A GEOLOGICAL OUTLINE OF THE NORTHERN PENNINES

Brief notes to introduce essential features of the area's geology relevant to mining sites under investigation as part of the AONB OREsome Project

Prepared for the North Pennine AONB OREsome Project

By

B. YOUNG B Sc, C Eng, FIMM

Honorary research Fellow, Department of Earth Sciences, University of Durham

OREsome Geology Report No. 2. November 2016

CONTENTS

WELCOME & DON'T PANIC!

Thank you for volunteering to join this project, and in particular thank you for taking an interest in the geological aspects of what promises to be a useful and hopefully very enjoyable programme of work. I very much look forward to working with all volunteers in the variety of tasks we will be setting ourselves. The project organisers do not expect volunteers to be trained or expert geologists, archaeologists or ecologists, so please don't be put off by repeated references to these - ologies!

As you may already appreciate, all of the topics we will be exploring have much to offer and can be extremely rewarding even if you have no formal training or experience in those fields. In particular, geology in all of its aspects is an exciting and rewarding pursuit, and one of the most accessible of all the natural sciences, where the interested amateur (I use the term 'amateur' here in its very best, and non-pejorative, sense) can still make valuable discoveries and contributions. It also has the huge advantage of taking us into the field to enjoy, and hopefully add to, the understanding of our natural and man-made landscapes in all their variety.

I hope we will all find this both enjoyable and rewarding.

1. INTRODUCTION

Essential to the understanding the mines of the AONB in their true context as part of the Northern Pennine Orefield is an appreciation of the main geological features of the area, together with an understanding of the wider geological framework of Northern England.

Throughout its long history of mining this area has played a prominent role in the development of the geological sciences both in the UK and across the world. It remains an active focus of varying strands of geological research. As a result the area has spawned an enormous technical literature describing and interpreting its many and varied geological features. Whereas during the course of the OREsome Project we will employ relevant parts of a handful of these publications, it is plainly both impossible and unnecessary to attempt to access much of this vast literature archive. The notes offered here have been compiled to offer a brief, simplified outline of the most significant of these geological features necessary to assist volunteers who may have no formal training in the geological sciences. For anyone wishing to explore these topics further a summary of key literature and other relevant data sources is attached in the **INFORMATION SOURCES** of this document.

In addition to the obvious direct link between former centres of mining and the geology which underpins them, an understanding of those geological factors is an essential foundation necessary to inform studies and interpretations of ecological issues, most notably the occurrence and distribution of lichens and calaminarian plant communities. An appreciation local geological features is also vital to any consideration of conservation or preservation of mining related archaeological features. The importance of this latter relationship is commonly overlooked or ignored in many archaeological and 'heritage 'projects. There are several examples of such 'oversights' in this area.

Whereas the notes offered here are intended as background to the small number of sites currently under investigation within the OREsome project, they are also intended to serve as essential background to any future work on mining, geological or ecological studies within the area.

2. THE NORTHERN PENNINE OREFIELD: A BRIEF GEOLOGICAL SUMMARY

Although details of the area's geological succession do not need to be considered in great detail for the purposes of this project, it is important to appreciate that the geology of the sites under review is an essential part of the present investigation. Accordingly, brief outlines of the main geological deposits are presented below. For more detailed descriptions of individual parts of the geological succession, or for greater understanding of particular areas or sites, reference should be made to the very extensive technical literature and other sources listed within the **INFORMATION SOURCES** section of this document.

We will first look briefly at the bedrock or 'solid, geology of the area. By 'solid' we mean the rocks formed millions of years ago that make up the area and which lie beneath the intermittent superficial, 'drift', covering of much more recently formed clays, sands etc.

2.1. 'SOLID' or BEDROCK GEOLOGY

Much of the 'solid' geology of the Northern Pennines comprises a succession of sedimentary rocks of Carboniferous age which rest unconformably upon a 'basement' of sedimentary, metamorphic and volcanic rocks, mainly of Ordovician to Silurian age and equivalent to the rocks seen today as the Skiddaw, Borrowdale Volcanic and Windermere groups of the Lake District.

Basement rocks

Parts of these 'basement' rocks crop out on the face of the Pennine escarpment between Melmerby and Brough, where they are collectively termed the 'Cross Fell Inlier'. A very small outcrop of these rocks, known as the Teesdale Inlier, is also present in Upper Teesdale around Widdybank Farm, though exposures here are restricted to a very small area at the foot of Cronkley Fell.

Included within this 'basement' is the large wholly concealed granitic body today known as the Northern Pennine Batholith, an igneous intrusion of Caledonian age. Since the proving of this granite in the Rookhope Borehole in 1961, more detailed geophysical investigations have provided evidence that the batholith is a composite intrusion comprising the Weardale Granite (the portion first proved in the Rookhope Borehole) together with the closely associated plutons of Tynehead, Scordale, Rowlands Gill and Cornsay, the last two of which lie almost entirely outwith the AONB.

In addition to the outcrops within the Cross Fell and Teesdale inliers, Lower Palaeozoic rocks have been proved in a number of deep boreholes within the area at Allenheads and Roddymoor (a short distance beyond the eastern boundary of the AONB) and in a shaft at Cowgreen Mine, Teesdale. Recent mineral exploration has proved volcanic rocks, provisionally assigned to the Ordovician Borrowdale Volcanic Group, in several boreholes in the Nenthead area. The only portion of the Northern Pennine Batholith so far reached by drilling is the Weardale Granite, proved in the Rookhope Borehole, and more recently in two boreholes in the Eastgate area, Weardale.

Carboniferous rocks

A highly simplified classification of the Carboniferous rocks, which comprise the greatest proportion of the area's surface solid geology, is presented in the accompanying table (Table 1).

COAL MEASURES	
YOREDALE GROUP	STAINMORE FORMATION
	ALSTON FORMATION
GREAT SCAR LIMESTONE GROUP	
BASAL CONGLOMERATES etc.	
unconformity	
LOWER PALAEOZOIC BASEMENT ROCKS INCLUDING WEARDALE GRANITE	

TABLE 1. Simplified classification of Carboniferous rocks

The lowest Carboniferous rocks which rest unconformably upon the pre-Carboniferous 'basement' comprise a succession of sedimentary rocks at the base of which occurs a variable series of basal beds, including conglomerates, exposed locally on the Pennine escarpment and in Upper Teesdale. Above these, and exposed mainly on the Pennine escarpment and in Upper Teesdale, is a succession dominated by limestones, including the prominent Melmerby Scar Limestone, together with a few thin mudstone and sandstone intervals. This succession is today referred to as the Great Scar Limestone Group.

Above this, the greater part of the area's Lower Carboniferous succession comprises a series of typical 'Yoredale-type' cyclic sequences, individually known as 'cyclothems', composed of regularly repeated units of limestone, mudstone, sandstones and locally thin coals. The main characteristics of a typical 'Yoredale' cyclothem are illustrated in Figure 1. This succession is collectively referred to as the Yoredale Group. The lower portion of the Yoredale Group, in which limestones are numerous, is referred to today as the Alston Formation. In older literature, it was common practice to refer to the units today identified as the Great Scar Limestone Group and the Alston Formation collectively as the 'Carboniferous Limestone'.

Above the Great Limestone, the uppermost unit of the Alston Formation, the succession is dominated by mudstones, siltstones and sandstones, with some thin coals and only a few thin and commonly impersistent limestones units. This succession of rocks above the Great Limestone is today referred to as the Stainmore Formation, though was formerly grouped with the Millstone Grit of the southern Pennines. The Stainmore Formation passes up conformably into the group of rocks known as the Coal Measures. Only very small areas of Coal Measures rocks lie within the AONB.

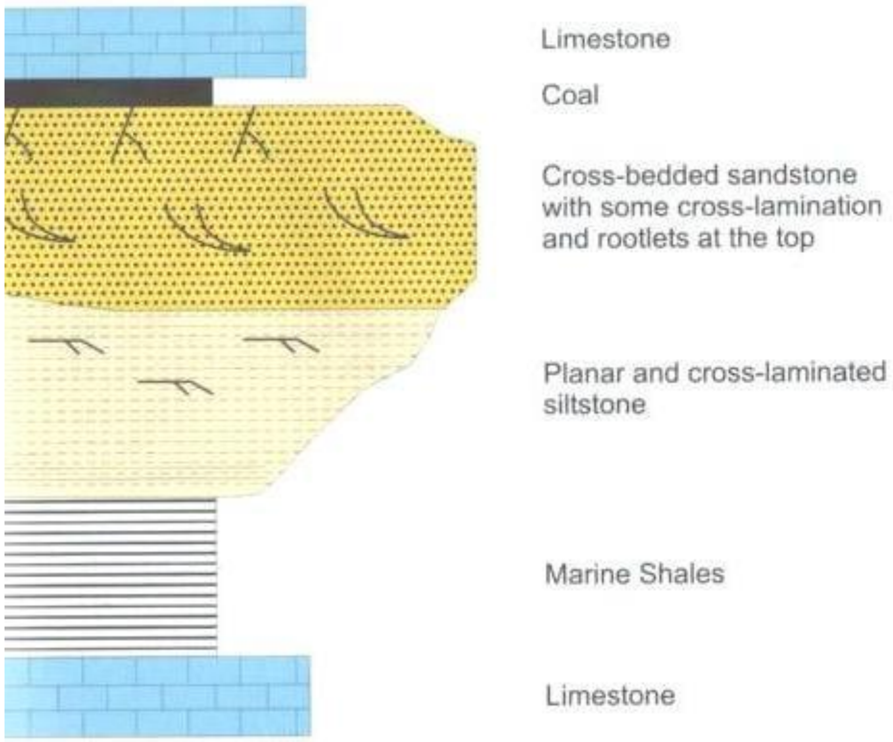

Figure 1. Simplified section through a typical 'Yoredale' cyclothem

These Carboniferous rocks exhibit a gentle regional dip to the east (Figure 2). In consequence, progressively younger rocks are encountered at the surface when passing from west to east across the area. The detailed disposition of these rocks is clearly depicted on geological maps. However, by way of a highly simplified generalisation, rocks of the Great Scar Limestone Group crop out primarily on the west-facing slopes of the Pennines escarpment, and in a few places in Teesdale;

rocks of the Alston Formation make up much of Alston Moor and the valley sides of Weardale and Teesdale; Stainmore Formation rocks cap the hills between the main valleys and form an eastern fringe to the area. Coal Measures rocks crop out only in the extreme east of the area.

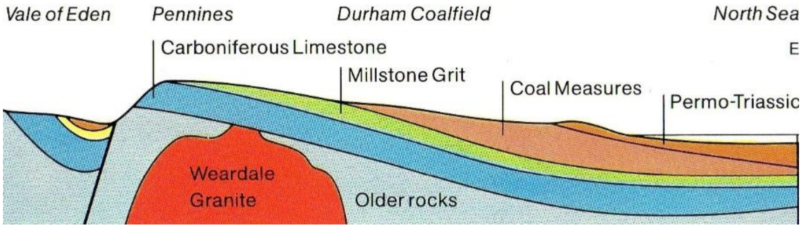

Figure 2. Simplified geological section through the Northern Pennines

The Whin Sill

Lying within the area's Carboniferous rocks are the dolerite intrusions comprising the sills and dykes of the Permo-Carboniferous suite of intrusions collectively referred to as the Great Whin Sill. These hard resistant rocks crop out today on the Pennine escarpment, notably at High Cup Nick, and in Teesdale where they gives rise to the waterfalls of Cauldron Snout, High and Low Force and the cliffs of Cronkley and Holwick Scars. A thin upper leaf of this intrusive suite, known as the Little Whin Sill, crops out in Weardale between Stanhope and Rookhope and a small area of the sill is also exposed near Cowshill in Weardale..

The Cleveland-Armathwaite Dyke

Completing the area's suite of 'solid' rocks is the Cleveland-Armathwaite Dyke, a basaltic intrusion of Palaeogene age which comprises part of the group of intrusions centred upon the Hebridean Isle of Mull. These rocks crop out only in a very few small areas on parts of the Pennine escarpment, in the headwaters of the South Tyne and in the lower reaches of Teesdale, notably in Coldberry Gutter. A previously unknown portion of this dyke has recently been identified in the Harwood Valley, Upper Teesdale, though it does not reach the surface here.

SUPERFICIAL OR 'DRIFT' GEOLOGY

The area's 'solid' rocks are locally concealed beneath a patchy mantle of sediments of Quaternary and later age. Most widespread of these deposits is till, or boulder clay, a variable and usually heterogeneous material composed of clay, sand, gravel and boulders deposited from ice sheets during the last glacial period to affect the area, and which ended as recently as around 10 500 years ago. Conspicuous topographical features developed during immediately post-glacial times include the prominent glacial meltwater channels seen in the lower parts of Teesdale and some large landslips on parts of the Pennine escarpment. Low angle landslips, composed mainly of glacial sediments, are prominent on some valley sides, particularly in the East and West Allendales. Spreads of peat, formed only within the past few thousand years, mantle extensive parts of the higher ground, most notably between the head of Teesdale and Cross Fell. Alluvial deposits, including a variety of river terrace deposits, and comprising variable assemblages of clays, silts, sands and gravels, fringe the main rivers and many of the tributary streams: these deposits are still being deposited and modified today by active fluvial processes.

Where limestones crop out at the surface, lime-rich soils with relatively high pH values occur. Outcrops of most mudstones and sandstones typically support rather acidic soils. Soils on outcrops of Whin Sill dolerite are commonly rather acidic. Spreads of glacial and more recent 'drift' materials greatly influence soil conditions. Thus, for example, when mantled by boulder clay with little or no lime content, a limestone outcrop may be covered by rather acidic soils. Conversely, where the 'drift deposits' are notably rich in limestone debris, soils of comparatively high pH may be present over outcrops of sandstone or mudstones that might otherwise be expected to support acidic soils. Plainly, it is vital to examine both 'solid' and 'drift' geological maps when beginning to investigate likely soil chemistry and the associated flora.

3. THE MINERAL DEPOSITS OF THE NORTHERN PENNINE OREFIELD

In order to understand the range of minerals worked in the area it is vital to have a clear perception of the overall characteristics of the area's mineralisation. In the Northern Pennines this requires an appreciation of the nature, form and distribution of vein and associated replacement deposits and the close relationships these have with wall-rock lithology. Crucial too is a knowledge of the varied range of constituent minerals within the deposits, together with an appreciation of the distribution, relative abundance and chemical composition of those minerals.

As has been mentioned above, the Northern Pennine Orefield has spawned a very extensive technical literature touching upon almost every aspect of its geology and mineralogy. Voluminous though this resource is, it is important to recognise that research into all aspects of the area's geology continues, with new interpretations and new occurrences of mineral distribution appearing regularly in the technical literature. A selection of the most up to date and comprehensive authoritative accounts of this topic are listed in the **INFORMATION SOURCES** section (below). References to more detailed topics, including descriptions of individual sites, deposits or mineral species or assemblages, are to be found in the extensive bibliographies and reference lists contained in these publications. Whereas it is neither appropriate nor necessary to present here a detailed description of the mineralisation, it is important to highlight those key aspects that are most relevant to the present study.

Within the Northern Pennines the Carboniferous rocks and Whin Sill are cut by a widespread conjugate system of faults and fault zones. Infilling of these fractures by mineralising fluids, in whole or in part, has created the area's huge number of mineral veins. In passing, it is worth noting that although these fractures penetrate the underlying pre-Carboniferous rocks, with the exception of the Weardale Granite, proved only in three boreholes in Weardale, little or nothing is known of any related mineralisation within these the pre-Carboniferous rocks.

The area's veins typically comprise mineralised infillings of fault fractures (Figure 3). Veins range in width from a millimetre or so up to 10 m, or in a very few instances, more. Vein width is greatly influenced by wall-rock lithology. Wide veins typically occur within competent wall-rocks such as most limestones, hard sandstones and Whin Sill dolerite: veins are characteristically narrow or un-mineralised and barren within incompetent lithologies such as siltstones, mudstones and soft sandstones. Veins typically exhibit a steep inclination, or hade, within competent wall-rocks, and adopt much shallower inclination in weaker rocks.

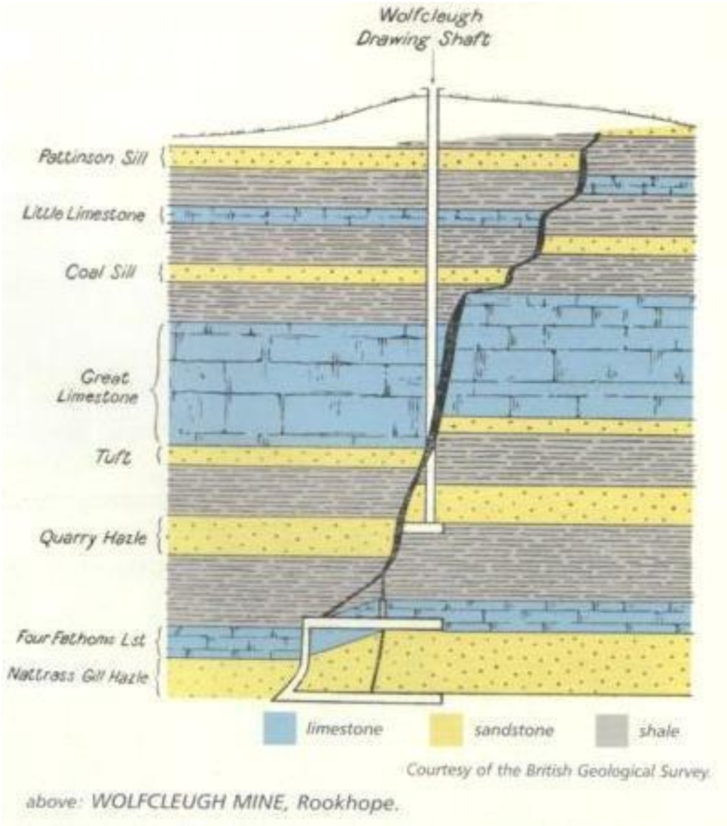

Figure 3. Section of Wolfcleugh Vein, Rookhope.
The section clearly illustrates both the change in inclination (hade) of the vein between hard (competent) sandstones and limestones and weaker (incompetent) shales, together with the conspicuous widening of the vein fracture within these harder wall-rocks

Although the Northern Pennine Orefield is grouped with the international class of Mississippi Valley Type orefields, after the lead-zinc fields of the central USA, it has long been celebrated as an exemplar of its type and has contributed hugely to the understanding of this style of mineralisation world-wide.

The veins most usually comprise coarse-grained assemblages of one or more gangue, or 'spar' minerals, commonly with wall-rock fragments, accompanied by variable proportions of sulphide ore minerals. Galena and sphalerite are generally the most abundant ore minerals, but normally do not exceed 10% of the vein content.

Adjoining many veins within limestone wall-rocks, the host limestone has commonly been extensively replaced by mineralising solutions, creating extensive bodies of replacement mineralisation known to the miners as 'flats' (Figure 4). These may extend for many metres on either side of the parent vein and in many instances carry higher proportions of sulphide mineralisation that the parent vein. Across this orefield the bulk of the replaced rock within the 'flats' is composed dominantly of iron carbonate minerals such as siderite and ankerite: sulphides and other gangue minerals typically occur as bands or pockets within the altered rock.

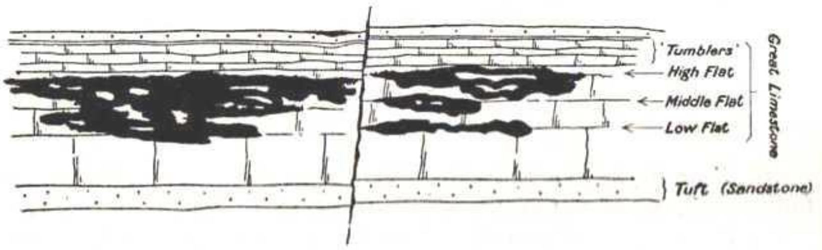

Fig. 2.—Section of 'Flats' in the Boltsburn Mine.

Figure 4. Section through the famous 'flat' deposits at Boltsburn Mine, Rookhope.
Note the extensive nature of the mineralisation within the 'flats' and the occurrence of this mineralisation at three distinct horizons within the limestone of the right hand side of the section

A remarkable feature of this orefield is the marked zonal distribution of certain constituent minerals (Figure 5). Deposits within a central zone which includes much of Weardale, parts of the Allendales, Teesdale and Alston Moor, are typically dominated by an abundance of fluorite within the gangue assemblage. This is surrounded by an outer zone in which barium minerals, including baryte and witherite predominate. The separation of the two gangue assemblages is remarkably sharp with fluorite and barium minerals typically being mutually exclusive in their occurrence. A number of other deposits exhibit a remarkable concentration of zinc-rich mineralisation, not necessarily related to the fluorite or barium mineral zones.

This zonal pattern is crucial to understanding the origins of the orefield. It reflects the presence at depth of the Northern Pennine Batholith which is generally regarded as having provided the heat source which created and drove the convective flow of mineralising fluids through the conjugate pattern of faults within the Carboniferous rocks. Indeed, it was this pattern of temperature-related zonation that first invited speculation on the presence of a concealed granitic body at depth and of its likely role in the formation of the ore deposits. The presence of the granite was confirmed by the drilling of the Rookhope Borehole. Since then, the area has played a major role in the understanding of orefields of this sort worldwide and is the subject of a very extensive technical literature. Details of this huge body of research are out of place here, but can be accessed through the references cited in the **INFORMATION SOURCES** section (below). Whereas the existing literature reflects widely accepted models of ore genesis and emplacement, it is important to recognise that recent, and as yet unpublished work, has challenged many of these now long-held hypotheses, reflecting the continuing research interest in and importance of this world famous orefield.

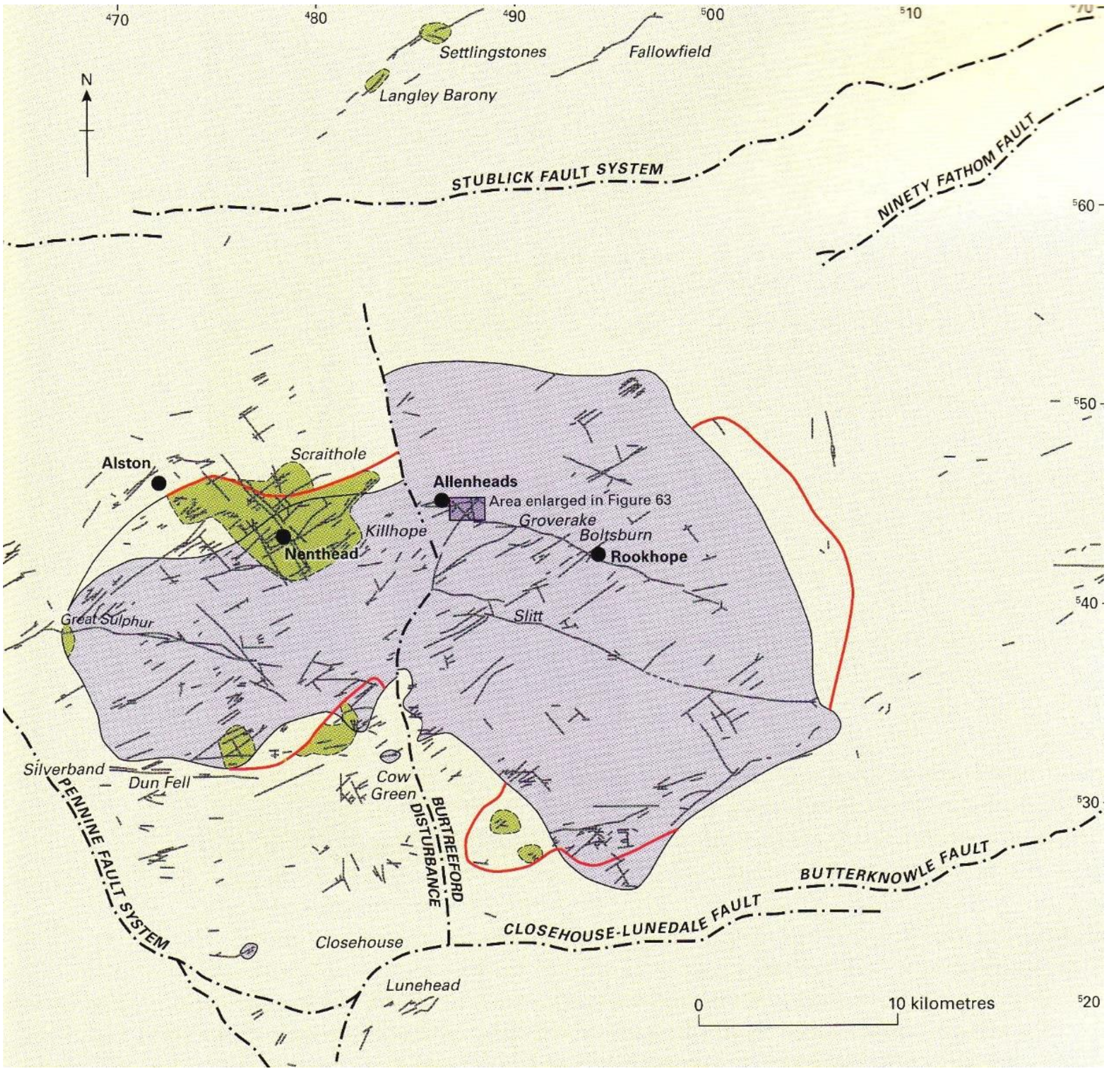

Figure 5. The main mineral zones of the Northern Pennine Orefield.
Veins are shown as thick black lines, The purple colouring depicts the central zone of fluorite mineralisation: deposits outwith this zone are typically characterised by barium mineralisation.
The green areas are concentrations of zinc-rich mineralisation, not necessarily associated with either fluorite or barium mineral gangues.

The minerals so far discussed are all primary, or hypogene, species, deposited at the formation of the deposits. As with all mineral deposits of this sort, near-surface supergene alteration processes have affected the deposits, giving rise to a variety of secondary, or supergene, minerals. Whereas some of these supergene minerals, notably limonitic iron ores, have been of considerable economic value, most are present in very small amounts and are of academic, rather than economic, interest. However, some supergene species are colourful and conspicuous indicators of the presence of some metals that might otherwise not be suspected from a superficial examination of the primary ores.

4. MINERALS OF THE NORTHERN PENNINE OREFIELD

Although renowned as the source of some of the world's finest known specimens of fluorite as well as witherite, barytocalcite and alstonite, three mineral species first described from this orefield, and rare or unknown in many parts of the world, the following valid mineral species have all been reliably reported from this orefield. However, only a small number of these are present in abundance and of these only a handful have ever been of economic interest.

ALBITE
ALSTONITE
ANALCITE (ANALCIME)
ANDALUSITE
ANGLESITE
ANHYDRITE
ANKERITE
ANNABEEGITE
ANORTHITE
ANTIGORITE
APATITE
APOPHYLLITE
ARAGONITE
ARSENOPYRITE
AUGITE
AURICHALCITE
AZURITE
BARIUM MUSCOVITE
BARYTE (BARITE)
BARYTOCALCITE
BERTHIERINE-CHAMOSITE
BEUDANTITE
BINDHEIMITE
BIOTITE
BISMITE
BISMUTHINITE
BOTTINOITE
BOURNONITE
BOWLINGITE
BRIANYOUNGITE
BROCHANTITE
CALCITE
CARBONATE-CYANOTRICHITE
CASSITERITE
CERUSSITE
CHABAZITE
CHALCANTHITE
CHALCOCITE
CHALCOPYRITE
CHLORITE
CHRYSOCOLLA
CINNABAR
COBALTITE
COOKEITE
COPIAPITE
COPPER
CORONADITE
COVELLITE (COVELLINE)
CUPRITE
DEVILLINE
DICKITE
DIPOPSIDE
DOLOMITE
DYPINGITE
ENSTATITE
EPIDOTE
EPSOMITE
ERYTHRITE
FERRICOPIAPITE
FLUORITE
GALENA
GARNET
GERSDORFFITE
GLAUCODOT
GOETHITE (includes 'LIMONITE')
GOSLARITE
GREENOCKITE
GROSSULAR
GYPSUM
HEMATITE (HAEMATITE)
HARMOTOME
HEMIMORPHITE
HORNBLENDE
HYDROMAGNESITE
HYDROZINCITE
HYPERSTHENE
ILMENITE
ILVAITE
JAROSITE
KAOLINITE
KTENASITE
LABRADORITE
LEADHILLITE
LINARITE
MAGNETITE
MALACHITE
MARCASITE
MELANTERITE
MILLERITE
MIMETITE
MINIUM
MOLYBDENITE
MONAZITE
MUSCOVITE
NAMUWITE
NICCOLITE (NICKELINE)
OLIGOCLASE
OLIVENITE
OLIVINE
OPAL
ORTHOCLASE
PECTOLITE
PENNINITE
PIGEONITE
PLUMBOGUMMITE
PREHNITE
PYRITE
PYROLUSITE
PYROMORPHITE
PYRRHOTITE (PYRRHOTINE)
QUARTZ (includes CHALCEDONY)
ROMANÈCHITE
ROSASITE
RUTILE
SCHULENBERGITE
SEGNITITE
SERPIERITE
SIDERITE (CHALYBITE)
SKUTTERUDITE
SMITHSONITE
SPHALERITE
STEVENSITE
STILBITE
STRONTIANITE
SULPHUR
SYNCHYSITE
TALC
THAUMASITE
TOURMALINE
ULLMANNITE
URANINITE (PITCHBLENDE)
VESUVINITE (IDOCRASE)
VIVIANITE
WITHERITE
WOLLASTONITE
WROEWOLFEITE
XENOTIME
ZIRCON

Whereas it might be supposed, from the area's long history of well documented geological and mineralogical research, that little remains to be discovered, it is important to recall that over recent years significant finds of minerals not previously reported from the area continue to be made. Moreover, a chance discovery in the early 1990s revealed a new mineral species (brianyoungite) previously unknown to mineral science. As with similar areas elsewhere, the Northern Pennines continues to offer opportunities for significant new discoveries, something that should always be borne in mind when investigating mine sites, especially in projects such as OREsome.

5. MINERAL PRODUCTS OF THER NORTHERN PENNINES

Although best known as a producer of lead ores, over centuries of recorded mineral production the Northern Pennine Orefield has yielded a much wider range of economic minerals, both metal ores and associated 'spar', or gangue, minerals. It has been a significant source of iron ores and, on occasions, a major source of zinc ores. By-product silver is often claimed as a major product of the orefield and, whereas the importance of this cannot be denied, it is necessary to appreciate that, contrary to all too frequently made claims, the vast majority of the lead ores of this field are distinguished by being lead-poor, not lead-rich. Too many extremely unreliable, unsustainable and scientifically implausible claims have found their way into the historical literature and must be treated with great scepticism.

In addition to its world importance as a producer of lead ores, the orefield was at the forefront of the development of fluorspar production in the late 19th and early 20th centuries. It also has the distinction of being the world most important source of the barium carbonate mineral witherite, and was for very long periods the only world source of this mineral which found a variety of uses in the chemical and other industries.

The main mineral products, including metal ores, and the ore minerals involved, are listed below. Production figures have been compiled from a variety of sources and should generally be regarded as minimum estimates of the likely historical totals.

<u>Metal ores:</u>

LEAD (ore minerals: mainly galena and locally some cerussite)	at least 4 million tonnes
ZINC (ore minerals: sphalerite and smithsonite)	about 0.75 million tonnes
COPPER (ore minerals: chalcopyrite, malachite and azurite)	<1500 tonnes
IRON (including some 'umber' pigment) (ore minerals: siderite and goethite)	unknown, but substantial

SILVER (ore minerals: galena and cerussite – by-product of lead smelting)	170 tonnes
NICKEL (ore mineral: niccolite)	?<0.5 tonnes

<u>Spar minerals:</u>

***FLUORSPAR**	at least 2 million tonnes
***BARYTES**	1.5 million tonnes
WITHERITE	1.0 million tonnes
QUARTZ	unknown, but ? <100 tonnes
CALCITE	unknown, but very small

**In this report, as in other reports associated with this project, the convention is followed of employing the term 'fluorspar' and 'barytes' for the commercial products: 'fluorite' and 'baryte' for the respective mineral species.*

6. INFORMATION SOURCES

Over many centuries of mineral extraction the area has been at the forefront of research into all relevant aspects of Earth science. Indeed, from the practical day to day need of miners to locate and exploit the area's mineral resources as efficiently as possible, grew many of the principles and concepts of geological science that today lie at the heart of those sciences worldwide. In consequence, the area has spawned a voluminous technical literature and archive of immeasurable importance to understanding the area's geology and mineral deposits. Listed below are the main groups of information relevant to this study, accompanied by brief explanatory notes on their relevance, application and whereabouts.

6.1. Technical publications

So large is the volume technical literature, in the form of research papers, reports, memoirs and books, that it is impossible to cite more than a few of the key references in a review of this sort. However, in order to fully understand the wide range of issues that influence the sources and distribution of metals in the environment it is essential to be aware of these and to make reference to them whenever necessary. Listed here is a selection of the most recent and comprehensive summaries and compilations of relevant topics: references to more detailed descriptions of individual sites, features or concepts are listed in the reference lists contained within these:

ARTHURTON, R.S. and WADGE, A. J. 1981. *Geology of the country around Penrith.* Memoir of the Geological Survey of Great Britain Sheet 24. London, H.M.S.O.

BEVINS, R.E., YOUNG, B., MASON, J.S., MANNING, D.A.C. and SYMES, R.F. 2010. *Mineralization of England and Wales.* Geological Conservation Review Series, No 36. : The Mineralogy of Great Britain. Joint Nature Conservation Committee, Peterborough, 598 pp.

BURGESS, I. C. and HOLLIDAY, D. W. 1979. *Geology of the country around Brough-under-Stainmore.* Memoir of the Geological Survey of Great Britain, England and Wales, Sheet 31. London, H.M.S.O.

DUNHAM, K. C. 1990. *Geology of the Northern Pennine Orefield (2nd edition); Volume 1 Tyne to Stainmore.* Economic Memoir of the British Geological Survey, England and Wales. London, H.M.S.O.

JOHNSON, G.A.L. (editor). 1995. Robson's geology of North East England. *Transactions of the Natural History Society of Northumbria.* Vol. 56, part 5.

JOHNSON, G.A.L. and DUNHAM, K.C. 1963. *The geology of Moorhouse.* Monograph of the Nature Conservancy. London, H.M.S.O.

MILLS, D.A.C. and HULL, J.H. 1976. *Geology of the country around Barnard Castle.* Memoir of the Geological Survey of Great Britain. Sheet 32. London, H.M.S.O.

STONE, P., MILLWARD, D., YOUNG, B., MERRITT, J.W., CLARKE, S.M., McCORMAC, M. and LAWRENCE, D.J.D. 2010. *British Regional Geology: Northern England* (Fifth edition). (Keyworth, Nottingham: British Geological Survey).

SYMES, R.F. and YOUNG, B. 2008. *Minerals of Northern England*. NMS Enterprises, National Museums Scotland. 208 pp.

6.2. Geological maps

The area benefits from complete coverage of British Geological Survey (BGS) geological maps, of varying vintages and styles. All are essential to any consideration of the geology of the mines that are the subjects of this project. The area is covered by maps at the 1:50 000 scale, save for the area of the Barnard Castle Sheet (BGS Sheet 32) which is available at the 1:63 360 scale. For a substantial portion of the Pennine escarpment and the High Force – Middleton-in-Teesdale area 1:25 000 scale mapping is also available.

Maps at these scales are published either as bedrock or 'solid 'editions (which depict only the underlying 'solid' geological formations with overlying superficial deposits omitted), or as 'drift' maps in which the superficial deposits are depicted. It is important to consult appropriate maps which depict both 'solid' and 'drift' geology.

These maps are readily obtainable from BGS sales desks or through book and map sellers, including Ordnance Survey agents. Listed below are the maps at these scales, together with an indication of their styles and dates of publication:

<u>1:50 000 & 1:63 360 scale sheets:</u>

Sheet 19 (Hexham): 10 000 scale edition available as Solid edition only. Published 1975, incorporating partial revision of original 1881 mapping up to 1956

Sheet 24 (Penrith): 1:50 000 scale edition available as both Solid only and Solid & Drift editions. Published 1974

Sheet 25 (Alston): 1:50 000 scale edition available as Solid & Drift edition only. Published 1973, incorporating partial revisions of original 1883 mapping made in 1965

Sheet 26 (Wolsingham): 1:50 000 scale edition available as both Solid & Drift and Solid with Drift editions. Published 1977

Sheet 30 (Appleby): 1:50 000 scale edition available both as Solid and Solid & Drift editions. Published 2004

Sheet 31 (Brough-under-Stainmore): 1:50 000 scale edition available as both Solid & Drift and Solid with Drift editions. Published 1974

Sheet 32 (Barnard Castle): 1:63 360 scale edition available as both Solid & Drift and Solid with Drift editions. Published 1969

1:25 000 scale Classical Areas sheets:

Sheet 12 (Cross Fell Inlier): Solid & Drift edition. Published 1972

Sheet 17 (Middleton-in-Teesdale): Solid & Drift edition. Published 1974

BGS 1:50000 scale maps are compiled, usually with some considerable generalisation of geological content, from field surveys undertaken at the 1:10 560 or in more recent years 1: 10 000 scales. Geological maps at these scales are available for the whole of the Northern Pennines being considered here. Geological maps at these scales depict both ‘solid’ and ‘drift’ deposits on the same map. Ideally maps at these large scales offer the best available level of information for a project of this sort. However, it is appreciated that it may not be feasible, or even affordable, to access mapping at these scales and, with appropriate local geological expertise, it may be necessary to restrict reference to geological mapping to that at the 1:50 000 or 1: 63 360 scales, though wherever possible with appropriate additional information from other sources.

The primary geological mapping of the Northern Pennines began late in the 19th century and has benefitted greatly from subsequent revision and, in some areas, complete re-mapping. However, it is important to appreciate that the differing dates of survey reflect the evolution over time of geological science and the means of interpretation and presentation, particularly when dealing with areas where widely differing ages of survey may be involved.

Modern 1:10 560 and 1:10 000 scale geological mapping based on the National Grid covers the areas of BGS sheets 24 (Penrith), 26 (Wolsingham), 30 (Appleby), 31 (Brough-under-Stainmore) and 32 (Barnard Castle). For Sheets 19 (Hexham) and 25 (Alston) geological mapping at this scale pre-dates the advent of the National Grid and is available on 1:10 560 County Series Sheets.

The positions of component 1:10 560 or 1:10 000 scale maps are indicated on all published 1:63 360 and 1:50 000 scale maps.

These large scale geological maps are only obtainable directly from BGS sales desks, or can be consulted by appointment at BGS offices.