining. The visit will provide participants with the opportunity to see equipment currently being manufactured.

NOTES:

Field Excursion Information

DAY 2

12 June 2015

Field Excursion Part 2 – The Northern Pennine Orefield 12 June 2015

Field excursion leader: Brian Young

Honorary Research Fellow, Department of Earth Sciences, University of Durham, South Road, Durham, DH1 3LE, UK

Email: brian.young@hotmail.co.uk

INTRODUCTION

Although the economic development of North East England is commonly assumed to have been based on coal mining and the heavy industries to which it gave rise, the region has a very much older mining legacy based upon the working of metal ores from the Pennine dales, west of the coalfield. Here, perhaps as long ago as the Bronze Age, small deposits of copper are likely to have been the first ores to attract human interest. Such deposits are, however, small and pale into insignificance compared to those of lead and iron, which were to dominate the area's economy over succeeding centuries. Although no proof of Roman mining has yet been discovered, it is inconceivable that, during their long occupation of the region, the Romans did not exploit these ores, though the first documentary records of metal mining here date from the early 12th century. Lead mining was to play an increasingly important role in the local economy, with production of lead, and by-product silver, peaking in the 18th and 19th centuries. In no other area of the UK has metal mining and smelting had a more profound effect on the human and physical landscape than here in the Northern Pennines. Whereas the collapse of world lead prices in the late 19th century proved disastrous, resulting in the closure of all but a handful of mines, emerging markets for zinc ores and the gangue minerals barytes*, witherite and fluorspar* were to sustain a mining industry, albeit on a declining scale, until world prices forced the closure of the last fluorspar mine in 1999. The orefield is known to have yielded >4 million tonnes of lead concentrates, 0.75 million tonnes of zinc concentrates, >2 million tonnes of fluorspar, 1.5 million tonnes of baryte and about 1 million tonnes of witherite, together with unknown, but substantial tonnages of iron ore, minor amounts of copper ores and around 170 tonnes of silver as a by-product from lead smelting. The economic potential of the orefield cannot, however, be regarded as exhausted: commercial evaluation of recent exploration for base metal deposits is still under way and attractive possibilities remain for identifying further significant deposits of industrial minerals, particularly fluorspar.

*****_In line with common practice, the term fluorspar is used here for the commercial product: fluorite for the pure mineral. The terms barytes and baryte are used in the same sense._

Key references:
DUNHAM, 1990; FORBES et al., 2003; RAISTRICK and JENNINGS, 1965; SYMES and YOUNG, 2008

GEOLOGICAL BACKGROUND

The Northern Pennine Orefield coincides with the structural unit known as the Alston Block. This comprises a fault-bounded ‘block’, composed predominantly of Ordovician mudstones and volcanic rocks intruded by the Caledonian North Pennine granitic batholith, upon which lies a comparatively thin succession of Carboniferous cyclothemic units typically composed of limestones, mudstones, sandstones and locally thin coals. Into these was emplaced the Permo-Carboniferous Whin Sill suite of tholeiitic quartz dolerite intrusions. The gentle easterly regional dip of these rocks is interrupted by some gentle flexuring and by a conjugate system of normal faults with maximum throws typically of only a few metres. It is these faults which host the main mineral veins.

Wall-rock lithology exerts a profound influence on the potential of each fault as a mineralised vein. Hard, competent rocks such as limestones, sandstones and Whin Sill dolerite provide clean open fractures which typically host wide, well-mineralised veins: incompetent lithologies, such as mudstones and siltstones typically allowed fault fissures to close, effectively preventing their filling by mineralising fluids. Extensive replacement of limestones adjacent to many veins has created numerous laterally extensive ‘flat’ deposits.

A conspicuous feature of the orefield is the marked concentric zoning of the mineralisation. A large central zone, in which fluorite is the principal gangue mineral, is surrounded by an outer zone in which the barium minerals baryte and witherite comprise the main gangue assemblage. The separation of these zones is very sharp, with fluorite and barium minerals normally exhibiting a mutually exclusive relationship. It was this conspicuous pattern of mineral zonation, supported by evidence from gravity surveys, which prompted speculation on the presence of a concealed granite as the source of the mineralisation. However, the discovery of a Devonian age for the Weardale Granite proved in the Rookhope Borehole, drilled in 1960-61, clearly demonstrated that the mineralisation could not be the direct result of granite intrusion. Instead, as a ‘high heat production’ granite, the Weardale Granite is now considered to have driven a convective circulation of mineralising brines derived from dewatering of adjoining sedimentary basins which scavenged chemical elements from the rocks through which they passed, including the granite itself. The mineralisation must have been introduced very soon after emplacement of the Whin Sill in the late Carboniferous or early Permian.

Since the earliest days of geological science, investigations of the area’s geology and mineral deposits have played an important role in the understanding of comparable orefields worldwide. The area today coincides closely with the North Pennines Area of Outstanding Natural Beauty (AONB) which, since 2003 has been designated as a UNESCO sponsored European Geopark, designations which could impact upon the orefield’s future economic potential.

Key references:

DUNHAM, 1990; NORTH PENNINES AONB PARTNERSHIP, 2004; STONE et al., 2010: SYMES and YOUNG, 2008.

THE EXCURSION ROUTE

Whereas the principal objective of the day's outing will be to introduced important aspects of the orefield, our outward and return journeys will give us fine opportunities to see, and interpret, other key features of the region's geology and mining legacy.

The outward journey from Newcastle to Weardale will take us across the central and western portions of the Northumberland and Durham Coalfield. Although all underground mining has now ended the present landscape derives many of its distinctive features from this formerly dominant industry. Characteristic colliery settlements, remnants of the transport infrastructure of coal mining, reclaimed mine sites and recent opencast coal extraction will be pointed out *en route.*

The following notes will introduce the main features of interest at the stopping points, with brief general remarks on topics of interest to be seen between stops.

Stop 1.
ROOKHOPE BOREHOLE [NY9374 4278] & BOLTSBURN MINE [NZ9368 4279]

Rookhope Borehole

As early as the 1930s the marked mineral zonation of the orefield led the late K.C.Dunham to speculate on the possibility of concealed granite beneath the Northern Pennines. Gravity surveys by Bott and Masson-Smith in the 1950s added further support for this suggestion, but it was not until 1960-61 that the hypothesis came to be tested by the drilling of the Rookhope Borehole.

The postulated granite was proved at 390.5 m, almost exactly its predicted depth, and drilling continued in granite to the terminal depth of 807.72 m. It is notable that, except for an interval in the Whin Sill, the borehole was continuously cored, a feature that with modern drilling costs would be an unaffordable luxury today!

With a weathered top beneath the Carboniferous basement beds, this was not the post Carboniferous, Hercynian, intrusion originally envisaged, but a pre-Carboniferous, Caledonian, body. Clearly, its role in the generation of the local mineral deposits required re-evaluation. Revealed to be a ‘high heat production’ granite, it soon came to be accepted as the likely ‘heat engine’ responsible for driving the convective flow of metal-bearing fluids through the conjugate system of fractures in the overlying Carboniferous rocks and Whin Sill. The metals and other elements required to form the deposits are believed to have been scavenged from the Lower Palaeozoic basement rocks, the granite itself and the Carboniferous cover rocks of the Alston Block and surrounding basinal areas to the north and south.

The borehole had a major impact not only on the understanding of the geology and ore deposits of Northern England, but upon concepts of ore genesis in similar settings world-wide. The bulk of the borehole core is now in the care of the British Geological Survey at its Keyworth, Nottingham, headquarters.

Interest in potential geothermal energy sources led to a re-investigation of the borehole in the 1980s and, more recently, modern innovative concepts in geothermal exploration have led to further investigations, including the sinking of two further boreholes, into the Weardale Granite as a potential source of commercial geothermal energy.

Key references:
BOTT and MASSON-SMITH, 1957; DUNHAM, 1990; DUNHAM et al., 1965; MANNING and STRUTT, 1990; MANNING et al., 2007.

Boltsburn Mine
A short distance west of the borehole site lies the comparatively meagre remains of Boltsburn Mine.

Although the date of its opening is unknown, Boltsburn Mine was in production for much of the 19^{th} century. Its mineralogical claim to fame lies in the ‘flat’ deposits associated with the Boltsburn Vein, that were the mainstay of the mine’s lead production from their discovery in 1892 until its closure in 1932. The mine is known to have raised almost 128 000 tonnes of lead concentrates, together with a little over 7000 tonnes of fluorspar. Although never a major source of commercial fluorite the mine is of interest as having produced, during the 1930s, a small, but unrecorded output of clear fluorite used in the making of specialised lenses.

The extensive replacements of the Great Limestone, which extended in places for up to 60 m on either side of the vein, were composed principally of ankerite and siderite. They contained abundant bands and pockets of coarsely crystalline galena and were famous for numerous cavities within them lined with beautiful large transparent interpenetrant cubes of, mainly purple, fluorite. Magnificent specimens of Boltsburn fluorite figure prominently in almost all of the world’s major mineralogical collections. Other cavity fillings included quartz, calcite, siderite and sphalerite. Although such fine specimens can no longer be found, the small remaining spoil heaps contain good representative examples of the ankeritised limestone in which fluorite and other minerals form conspicuous cavity fillings.

Key references:
DUNHAM, 1990; SYMES and YOUNG, 2008.

> *En route* from Rookhope to our next destination the landscaped site of Redburn Mine, an important underground fluorspar mine, developed in the 1960s, is passed. A short distance to the west, the sole surviving arch from the Rookhope, or Lintzgarth, lead smelt mill [NY9250 4295], which closed in the early years of the 20th century, is a conspicuous landmark. This carried the flue across the road from the smelter to the 2.5 km long flue leading to the chimney on Redburn Common. Such flues, which acted as condensers for lead fumes, were a common feature of Northern Pennine lead smelters. Our route here turns left to follow the narrow hill road to West Rigg.

NOTES:

Stop 2.

WEST RIGG OPENCUT [NY9110 3920]

Figure 1.
West Rigg Opencut.
The quarry marks the extent of the 'limonitic' iron ore which was extracted from replacement 'flat' deposits in the Great Limestone adjacent to Slitt Vein. The vein itself, here composed mainly of quartz and a little fluorite, stands as an unworked pillar in the centre of the quarry. Narrow old lead stopes can be seen in the centre of the vein.
Photo: B.Young

This site provides one of the finest and most instructive surface exposures of mineralised ground within the orefield and is designated as a Site of Special Scientific Interest (SSSI). Its main features of interest are interpreted in a board erected at the roadside by the North Pennines AONB.

This is a large abandoned quarry (Figure 1) from which, during the 19th century, large tonnages of 'limonitic' iron ores were extracted from 'flat' deposits adjacent to the Slitt Vein. Small remnants of these ores may be seen locally in the walls of the excavation.

Slitt Vein, the longest single vein in the orefield, which is composed here mainly of quartz with a few narrow ribs of fluorite, stands as a prominent unworked rib a few metres wide in the centre of the pit. Although containing only small amounts of galena, the remains of narrow stopes, worked underground for lead prior to ironstone quarrying, may be seen in the western end of the vein exposure. Slitt Vein is one of a small number of predominantly E-W trending structures, known as 'Quarter Point' veins which are distinguished from other Northern Pennine veins in their sinistral transcurrent rather than vertical, sense of displacement. Although characterised by poor metal values, these veins commonly carry large bodies of spar minerals such as fluorite, and have been the main commercial sources of this mineral. Large tonnages of fluorspar have been raised from Slitt Vein at several Weardale mines.

The site plainly demonstrates the relationship between 'flat' deposits, formed by metasomatic replacement of limestone wall-rocks and the parent vein. The relationship is especially clear in the northern part of the quarry where, immediately adjacent to the vein, the full thickness of the limestone has been replaced: traced further from the vein this replacement became restricted to the upper beds of limestone. In common with similar situations elsewhere in the orefield, metasomatism here replaced the limestone with ankerite and siderite, though in contrast to Boltsburn Mine, here without significant sulphides or other gangue minerals. Such iron carbonate rocks are typically too low grade to have been worked as iron ores, though where affected by intense supergene alteration, as here at West Rigg, hydrated 'limonitic' ores, which may be regarded as of 'Bilbao Type', with workable iron contents of between 34 and 43%, were created.

This site offers fine views towards the western continuation of the outcrop of Slitt Vein. Its course is clearly marked by overgrown opencuts and shallow shafts on the hillside west of the Middlehope Burn. However, when followed towards the hilltop the disappearance of evidence of workings marks the passage of the vein from productive limestone and sandstone wall-rocks into incompetent mudstones and siltstones unfavourable to economic mineralisation.

The site also provides panoramic views across central Weardale with its distinctive pattern of intake fields and small farmsteads, typical of the dual 'miner-farmer' economy which was such an important feature of the area in the heyday of lead mining.

Slitt Vein has figured in recent research on the geothermal potential of the Weardale Granite.

Key references:
BOUCHE et al., 2006; BEVINS et al., 2010; DUNHAM, 1990; FORBES et al., 2003; MANNING and STRUTT, 1990; MANNING et al., 2007.

> From West Rigg the route returns to the Rookhope valley which is then followed upstream to the Co. Durham-Northumberland border.

NOTES:

Stop 3.
GROVERAKE MINE [NY8953 4412]

Figure 2.
Groverake Mine photographed in 1995.
The tall headframe stands over the Old Whimsey, or No. 2, Shaft: the lower headframe to its left is over the Drawing, or No. 1, Shaft. In the left of the picture is the heapstead buildings at the Firestone Decline. Old overgrown surface workings on Groverake vein may be seen on the hillside to the right of the Firestone decline heapstead. In the distance is the surface plant at Frazer's Hush Mine which was connected with Groverake Mine underground.
Photo: B.Young

Near the head of the valley, the prominent headframe on the Old Whimsey Shaft at Groverake bears witness to the orefield's most productive and last-worked fluorspar mine which closed in 1999 with an output of over 300 000 tonnes of fluorspar to its credit (Figure 2). Although up to 10 m wide in places, as one of the orefield's 'Quarter Point' veins, Groverake Vein was typically poor in galena and this was never a rich lead mine during its 19th century working. However, with the rise in demand for fluorspar in the 20th century Groverake embarked upon a new career as a major producer of this mineral. Hosted predominantly in thick Namurian sandstone wall-rocks, the fluorspar orebody here extended almost continuously from the surface to below the 80 fathom (146 m) level below surface, making it one of the largest orebodies known anywhere in the Pennines. In its latter years, Groverake was joined underground with adjacent veins being worked at Frazer's Hush and Greencleugh mines. Optimistic plans were in place to deepen the workings to explore the veins in potentially favourable wall-rocks including the Whin Sill and adjoining beds, when a catastrophic collapse in world fluorspar prices forced its closure. The potential of this vein in depth thus remains an untested and interesting prospect, though the deeper workings are now flooded.

Adjoining the veins at Groverake were extensive iron ore 'flats' similar to those seen at West Rigg, but here within the Lower Felltop Limestone. The spoil heaps from opencast workings on these are prominent on both sides of the valley around Groverake.

Key references:
DUNHAM, 1990.

A short distance west of Groverake, at the county boundary with Northumberland, a clear day offers fine views across the northernmost Northern Pennine fells and far beyond into Northumberland and the Scottish Borders. Immediately to the west, however, are glimpses of the surface traces of the strongly mineralised veins formerly worked in and around the small village of Allenheads, which lies in a wooded setting at the head of the East Allen valley.

NOTES:

Stop 4.
ALLENHEADS [NY8600 4550]

Figure 3.
Looking west over Allenheads village – a typical Northern Pennine mining landscape.
Old surface workings on the Old Vein may be seen between the distant areas of forestry. The pond is one of the many reservoirs built to supply water to the mines for power and ore dressing.
Photo: B.Young

At an elevation of over 400 m above sea level, at the head the River East Allen, Allenheads is a particularly fine example of a Pennine lead mining village (Figure 3). Several prominent veins unite beneath the village and were worked at Allenheads Mine, perhaps as early as the 16th century. The mine's greatest period of productivity was in the 18th and 19th centuries, especially after 1806 when rich 'flat's associated with the Diana Vein were discovered. At its closure as a lead mine in 1896 the mine had a grand total of around 260 000 tonnes of lead concentrates to its credit, making it the orefield's single most productive lead mine.

The village, which housed the headquarters of WB Lead, the major owners and operators of the Weardale and Allendale mines, abounds in remains of the great days of lead mining. The stone-lined Gin Hill Shaft, the stone-arched Fawside Level and the entrance to the horse incline, together with rows of miners' cottages, the village school, mine offices and the mine workshops, now converted to small business units, all attest to the importance of lead mining. Perhaps the most impressive building dating from this period is Allenheads Hall, a substantial mansion in landscaped grounds, built in the mid-19th century by W B Lead for Thomas Sopwith who was not only the most famous mine agent to work in the Northen Pennines, but also an important pioneer in understanding the area's geology.

An ambitious attempt to restart mining, but for fluorspar not lead, was begun here in the 1970s by the British Steel Corporation, based upon the assumption that substantial volumes of fluorspar remained underground from the days of lead mining. So confident of success were British Steel that rather than gaining access through the original mine entrances, they opted to drive a new large diameter inclined adit in anticipation of the large volumes of ore expected to be raised. Planning consents required the surface buildings to be faced with natural stone, adding very substantially to the costs of the project. However, when access to the abandoned workings was finally gained, the expected reserves of fluorspar, either in un-extracted ground or as back-fill, were not found. By 1981 this attempt at re-opening, surely the most expensive failure in Northern Pennine mining history, was finally abandoned.

In the 1970s, prior to the advent of computer modelling allowing imaging of complex mine layouts, detailed scale models of the mine workings were built as planning aids in several Northern Pennine mines. The recently restored Allenheads model is today housed in the blacksmith's shop as part of small interpretative display of local mining.

Key references:
DUNHAM, 1990; FORBES et al., 2003; SYMES and YOUNG, 2008.

The excursion continues along the hill roads to the tiny, and appropriately named hamlet of Coalcleugh, at the head of West Allendale. Not only was this an important local source of coal, employed in lead smelting, but also a significant centre of lead, and more recently fluorspar, mining, the remains of which are locally conspicuous landscape features. Beyond Coalcleugh, the route crosses the Northumberland-Cumbria boundary from which the highest peaks of the Northern Pennines, including Cross Fell, are prominent on the skyline, before descending into the village of Nenthead, passing *en route* the sites of the most recent explorations for base metal deposits.

NOTES:

Stop 5.

NENTHEAD [NY7800 4370]

Figure 4.
Mineralised Great Limestone in the banks of the River Nent. Although here completely replaced by ankerite, adjacent to Carr's Cross Vein, original bedding, jointing and other features are preserved in the altered rock. Weathering of the iron-rich ankerite gives the strong brown colour. Photo: B.Young

The village of Nenthead, at the head of the River Nent, a tributary of the River Tyne, owes its existence to the activities of the Orefield's other major mining company, the London Lead Company. It was this Quaker company who built the village as they came to recognise the great extent and value of the complex of lead deposits they had leased in this part of Alston Moor. Much of the village dates from the 1820s but, despite the long abandonment of the mines and the demolition of many original buildings, significant parts of the village remain substantially as originally conceived by this company. Notable buildings include the church, chapel, miners' reading room (now the village community shop), the Miners' Arms public house and rows of cottages. Several major mines were sited within or in the immediate vicinity of the village and many of the associated buildings, together with the remnants of the Lead Company's smelt mill are still prominent features.

The worldwide collapse of lead prices at the turn of the 19th and 20th centuries caused the London Lead Company to abandon its leases here, though these were in part taken up by the Belgian Vieille Montagne Zinc Company who continued mining, though on a more modest scale, until the 1930s, principally for zinc ores which hitherto had been of little value. It was this company who in 1909 erected the huge processing plant in the village centre. Although partially demolished, substantial parts of this survive as a bus garage. A new plant was erected in this building during World War II to process of old dumps for zinc and lead ores. In the immediate post war years, fluorspar was extracted here from ores derived from several mines.

The valley of the River Nent upstream from the village provides fine opportunities to examine the types of deposit formerly worked here. The base of the Great Limestone, the most productive host rock of the local mineralisation is here beautifully exposed in the right bank of the river. Resting upon a sharply defined surface of subaerial carbonaceous mudstones and siltstones, the limestone base represents a major Carboniferous flooding surface. Particularly prominent here, within the lowest 1.5 m of the limestone, is a fine section through the *Chaetetes* Band, a bed composed principally of encrusting mats of the sponge *Chaetetes depressus* in life position, accompanied by several conspicuous large colonial corals.

A few metres NE of this exposure the limestone is cut by the NW-SE trending Carr's Cross Vein, one of the main mineralised faults of the upper Nent valley. Whereas across much of the Orefield, veins with this orientation and known locally as 'cross veins', are typically barren, in the Nent Valley they are commonly richly mineralised, and are often associated with extensive replacement 'flats'. Large quantities of lead and zinc ores have been extracted from such deposits at several mines here, and whereas the finest exposures of this type of mineralisation may still be examined in some relatively accessible underground workings, good exposures can be seen at surface, most of which are within the Smallcleugh Mine SSSI.

A few metres upstream from the *Chaetetes* Band exposure, the otherwise dull grey limestone exhibits a distinctive patchy brown colouration, particularly adjacent to joints. This indicates the proximity of the Carr's Cross Vein: the brown tint reflects surface weathering of ankerite replacement by mineralising fluids adjacent to joints. Although the vein itself lies a few metres NE of the stream and does not crop out here, a few metres further upstream at the waterfall, this replacement is virtually complete. The limestone here is wholly replaced by medium-grained ankerite, but with original features including joints, bedding planes, mudstone partings and even stylolites faithfully preserved in the ankerite rock (Figure 4). Within this are roughly horizontal bands of coarse-grained galena with locally some sphalerite. Numerous vugs may be seen partially lined with quartz and galena.

For reasons that are as yet not understood, the veins and 'flats' in this part of the Nent Valley are characterised by the almost complete absence of fluorite or barium gangue minerals, and by the unusually high proportion of sphalerite.

The extensive spreads of mine waste here offer good opportunities to examine and collect representative examples of most of the minerals found in these deposits.

Key references:
BEVINS et al., 2010; BOUCHE et al., 2006; DUNHAM, 1990; RAISTRICK, 1938; RAISTRICK and JENNINGS, 1965; SYMES and YOUNG, 2008.

From Nenthead the route continues north through the Allen Valley to join the South Tyne valley near Hadrian's Wall.

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Stop 6.

HADRIAN'S WALL, STEEL RIGG [NY7510 6760]

The course of the South Tyne Valley here coincides very approximately with the line of the Stublick Fault System, the major structural line bounding the northern margin of the Alston Block and hence the northern Pennine Orefield. A few miles north of the river lies one of North East England's best known and iconic landscape and geological features – Hadrian's Wall and the Great Whin Sill.

The Permo-Carboniferous suite of sills and related dykes, collectively known as the Great Whin Sill Suite, crops out here between beds of Carboniferous sandstones and limestones, forming an E-W line of prominent cuesta ridges with north-facing crags. These provided Hadrian's army with the almost perfect defensive setting to mark the northern frontier of the Roman Empire.

The Whin Sill, which in this area is up to 30 m thick, is composed of medium to fine-grained tholeiitic quartz dolerite in which crude columnar jointing is conspicuous in natural outcrops and quarry faces. The rock makes a high quality roadstone and is worked from several quarries across the region.

However, the sill's importance extends beyond its road-making qualities and its effect on Northumberland's landscape. This is the 'type' sill of geological science. Northern England miners and quarrymen used to refer to all roughly horizontal beds of rock as 'sills'. Formal stratigraphical nomenclature in this region still recognises beds such as the Grindstone Sill and the Firestone Sill, sandstones that were well-suited to the making of millstones and hearth linings respectively. 'Whin' was the almost contemptuous term applied by these quarrymen to any hard black rock that was difficult to shape. It is said to derive from the 'Whinnnn…..' noise made when fragments of this rock are broken from larger blocks. Only in the 19th century when geological science took an interest in these rocks was the true nature of the Whin Sill realised and the term 'sill' was adopted for intrusive bodies of this sort worldwide.

Key references:

PICKETT et al., 2006; STONE et al., 2010.

Stop 7.
SETTLINGSTONES MINE [NY8430 6830]

Although lying several kilometres north of the Alston Block, for convenience of description a small group of veins around the small town of Haydon Bridge are generally regarded as an outlying portion of the main orefield, though there are good grounds for regarding them as a separate group of deposits structurally related to the Stublick Fault and margin of the Northumberland - Solway Trough.

Whatever their affinities, these deposits resemble the veins within the outer, barium-rich, zone of the main orefield.

The most celebrated of these deposits is that formerly worked at Settlingstones Mine. Originally worked as a moderately successful lead mine, as working progressed, the lead content virtually disappeared as the vein became dominated by the unusual barium carbonate mineral witherite. The local abundance of witherite, and other barium carbonatre minerals, is a curious feature of this orefield. From 1873 Settlingstones changed its production from lead to witherite, which found a wide variety of uses in the chemical industry. For long periods it was the world's sole commercial source of this mineral, but by 1968, this unusual deposit was exhausted and the mine closed, having yielded a grand total of 630 000 tonnes of this mineral during its working life.

Little survives today of this unique enterprise, though the site of Fredrick Shaft, the main working shaft, is marked by a small pipe allowing gas to escape from the underground workings. The original miners' cottages remain, but the other buildings have been largely demolished and the remaining spoil heaps, although scheduled as an SSSI for their mineralogical interest, are today heavily overgrown.

Key references:
BEVINS et al., 2010; DUNHAM, 1990; PICKETT et al., 2006: SYMES and YOUNG, 2008.

> Our return to Newcastle continues along the main Tyne Valley, in part following the line of the Stublick Fault System, before and returning to the coalfield a few miles west of the city.

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