IRON MINING IN THE PEAK DISTRICT

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Abstract: A summary is presented of the occurrence and distribution of hematite and ochre deposits in the Carboniferous Limestone of the White Peak. Veins with hematite are present around Hartington station and Newhaven, near Dovedale and at Cauldon Low in Staffordshire. Ochre deposits were widespread and the main workings were near Elton and Brassington. The limited historical and production records are summarized. It is suggested that the hematite veins may reflect a late phase of re-opening fractures sufficient to receive downward-percolating solutions from the Triassic cover. Some ochre deposits may be weathered hematite veins whilst others are iron-enriched clays, some possibly of loessic origin, whilst others are cave sediments.

Introduction

Whilst the mineral veins hosted in the Carboniferous Limestone of the White Peak are well known for their content of lead and zinc ores, fluorspar, barytes and calcite, the fact that they were also the focus of some iron ore mining is little known. Iron ores are not usually a component of the Mississippi Valley type mineralization, so it is desirable to consider what iron minerals are present, what their genesis was, what they were used for and any production data which can be found. The following review is presented in the hope of stimulating further geological and historical research. The ironstone nodules present in the Coal Measures formed an important iron ore resource in Victorian times but they are not considered herein.

The iron minerals present in the Peak District have previously been discussed (Ford *et al.* 1993) and are thus only summarised here.

Magnetite (Fe_3O_4) is found as a minor component of basaltic igneous rocks (toadstones), particularly the coarser doleritic intrusions, but the quantities are much too small to warrant economic exploitation.

Hematite (Fe_2O_3) - (the modern spelling hematite has replaced the older haematite as used in some of the quotations herein). It is common as a red-staining agent in many veins and in a few limestones such as the Duke's Red Marble from Alport-by-Youlgreave. Both kidney ore and earthy varieties of hematite have been exploited commercially in a few veins around Hartington, on the hill-tops near Dovedale and around Cauldon Low in Staffordshire. Most hematite was apparently ground for use as a red pigment in paint: only a small proportion was sent to smelters. A little seems to have been crushed very fine and used as a polishing medium, akin to jewellers' rouge. Hematite was common as inclusions in quartz crystals at Calton Hill, Taddington, where it gave grey or amethystine colours to the quartz.

Goethite ($Fe(OH)_2$ (impure soft earthy varieties are often known as limonite); rarely crystallizes in a pure form and is usually pseudomorphous after marcasite or pyrite. Small quantities are scattered in many veins but it was only occasionally exploited for ochre.

Lepidocrocite is a rare orthorhombic dimorph of goethite, generally recognizable only under the microscope, but it may be more common in the Peak District than known at present.

Pyrite and Marcasite (FeS_2). Though these two minerals are chemically the same, pyrite crystallizes in the cubic system and marcasite in the orthorhombic system. Together with chalcopyrite and bravoite they are widespread as inclusions in fluorite; pyritic inclusions are also present in calcite forming "ghost" outlines of early scalenohedra within larger calcite crystals, usually blunt scalenohedra terminated with flat rhombohedra. Pyrite is locally common as scattered cubic crystals in limestones adjacent to toadstones and as veinlets in altered toadstones, where it has occasionally been mistaken for gold! Marcasite is sometimes found as a precipitate in the bottoms of pipe veins, as at Oxclose Mine. Nowhere in the Peak District is either of these two sulphide minerals present in sufficient quantities for exploitation for their iron content, though pyrite from decomposed toadstone was worked for a short period in Lathkilldale for its supposed gold content (Grigor-Taylor 1972)..

Siderite ($FeCO_3$) is the iron-bearing equivalent of calcite. Though common in North Pennine veins, there are few records in the White Peak: traces have been recorded on Brassington Moor (Mawe, 1802), Ecton, Cumberland Cavern and Wapping Mine (Ford *et al.* 1993; Ince, 1991). Otherwise it is known mainly in the Peak District Millstone Grit as impure sideritic nodules in the Edale Shales, e.g. at Mam Tor. Generally fine-grained, these sometimes have crystalline siderite filling cracks but they have only been worked at Ironpits Farm, near Waterhouses, Staffordshire. Siderite nodules were once an important iron ore resource in the Coal Measures of both the Derbyshire (Willies, 1997; Williams, 1998) and Staffordshire coalfields (Chester, 2003).

Ankerite is the magnesium-bearing equivalent of siderite. Though well known in North Pennine veins, the only record in the Peak District is in an unpublished report on Cauldon Low quarry (Jeffrey, 1983).

Ochre is the name given to yellowish to brownish, occasionally red, earthy materials of no fixed composition (Pocock, 1942). Ochre was mostly impure goethite (limonite) mixed with clays. Some ochres may be loessic clays or derivatives washed into caves; others went under various old names such as "foxsoil", "foxearth" and "eccles or eagle stone". Whilst no mineralogical definitions of these are possible, foxsoil and foxearth seem to have been limonitic loess; eccles or eagle stones were partly hollow iron pan nodules. Together with umber these materials were found around the margins of some of the silica-sand pockets. Ochre is said to have been worked on a small scale near the Harborough Rocks sand pockets and there was a "paint mill" near Manystones Quarry (R. Paulson, pers. comm). In the coalfields ochre settling ponds were set up outside several drainage adits. After drying the ochre was used as a pigment for paint manufacture. Details of ochre processing, usage and marketing were given by Paulson (1997). Both ochre and earthy hematite were sometimes known as "raddle" and mines were raddle pits. Raddle was sometimes used for marking sheep.

Only hematite and ochre have been worked commercially as iron minerals.

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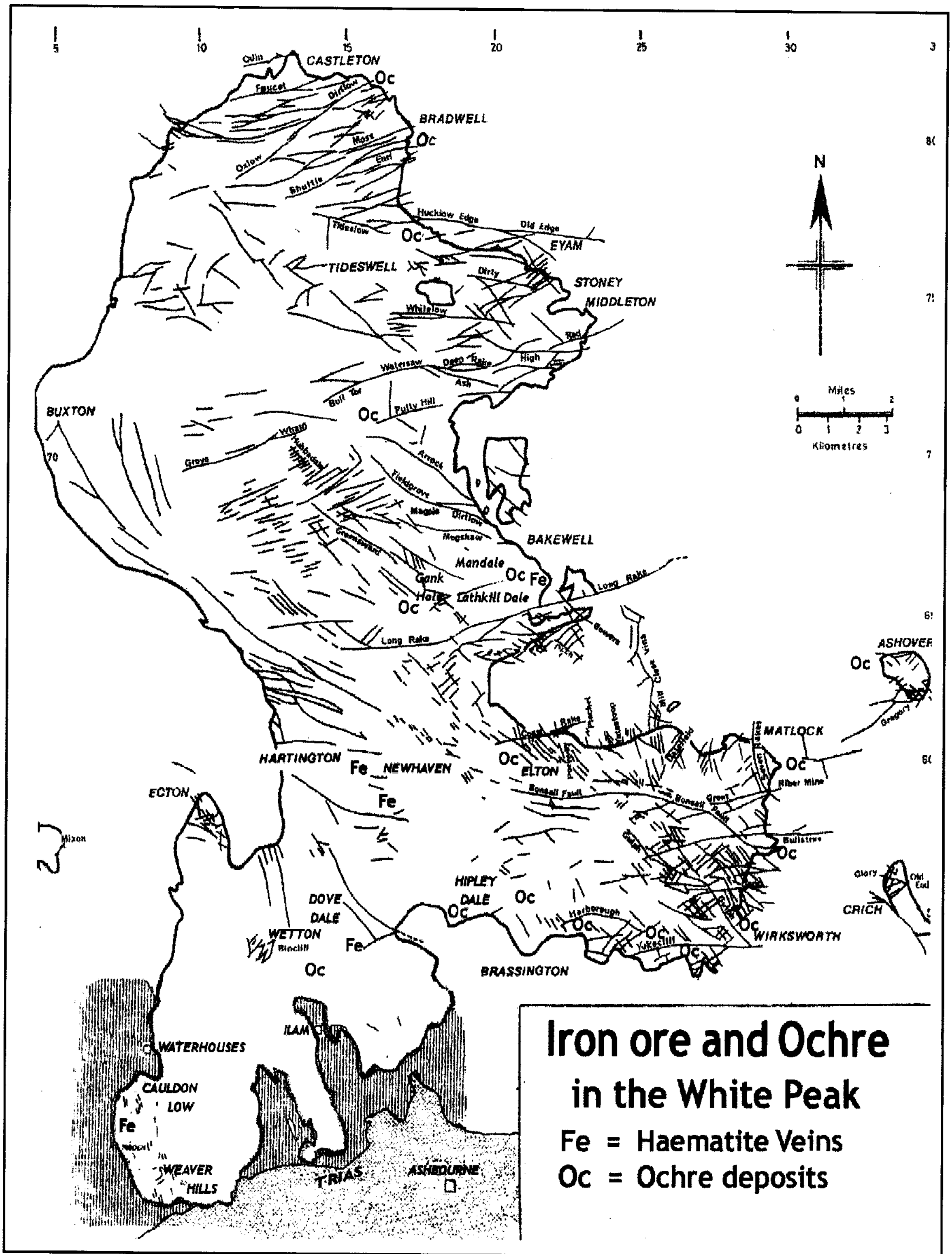

Sketch map of the South Pennine Orefield to show hematite and ochre localities (most of the latter are only at Parish level). Map based on one compiled by N.J.D. Butcher.

Previous Records

Most of the old literature referred to the iron ores found in the coalfields which are not considered herein. Only limited remarks were made on the iron ores of the White Peak and these are vague at best and misleading at worst, but they do give a little idea of what has been exploited and where.

As early as 1686 Robert Plot recorded "yellow and red ochres sometimes met with (but in small quantities) near Stanshope in the parish of Allstonefield" (about SK 123 542).

Emanuel Mendes Da Costa (1757) listed various forms of ochre in his *Natural History of Fossils*, but some of his varieties were clearly either manganese wad or umber. He evidently regarded ochre as a deposit allied to wad, but unfortunately he gave no details of localities.

Mawe (1802, p.96) noted "haematites or liver stone is sometimes found incumbent in a solid mass or ball" but he said nothing about localities.

Davies (1811, p.98-99) referred to "Martial ochres", supposed to result from the decomposition of iron ores. The best, of a rich yellow colour, was found in a cavern, called the Water Hull, near Castleton. Dark brown ochre was met with in a lead mine under High Tor at Matlock; a pale yellow ochre was found at Winster and balls of a darker yellow were found in shale at Hassop He commented they were the most durable pigments in nature

Farey (1811) commented briefly that some of the rakes contained Oxide of Iron (hematite). Pyrite was recorded at Cromford, Eyam, Matlock, Overton, Stanton-in-the Peak, Stony Middleton. Taddington and Wirksworth, though not in workable quantities. Yellow and red ochres were found at Ashover, Bradwell, Brassington, Brushfield, Castleton, Cromford, Great Hucklow, Hartington and Wirksworth. In his List of Lead Mines, Farey noted ochre as being found at Ashcross Mine, Cromford (exact location not known), at Baldmare Mine, Brassington, at Dream Mine, Godfreyhole, and at Ranter Mine in the Gulf at Wirksworth. Regrettably no details were given of the nature or relationships of the ochre deposits, but Dream Mine is well known for its sticky yellow clay, probably inwashed loess. Baldmare Mine was said to have yielded ochre which may be loessic clay. Ranter Mine's ochre may have been derived from drainage of pyritous shales in the Gulf depositing limonite material at a sough tail. Farey said little about whether ochre was then being worked and gave no indication of quantities produced. Farey also noted "Polishing haematites, Bloodstone or Burnishing stone" in a highly rounded state being found in "alluvium" at several localities including Grindon, Newhaven, Over Haddon and Willesley. It was apparently prized by button-makers in Birmingham, though it is not clear whether they made buttons of hematite or used it as rouge to polish brass buttons. Again, regrettably few details of the occurrences were given by Farey.

White Watson's comments (1811, p67) were similar to Farey's but much shorter. He referred to "Bloodstones, haematites, iron ore in pipe works" being found in rare obtuse-angled nodules in or on the limestone around Chelmorton and Winster, with no further details. He had very little to say on ochres.

Glover (1829, p83), mostly repeating Farey, listed yellow and red ochres as being found at Ashover, Bradwell, Brassington, Brushfield, Castleton, Cromford, Great Hucklow, Hartington and Wirksworth, as well as various localities in the coalfield. "Haematites or bloodstone" was also noted at various sites, the only one in the Peak District being Over Haddon.

Adam (1851, p383) noted that "haematites and jaspberry iron ores" were found at Parwich and on End Low (about 500m west of Newhaven) where "immense quantities" were raised and sent for smelting at Codnor Park iron works in the Derbyshire coalfield, where it was preferred over the Coal Measures clay ironstones owing to the higher iron content.

Stokes (1878), otherwise so informative, did not have much to say on either iron ore or ochre. Hematite was said to be found in "fissures" in the limestone (like those of Barrow-in-Furness) though the writer has been unable to find any record of deposits being found to match the "sops" of Cumbria. According to Stokes (1878, p 46) iron ore deposits were worked in Hand Dale, near Hartington, and in Friden Dale, near Newhaven (see below). He said that transport costs precluded unspecified deposits around Newhaven being workable, but this seems unlikely as the High Peak Mineral Railway was close by. At some stage a stockpile of some 2000 tons of iron ore was awaiting shipment at Friden station (L. Porter, pers. comm.).

Ochre was described by Stokes (1878, p64) as "a kind of clayey earth" - sedimentary in appearance and it was supposed to result from the decomposition of iron ores. It was varied in colour, but rich yellow was regarded as the best. It was produced around Wirksworth, Bakewell and Ashover. Stokes reported that, after processing, it was sold to colour manufacturers at paint mills and was also used in making coloured paper.

The Geological Survey Memoir (Green *et al* 1887, p159) does little more than summarize the comments made by Farey (1811) and Stokes (1878). In turn Green *et al*'s comments were summarized in the Chesterfield and Matlock Memoir by Smith *et al.* (1967) without further comment.

Barnes and Holroyd (1897) gave the only report so far located which described the iron ores of Cauldon Low in the Weaver Hills. Without giving a map or any orientation, they referred to vertical fissure veins apparently opened across the crest of a gentle anticline in the Carboniferous Limestone which were filled with calcite to the full depth of the quarry: "All the cracks and joints seem encrusted with . . . haematite . . . it is found in more or less reniform masses, as a kind of kidney ore". They regarded the iron as having come from the former cover of New Red Sandstone (Permo-Triassic) and compared the occurrence with the iron ores of Cleator Moor in Cumbria and at Llanharry in Glamorgan, etc. Hematite was also recorded in pockets which were previously-formed holes and caverns in the limestone, though no dimensions were given. They also noted an unusual cubic form of calcite encrusted with hematite, but opined that the cubic shape was due to it filling spaces previously occupied by pyrite cubes. As far as can be ascertained all the veins seen by Barnes and Holroyd have long since been quarried away.

Ironstone nodules were worked from Millstone Grit shales at Ironpits Farm, some 3 km northwest of Cauldon Low in Staffordahire. They have no bearing on the veins in the nearby Carboniferous Limestone. The Churnett Valley, part of the Cheadle coalfield, is close by and produced up to half a million tons of iron ore per annum, an amount which makes the little thought to have been obtained on Cauldon Low look very small.

The Derbyshire Coalfield Memoir (Gibson and Wedd, 1913, p 117), which included the area around Matlock, referred briefly to "yellow and red ochre seen here and there on decomposed upper parts of veins and as deposits in other superficial cavities". Nothing was said about what there was in such veins which might decompose and yield ochre. They also noted on p119 "Raventor Rake on the Gulf Fault . . Ochre", which might refer to derivation from the shales in the Gulf, possibly at the outfalls of springs or soughs.

In the Geological Survey's Special Report, Cantrill *et al.* (1919) repeated Stokes (1878) comments on hematite and noted that no iron ore had been worked since 1878. They added a few localities, mostly culled from Green *et al*'s two editions of the Geological Survey Memoir (1869 and 1887): these included an ironstone (earthy hematite?) mine on Elton Common, 2 miles WSW of Winster, a lode at Narrow Dale 1¾ miles south of Hartington and ¾ mile west of Winster, and others at Gateham Grange 2¼ miles SSW of Hartington.. Covered shafts are said to exist near Gateham Grange (R. Paulson, pers. comm.). A trial was made in 1903 at Alsop Moor Plantation 3 miles SE of Hartington. Cantrill *et al.* did not discuss ochre.

In a Geological Survey World War II pamphlet, Pocock (1942) reviewed natural earth pigment production throughout Britain, including ochre, umber and wad (for discussion of wad see Ford, 2001). He noted that ochre was known under various names: mineral yellow, Roman ochre, Roman earth, Oxford ochre, Chinese ochre and golden ochre. Without going into details of the subtle differences between these or of their geological occurrence, he described ochre as a mixture of clay, siliceous matter and hydrated iron oxide (limonite) with the iron oxide content generally around 15-30%. He summarized production statistics from 1919 to 1938 showing that the total U.K. output ranged around 8000 to 10000 tons per annum. Derbyshire yielded 300 to 400 tons per annum up to 1928 whereafter production declined to 59 tons in 1938. The Derbyshire figures were apparently for output from the coalfields, particularly where limonite was deposited by water discharging from old adits. Only a small unspecified fraction came from the Peak District. Ochre was noted as occurring with wad around Winster, whence it was supplied to the Via Gellia paint works. A little ochre was said to have been obtained from High Tor Rake at Matlock and from Fall Hill, Ashover. The exact localities were not given.

In his unfinished draft Memoir on the South Pennine Orefield, Stephens (1942) repeated Farey's ochre localities with little comment, but added that ochre was "more recently" worked at Doglow Wood, Carsington. He gave no geological details but the ochre may have been a ferruginous clay in one of the silica-sand deposits of the Carsington Pasture area.

In their survey of the mines round Ribden, Staffordshire, Robey and Porter (1972, p26) noted hematite veins (one with quartz) in two small quarries at Ribden. They noted that Watson (1860) had recorded Ingleby's Vein as being calcite with iron ore: bearing 305°, it was inclined at 25° to the east. Regrettably the old quarries have now been filled in with rubbish.

The *Limestone Resources Report* on the Ashbourne area (Bridge and Kneebone, 1983, p15) included Cauldon Low but only made a passing mention of iron ore: "hematite sometimes forms quite rich deposits especially along faults, when it can be removed by selective digging, but more often, it occurs disseminated through the rock as blebs and infilling micro-veinlets". No further details were given. An illustration was given of a core (page 21, Plate 8, fig. 2) from a borehole west of Wetton which showed quartz sand (Triassic?) filling a subsurface fissure in reef limestone.

The general Limestones Resources Report (Harrison and Adlam, 1985, pp.20 and 23) included a map of the distribution and concentration of iron within the limestones amounting up to 2.8% Fe (but mainly less than 0.1%) in the more shaley off-shelf facies (as pyrite?) and on the Staffordshire shelf, where the limestones were reddened by iron oxides - along joints, cracks and fissures - presumably the result of iron-rich fluids possibly derived from a former cover of Triassic sands". No details were given of localities with iron mineralization.

The Geological Survey Memoir for the Ashbourne area (Chisholm *et al.* 1988, p129) noted that there were hematite-bearing veins in the Weaver Hills, to the north of the Ribden lead mines, and adjacent to the Cauldon Low limestone quarry. Veins of calcite up to 0.5 m wide (rarely 2 m) contained hematite but were said not to contain lead ore. Most veins had a north to northwesterly trend with horizontal grooving indicating wrench-fault origin, e.g. on the west side of Hemmings Low (SK 075 488) now largely removed by the Cauldon Low quarry. Neptunian dykes of pink siltstone and red sandstone were noted in some veins which suggested to Chisholm et al. that there had been a connection with the former Permo-Triassic land surface.

In his admirable review of the Derbyshire paint industries, Paulson (1997) described the processing of ochre and ground hematite for pigments and their subsequent marketing, but he did not go into any detail on the deposits or their geology.

Still in active production, Cauldon Low cement works quarry in Staffordshire has intersected several N-S and NW-SE veins with calcite and earthy hematite some of which are said to have yielded occasional large masses of galena (Ford, 2000 and pers. comm. from L. Porter). Iron ore was raised from several small mines hereabouts in the 18th century but little was recorded then and still less is known about them today. Later 19th century trials produced little ore.

In his unpublished thesis on the Cauldon Low cement-making materials, Jeffrey (1983) provided sketch maps of the quarries showing the minor folds and faults then visible, both generally with N-S trends. Jeffrey (pp.25-27) commented that many faults were occupied by veins of calcite and hematite up to 0.3 m wide. Up to twelve crustiform bands were seen in some veins with iron-stained calcite alternating with hematite and occasional ankerite. Thin-section studies showed the presence of micro-veinlets of calcite and hematite in the limestone bordering the veins: the limestone analyses generally showed less than 0.5 % iron oxide. Some of the veins also contained "clay washed in from above". Regrettably no description or illustration of any individual vein was included by Jeffrey and the origin of the hematite was discussed only in the light of an Eh/pH stability field which showed that both calcite and hematite could be deposited under similar conditions. The overlying shales, used in cement-making, were found to be locally rich in pyrite, but no connection between pyrite and hematite veins was established.

Several "paint" mines with earthy hematite or limonite have been recorded in the Manifold Valley and Dovedale area (Ford, 2000, p17). Narrowdale Mine (SK 124 574) and shafts close to the Gateham-Alstonfield road (SK 121 569) produced earthy hematite and calcite. Hope Dale Mine (SK 118 545) was another iron mine nearby. Strong Stys Mine (SK 101 555) was a "paint" mine on the north side of the hill containing Thors Cave near Wetton. Lead ore and "ruddle" (= raddle) were obtained on the hilltop opposite Reynards Cave (SK 141 523) and from Sandbroom Wood nearby (SK 137 523). Little is known of the details of the deposits but they seem to have been mostly limonitic ochre, though mentions of "blue iron ore" and "a ton sold to Derby" suggest that some hematite was mined and possibly sent to a smelter. These small Dovedale iron mines seem to be similar to the Hartington mines. At least some of the iron ore was processed at a paint mill at Milldale in Dovedale..

In his book on Lathkill Dale mines, Rieuwerts (2000) made several references to Gank Hole Mine towards the western end of the Dale. It was worked for "ochre" for paint manufacture in the 1880s. This WNW-ESE vein had yielded a little lead ore earlier: the vein-stuff visible in the adit today is mostly calcite with earthy ochre, and traces of the copper-zinc carbonate mineral rosasite. Some writers have regarded the iron ore-bearing veins as distinct from the lead veins, but the Gank Hole vein appears to be a split from the Lathkill Dale vein with its rich galena deposits. Small nodules of goethite within soft ochre can still be found in the nearby Mandale lead mine. The waste hillocks of Mycross Vein, a branch off Mandale Rake, were reported to have baryte cemented by iron ore (Craven, 1959). Goethite, replacing marcasite, was also found at Hubberdale (Worley *et al.* 1978) and other veins north of Monyash but not in economic quantities. Mine names such as Dirty Red Soil, Gorse Redsoil and the Great and Little Redsoils. all near Magpie Mine (the Society's field centre) at Sheldon may also indicate ochreous occurences and it is possible the nearby Sheldon Bole Hill had iron smelting on it (L. Willies, pers com) suggesting fairly nearby exploitation on a very small scale in medieval times.

Ochre was also sometimes known as raddle, and there was a Raddlepits Mine near Moss Rake Head on Bradwell Moor (about SK 136 796) but no raddle is visible there today and it is not known what was mined there.

In his account of ironstone mining in the Derbyshire coalfield, Willies (1997) briefly referred to hematite being found in pockets near Winster, Elton, Brassington and Monyash, but no details were given. Williams (1998) added some details on iron mining in the coalfield.

The Hartington Veins

The only iron-ore veins accessible today are those around Hartington station, now part of the Tissington Trail. In the old limestone quarry immediately northeast of the car park (SK 151 612), a vein of calcite about a metre thick slopes at some 52° NNE. It has a central rib of granular hematite about 20 cms thick. Both calcite vein and hematite rib appear to occupy a WNW-ESE fault plane which may be later than the fractures containing the lead veins. No evidence was found that either lead or iron ores had been worked from this vein, which was only exposed by the much more recent quarry. Another old quarry some 500 m to the south (SK 149 606) may be the End Low locality mentioned by Adam (1851) though there is little to see now. To the west of the station and bridge, an obvious adit goes in northwards in Hand Dale (SK 145 611); it is variously known as Hand Dale Mine, Hartington Mine or Hartington Moor Farm Adit. Though it appears to be a 19th century adit, a lease to mine iron ore and other minerals in Hand Dale dates back to 1735 (Curry papers, Chatsworth). The adit is 231 m long with a collapsed shaft some 150 m in: it reaches a WNW-ESE cross-drift (30 m each way) in a iron-bearing vein. According to Stokes (1878) the adit was worked by the Sheepbridge Iron Co. and shafts were said to have been sunk to a depth of 40 yards. The iron ore in the adit is thoroughly weathered and has a semi-liquid consistency: presumably this would have been called ochre by the miners. Present day explorers are likely to emerge tomato-soup-coloured!

Some 2 km to the east of Hartington station another iron mine was opened in Friden Dale close to where the road makes a sharp bend across the dale (about SK 174 612). It was operated by the Butterley Iron Co. and the workings were said to be shallow (Stokes, 1878): there is little to see today. To judge from the extent of the Hand Dale and Friden Mines the quantity of iron ore obtained cannot have been enough to be of great value to the Sheepbridge and Butterley Companies.

In the nearby Arborlow Mine on Long Rake, pockets of ochre and hematite are said to have interfered with the extraction of clean calcite.

Production Statistics

Very few production figures have been found. Both Burt *et al* (1981) and Willies (1997) gave production totals, generally around 20,000 to 30,000 tons per annum from Derbyshire in the 19th century but it seems likely that almost all came from the coalfield. Burt *et al* (1981) listed only one mine in the Peak District - at Alsop-en-le-Dale - it yielded 10 tons in 1902. The situation is confused by hematite being ground up for use as a red pigment in the same works where ochre pigments were produced.

At Chatsworth, an entry for 1812 in the Duke of Devonshire's account books stated "Duty on Ochre got at Newhaven £33 (Devonshire Collection: Notebook for 1773-1812, p5).(L. Porter pers comm.). Other figures for iron ore production culled from the Duke of Devonshire's account books were cited by Porter and Robey (2000, p 187). Strong Stys Mine in Wetton parish, north of Thors Cave, yielded 3 tons 5 cwts of "brown and blue iron ore sold at £1 and 15 shillings (75p) per ton respectively in 1850". Other figures include 11 tons 13 cwts sold in 1850; 4 tons 13 cwts in 1851; 10 tons 10 cwts in 1859; 7 tons 13 cwts in 1860; 7 tons 5 cwts in 1861. Royalties varied from 5d to 9d per ton. Another record noted that 16 tons were raised in 1850-1 by independent operators. A further note was of 6 tons raised in 1861 at Hope Heath, apparently not the Strong Stys mine. At least one ton was "sold to Derby" - possibly for smelting.

The "immense quantities" of iron ore at End Low (Adam, 1851) may have come from a hematite in calcite vein like that in Hartington Station quarry.

A more complete idea of production for iron smelting might be obtained from a search of the Butterley Company's archives in the Derbyshire Record Office at Matlock and from a thorough search of the Curry Papers in the Duke of Devonshire's archives at Chatsworth House. The Barmaster's records of course pertained to lead mining and any mention of iron ore production would have been incidental, though iron miners might well have "freed" the veins concerned by registering that they were also lead mines. Iron mining on Cauldon Low might be covered in the Earl of Shrewsbury's papers at Ingestre Hall or in the Staffordshire Record Office, Stafford, but these have not yet been searched.

Geology of the Hematite Veins

With little to see in the field and with the old literature being so vague, any deductions on the origin and nature of the iron-bearing veins can only be speculative. Lead and iron ores are not usually found together in hydrothermal ore deposits, as galena is a sulphide and is deposited in a reducing environment, whilst hematite is an oxide and is usually formed under oxygenated conditions.

Most of the known hematite-bearing veins around Hartington and on Cauldon Low seem to have had ribs of iron ore in the middle of a calcite gangue. Galena, if present, was on the walls, indicating that it was an early precipitate and hematite was later in the paragenetic sequence: in other words deposition of lead and iron was separated in time, and that time was enough to change from reducing to oxidising conditions. This may also have been the case in Gank Hole and other mines in Lathkill Dale. Thus, hematite deposition as a late phase might indicate a much later re-opening of the fissures. If Barnes and Holroyd's (1897) argument, followed in the Ashbourne and Cheadle Memoir by Chisholm *et al* (1988), is accepted, the source of the iron was in groundwaters in the former cover of Permo-Triassic red beds, whereas the galena deposition was late Carboniferous. Deposition of lead ore and its gangue minerals took place under a thick cover of Upper Carboniferous strata giving hydrothermal temperatures appropriate to a depth of around 2 km. By Triassic times most of that cover had been eroded away and hematite deposition could have been at a shallow depth with much lower temperatures. The renewal of a stress-field necessary for re-opening fissures in late Triassic times correlates with the development of the Cheshire basin and its red-bed deposits of copper and lead ores (Plant *et al.* 1999). Triassic strata lie unconformably on the limestone not far from Cauldon Low and could well have been not more than 100 m or so above the limestone there and around Hartington and Dovedale.

It has been suggested to the writer that the hematite could have been the result of oxidation of pyrite and marcasite in the lead veins. Whilst these two iron sulphides were widespread as inclusions in fluorite and occasionally as accumulations of free-grown crystals, the quantities in the inclusions seem to be far too small to account for the amount of hematite found, and the distribution is different - most fluorite with inclusions is in the eastern part of the South Pennine orefield whilst hematite veins are in the west.

Some of the old accounts, e.g. Barnes and Holroyd (1897), mention "holes and pockets" with iron ore adjacent to veins. Although no details were given, it seems that none of these was large enough to be compared with the Cumbrian "sops", and they were probably less than a metre across.

There are similarities in the Peak District with the mechanisms proposed for the iron ore veins and "sops" of Cumbria (Rose and Dunham, 1977) and South Wales and the Forest of Dean (Trotter, 1942; Lowe, 1989, pp114-115; Moseley, 2000). The mechanisms were evidently not as effective in the Peak District and no large-scale iron ore deposits comparable with Cumbria were formed. In the Ashbourne and Cheadle Memoir, Chisholm *et al.* (1988) commented on some fissures having re-opened to admit inflowing sands and silts from the Permo-Triassic cover as in a borehole near Wetton (Bridge and Kneebone, 1983, plate 8). Regrettably no such fissures are visible at present, though they may be revealed in Cauldon Low quarry as the faces advance in future.

Several of the old accounts refer to goethite replacing marcasite in the rakes. Goethite nodules as seen in Mandale Mine, Lathkill Dale, and other nearby rakes are nowhere large enough to constitute iron ore deposits. The goethite nodules, rarely more than 1 cm in diameter, replace marcasite and are late in the paragenetic sequences: the goethite may be an indication of Triassic re-opening and oxidation in the veins of the Lathkill Dale area.

The Ochre Deposits

Analyzing the nature of ochre formation in the Peak District is hampered by the absence of any detailed description of an ochre deposit, indeed most of the old literature does no more than list villages or parishes where it was found. Also no present day ochre deposit is available for study (this account excludes the ochre deposited in ponds outside adits and soughs in the shales of the Millstone Grit and Coal Measures, wherein oxidation of pyrite could easily produce iron hydroxides).

So far as can be deduced ochre was ferruginous clay or silt, of variable colour, mostly yellowish-brown but ranging into red-brown. The iron oxide content was generally 15-30% (Pocock, 1942). From a study of the geology of the locations where ochre has been recorded in the White Peak, it seems that ochre deposits were of four kinds:

(1) limonitic stalactitic formations in soughs cut through pyritic shales; some of these were seen by the writer in Yatestoop Sough; in quantity they can rarely have been more than a few hundredweight.

(2) loessic clays in the subsoil; most loess is a fine quartz silt, but clay fractions with a ferruginous content are possible.

(3) ancient cave sediments, with silty clay layers locally enriched in iron hydroxide (comparable with and often associated with manganese wad deposits): these seem to have provided most commercial ochre.

(4) oxidation and hydration of pyrite or marcasite in the mineral veins, rarely in quantities worth exploiting.

After extraction the raw ochre was subjected to a process called levigation - crushing to form a suspension in water. Following stirring, silt, sand and clay were allowed to settle leaving tanks containing a suspension of iron hydroxide in water (Paulson, 1997). This was drained off and dried in a kiln: the temperature was kept below 100°C to avoid alteration (oxidation?) which was liable to change the colour. The resultant powder was then sold to the many colour works in the district. Evidently substantial quantities were involved to keep the colour works going. However, this gives us little idea of either the size of the ochre deposits or their geological origin.

The idea that ochre resulted from the oxidation of earlier iron deposits is not helpful as it gives no idea of what these other deposits were: the only earlier iron deposits known are the hematite veins and they hardly appear large enough to account for the amounts of ochre thought to have been supplied to the paint works. Anyway, the distribution of ochre deposits differs from hematite-bearing veins.

Only three occurrences are known to the writer which are useful in solving the ochre problem. West of Brassington, on the south face of Hipley Hill, the OS 1:10000 map marks two ochre pits at SK 209 539 and SK 214 536. Both are shallow overgrown diggings but rabbit holes show traces of yellowish silty clay, rather like loess. This may fill old caves or solution collapses in a similar manner to the loessic mud found in the Castleton caverns.

The other occurrence is in the Golconda Mine, northeast of Brassington, where one of a series of sand-filled caverns had been cut through by lead and barytes miners and showed a section with about 30 cms of manganese wad overlain by a similar thickness of orange-yellow ochreous clay. The sediments appear to be inwashed Neogene sands and clays of the Brassington Formation, possibly with a contribution of loess. As argued in the writer's recent discussion of wad-deposits (Ford, 2001), ground-waters migrating through such fills could have brought in iron hydroxides as well as manganese from any nearby sources such as from the Neogene sands and clays and from breakdown of dolomite, which has trace contents of Fe and Mn. Other sediment-filled caves have yielded wad in the White Peak and may have also yielded ochre, e.g. Heyspots Mine and the Portway Pipe near Elton..

Conclusions

Iron ore in the form of hematite was mined in a few rakes around Hartington and near Cauldon Low. Some was sent for smelting whilst the rest was crushed for use as red pigment for use in paint. Its presence in the middle of calcite veins suggests that hematite deposition was later than the rest of the hydrothermal ore suite and may indicate Triassic re-opening of some fissure veins. The source of the iron may have been groundwaters from the former cover of Trissic red beds. Few production figures have been unearthed.

Ochre included yellow, orange and red silty clays with 15-30% Fe. Some of the clays seem to have been of loessic origin whilst others were cave sediments. Ochre was produced from surface pits or ancient caves where infiltering groundwaters deposited the iron hydroxide in clays with limited permeability. Whilst the quantities produced appear to have been enough to keep several colour works going, only very limited production figures have been found.

Much more research is needed to ascertain exactly where hematite veins occurred and what yield of iron ore could have been obtained. The paragenetic relationship of hematite to lead ore and other gangue minerals also needs to be worked out wherever any vein can be seen today. Exactly what ochre was and where it has been worked is still uncertain. Comprehensive archival studies are badly needed to reveal the quantities produced of both hematite and ochre.

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