Alderley Edge District, Cheshire

[SJ 84 77]–[SJ 86 77], [SJ 87 78]

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Introduction

Alderley Edge lies some 20 km south of Manchester, in the north-eastern part of the Cheshire Basin (Figure 4.1), an asymmetric half-graben or rift that underlies most of Cheshire and north Shropshire. The basin is bounded to the east by the Red Rock Fault, part of the Wem–Bridgemere–Red Rock Fault System (Chadwick *et W.,* 1999), and is occupied by rocks of Permian, Triassic and Jurassic age (Warrington *et al.,* 1999).

Sandstones form the lower part of the Triassic succession and host a widespread barite mineralization, and, at scattered localities in north Shropshire, at Bickerton (west Cheshire), and in the Alderley district, a copper-dominated polymetallic mineralization (Dewey and Eastwood, 1925; Warrington, 1980a, 1995; Carlon, 1981; Plant *et al.,* 1999a). The Alderley mining district encompasses extensive workings on Alderley Edge and a small mine at Mottram St Andrew (Figure 4.30). It is the largest occurrence of sediment-hosted polymetallic mineralization in the Cheshire Basin, with a long mining history and the greatest known output; it is also the most extensively studied and documented. The influence of sedimentary host-rocks of different facies, and of structure, on the nature and distribution of the polymetallic ores and the form of the orebodies can be examined in three-dimensions in unweathered sections in more than 15 km of shallow, disused mine-workings that underlie an area of some 1.5 km^2 on Alderley Edge. Over 30 elements are present in a mineral assemblage comprising over 60 species. These factors render the site of unique importance in Britain, and farther afield, for scientific and educational purposes; appropriately, It is a geological SSSI. Entrances to mines on Alderley Edge are on National Trust property. Access is administered by the Derbyshire Caving Club (DCC) by arrangement with the National Trust; DCC members monitor conditions underground and have improved and extended access by clearing blocked shafts and tunnels.

Description

Alderley Edge is a topographical feature that rises to 197 m, as much as 100 m above the surrounding glacial drift-covered Cheshire plain. It comprises an abrupt N-facing scarp and a gently sloping southern side. It lies on a 3 km-wide horst of rocks uplifted between two major N–S-trending faults; the Alderley Fault to the west, and the Kirkleyditch Fault to the east (Warrington, 1980b, fig. 1). Rocks to the west and east of these faults respectively have been downthrown relative to those in the horst by several hundred metres. Faults with smaller displacements occur within the horst; these include important WNW–ESE-trending structures, and others with north-west–south-east and north–south trends (Figure 4.30). The stratigraphy and structure of the area has been described by Taylor *et al.* (1963), Mohr (1964a), Warrington (1965), Warrington and Thompson (1971), Carlon (1979), Warrington (1980b), Thompson (1991), Rowe and Burley (1997), Chadwick *et al.* (1999), and Plant *et al.* (1999a).

Alderley Edge was not included in the GCR volume on Permian and Triassic red-beds (Benton *et al.,* 2002), and therefore the stratigraphy and characters of the rock units that host the mineralization are summarized here.

Rocks exposed in the horst comprise two formations of the Sherwood Sandstone Group; the Wilmslow Sandstone Formation, of Early Triassic (probably Olenekian) age, between *c* 250 Ma and 246 Ma, and the succeeding Helsby Sandstone Formation, of early Mid-Triassic (Anisian) age *(c.* 242 Ma). The dip of these beds, south-west at 10°–15°, is slightly steeper than the slope of the land surface, resulting in progressively younger units in the Helsby Sandstone cropping-out in that direction. The succeeding Mercia Mudstone Group, the lower formations of which are also of Anisian age (Warrington *et al.,* 1999), crops out to the south, beneath glacial deposits; it formerly capped the Helsby Sandstone across the horst (Taylor *et al.,* 1963; Warrington, 1980b, fig. 1), but has been removed by erosion.

The Wilmslow Sandstone Formation is exposed on the scarp face of Alderley Edge where it is capped by the lowest, erosion-resistant, member of the Helsby Sandstone Formation. It is encountered underground in a long adit that runs from the base of the scarp near Stormy Point, southwards, to Engine Vein Mine (Figure 4.30) and continues farther south-west, then WNW connecting with other mines (Warrington, 1965, map 2). It consists of soft, orange- to red-brown sandstones that lack pebbles and have few interbedded mudstones. large-scale cross-bedding of aeolian-dune-type occurs and indicates wind transport from an easterly direction. It is an example of the 'soft sandstone' facies of Thompson (1970a), Interpreted by him as a largely aeolian continental deposit with some fluvial interbeds.

The Helsby Sandstone Formation overlies the Wilmslow Sandstone Formation unconformably. It comprises an alternating succession of the 'soft' and 'red-pebbly' sandstone facies of Thompson (1970a). The 'red-pebbly' facies, of fluvial origin, was deposited in a N- to NW-flowing river system (Thompson, 1970b, fig. 3.12; Warrington and Ivimey-Cook, 1992, map Tr1b). It comprises fining-upward sedimentary cycles which, in their lower part, consist of red-brown, cross-bedded, conglomeratic or pebbly sandstones that rest on an uneven surface created when a migrating river channel eroded underlying sediment. These beds pass upwards into finer sandstones and siltstones. If a cycle is complete, the highest bed is a mudstone; this was, however, usually partly eroded, or even completely removed, before the start of the next cycle, the basal bed of which contains the eroded mudstone debris (Thompson, 1970b, figs 7, 8).

The Helsby Sandstone Formation comprises five members, the lowest of which, the Engine Vein Conglomerate, is a representative of the 'red-pebbly sandstone' fades. It is exposed principally along the top of the scarp face of Alderley Edge, but is also encountered in quarries and other excavations between Stormy Point and Engine Vein (Figure 4.30) where it is seen in the openworks (Carlon, 1979, pl. 21; 1981, p1. II) and underground (Warrington, 1965, map 4). The other members are, in ascending order, the Beacon Lodge Sandstone, Wood Mine Conglomerate, West Mine Sandstone and Nether Alderley Sandstone; the first and third of these are 'soft' sandstones and the others are 'red-pebbly' facies.

On Alderley Edge rocks of both the 'soft' and the 'red-pebbly' sandstone facies host a geographically and stratigraphically widespread barite mineralization. The polymetallic mineralization is more localized. It occurs almost exclusively in the topmost Wilmslow Sandstone Formation and the succeeding Engine Vein Conglomerate Member, and in the Wood Mine Conglomerate and West Mine Sandstone members of the Helsby Sandstone Formation, and is visible in mine workings that, from east to west, display the different character of the mineralization and host rocks at these three successive levels (Warrington, 1965, map 2). Cobalt ore may occur in the Beacon Lodge Sandstone Member (Timberlake and Mills, 2003.)

Mineralization in the Wilmslow Sandstone Formation and the Engine Vein Conglomerate Member is seen in the east (Figure 4.30), around Stormy Point and at Engine Vein (Warrington, 1965; Pickin, 1974), where it is closely associated with WNW–ESE-trending normal faults (e.g. Carlon, 1979, pl. 4) that downthrow north-east. Mines here were worked mainly for lead ores, remnants of which remain in the fault-breccia at Engine Vein (Rowe and Burley, 1997, fig. 9a,b). Disseminations of copper ore in the Wilmslow Sandstone and Engine Vein Conglomerate were worked in the footwall on the upthrow side of the Engine Vein Fault (Warrington, 1965, map 4).

The next highest host-rock unit, the Wood Mine Conglomerate Member, crops out farther west and is seen in Wood Mine (Figure 4.30) where mineralization occurs in a succession of eight or nine fining-upwards sedimentary cycles and is more extensive and stratiform in appearance, and less clearly fault-related, than that in the lower beds farther east (Warrington, 1965, map 3). A mudstone at the top of a cycle near the middle of the succession is traceable throughout the central part of the mine. One in a higher cycle is traceable in the southern workings but was completely eroded farther north, where, like those at other levels throughout the mine, it is represented only by mudstone debris at the base of the overlying cycle. The mine is bounded to the north by a WNW extension of the fault seen at Engine Vein, and to the south by a parallel normal fault that also downthrows north-east; beds immediately north and south of these faults respectively are not ore-bearing. The main produce of this mine was copper ore; some lead mineralization is associated with the faults at the north and south boundaries of the mine and a NW–SE-trending fault in the middle of the workings (Warrington, 1965, figs 1D, 2A; Rowe and Burley, 1997, fig. 9c,d,f.). A large stope in the northern part of the mine represents a N–S-trending orebody that terminated against the northern fault; in the southern part of the mine large, flat stopes represent orebodies that extended up-dip from the southern fault (Warrington, 1965, map 3; Plant *et al.,* 1999a, fig. 136b).

The highest host-rock unit, the West Mine Sandstone Member, crops out farther west and south-west and is seen principally in West Mine. Here, the largest bodies of copper ore in the Alderley district are represented by very extensive workings in aeolian sandstone with very few mudstone intercalations ((Figure 4.30); Warrington, 1965, map 2). The south-west side of the mine is bounded by a NW–SE-trending normal fault that downthrows to the north-east, and the workings are intersected by several north–south normal faults that downthrow to the east. Mining was initially in a large opencast pit (Carlon, 1979, fig. 9, pl. 11), but progressed underground to the WNW, creating a very large stope (Carlon, 1979, pl. 7) from which an incline (Carlon, 1979, p1.6) was driven south-west, down-dip, and intersected other large orebodies (Carlon, 1979, pl. 10). Immediately west of these, the underlying Wood Mine Conglomerate Member is exposed in the footwall of a north–south fault (Plant *et al.,* 1999a, fig. 136c). Farther west, long, continuous stopes at three levels in the hangingwall of the south-west boundary fault (Milodowsld *et* ed., 1999, fig. 93) are aligned parallel to that fault (Figure 4.31), to the south-west of which no orebodies were proved.

Other accessible mines on Alderley Edge include one worked for cobalt ore (Johnson, 1984a; Timberlake and Mills, 2003) and one in Brynlow Valley (Johnson, 1984b) (Figure 4.30).

The Mottram St Andrew Mine is adjacent to the Alderley Horst, on the eastern (downthrow) side of the Kirkleyditch Fault (Figure 4.30). Orebodies there appear to be hosted by beds equivalent to those seen at Stormy Point and Engine Vein. The workings may be similar in character to those at Engine Vein but are poorly known. Carlon (1979) reviewed the then available information about this site; Ward (1982), and Rowe and Burley (1997, p.331) reported underground observations.

Braithwaite (1994) assessed previous records of minerals from the Alderley district and confirmed the presence of 52 species (Table 4.1), 48 of which comprise the polymetallic assemblage; the others are barite and gypsum (common), sulphur (common?), and calcite (rare?). The polymetallic assemblage is dominated by copper minerals but includes lesser quantities of those containing lead, cobalt, nickel, manganese, zinc, arsenic, molybdenum, vanadium and other elements; multi-element complexes, some including copper, are common. Primary minerals, other than barite, are scarce and are mostly sulphides; most of the species recorded are secondary carbonates, sulphates, oxides, hydroxides and hydrous complexes.

Records of caledonite, cobaltite, connellite, cyanotrichite, enargite, heterogenite, lavendulan, libethenite, liroconite, massicot, scorodite, siderite, vanadinite and witherite were considered doubtful or were unconfirmed (Braithwaite (1994). The record of lleterogenite has been discredited (Ryback *et al.,* 1998).

The following have been recorded since Braithwaite's survey: enargite (copper-arsenic sulphide) (Ixer and Budd, 1998); the cobalt-nickel-arsenic sulphides cobaltite (Milodowski *et al*., 1999, pls 25, 27) and possibly siegenite (Milodowski *et al.,* 1999, pl. 26), and a lead-chloro-phosphate with arsenic (mimetite) (Milodowski *et al*., 1999, p1. 28, fig. 93); silver sulphide (acanthite, as 'argentite'), mercury sulphide (cinnabar), a hydrated copper silicate (dioptase), a lead carbonate (hydrocerrusite), hydrated iron oxide (goethite) and manganese-iron oxyhydroxide (Milodowski *et* ed., 1999, fig. 93); gold (Milodowski *et* al., 1999, p. 145, fig. 94). Holmes *et al.* (1983) detected < 3 ppm of uranium in Alderley ore; cadmium (Ixer and Vaughan, 1982; Holmes *et al.,* 1983), chromium and zirconium (Mohr, 1964a, table 2), selenium and strontium (Milodowski *et* al., 1999, pp. 141, 148), and cerium and lanthanum (Timberlake and Mills, 2003, table 1) have also been reported. Ixer and Stanley (1998) referred to the occurrence of the copper-iron-arsenic sulphide tennantite in chalcopyrite, but the source cited (Ixer and Budd, 1998) does not contain that record.

(Table 4.1) Confirmed occurrences and relative abundances of ore minerals from the Alderley Edge mining district (from Braithwaite, 1994).

	Common	Uncommon	Rare	Very Rare
Main copper minerals				
Carbonates (hydrated)	Azurite Malachite			
Silicates (hydrated)	Chrysocolla			Plancheite
Sulphides	Covelline Djurleite	Chalcocite	Spionkopite	
Cu-Fe sulphides	Bornite Chalcopyrite		Waite	

Sulphates (hydrated)		Brochantite	Langite	Antlerite Posnjakite
Cu			Native copper	
Oxide			Cuprite	
Arsenates (hydrated)				Olivenite Tyrolite (sulphatian)
Main lead minerals				
Carbonate	Cerrusite			
Sulphide	Galena			
Chloro-phosphate + As	Pyromorphite			
Sulphate			Anglesite	
Ph-Cu-Fe-Al sulphate (hydrated)			Beayerite	
Pb-Fe-As sulphate (hydrated)				Beudantite
Sulphato-carbonate (hydrated)				Leadhillite
Oxide				Minium
Molybdate				Wulfenite
Main zinc minerals				
Sulphide		Sphalerite		
Silicate (hydrated)				Hemimorphite
Carbonate				Smithsonite
Other species				
Co-Ni-Mn complex (hydrated)	Asbolane			
Fe oxide	Limonite			
Fe-Ni sulphide		Bravoite		
Ni-As sulphide		Gersdorffite		
K-Fe sulphate (hydrated)		Jarosite		
Fe-Cu sulphate (hydrated)		Melanterite *var.* pisanite		
Fe sulphides		Pyrite		Macasite
Pb-Cu sulphate (hydrated)			Li nitrite	
Pb-Cu vanadate + As (hydrated)			Mottramite	
Ni-Co arsenide			Pararammelsbergite	
Co-Fe sulphide + Zn, Ag			Tetrahedrite	
Zn-Cu carbonate (hydrated)				Aurichalcite
Co arsenate (hydrated)				Erythritc
Pb-Cu-Al sulphate (hydrated)				Osarizawaite
K-Fe arsenate (hydrated)				Pharmacosiderite
Ag				Silver

With the exception of barite, which is widespread in the Wilmslow Sandstone and Helsby Sandstone formations, primary minerals only occur in proximity to faults. Secondary species, which include the bulk of the copper ores, are more widely dispersed and occur as disseminations occupying pore spaces in the host-rock sandstones, particularly in the Wood

Mine Conglomerate and the West Mine Sandstone members. The host rocks are typically red-brown in colour but sites of polymetallic mineralization are bleached, colourless to yellow, with a fairly distinct boundary (Warrington, 1965, fig. 1B) that is often a convex front that indicates the direction of fluid migration.

The Alderley deposits were worked mainly for copper ore, but lead ore, some of which yielded silver, was also produced, and cobalt ore was worked early in the 19th century.

Early mining on Alderley Edge may be indicated by a radiocarbon date of 3550 ± 70 years from charcoal associated with stone artefacts found in an excavation by the Engine Vein openworks (Timberlake and King, 2005, pp. 42–44). Roman coins were found in the 'Pot Shaft', also at Engine Vein (Nevell *et al.,* 2005; Timberlake and Kidd, 2005). The earliest known record of 'Myne holes' on Alderley Edge, from 1598 (Kidd and Taylor, 2005, p. 178), does not indicate whether there was contemporary mining or whether the excavations, around Stormy Point, were from an earlier period. Mining activity beginning in 1693 was implied in 1696, in the oldest known contemporary record of such activity. Mining was documented at various times in the 18th and 19th centuries and in the early 20th century, and finally ceased in 1919 (Carlon, 1979; Warrington, 1981). The most productive phases were in the mid-18th century and between 1857 and 1877. Prior to 1857 copper was recovered by smelting, with varying success due to the nature and low grade of much of the ore. From 1857 extraction by an acid-leaching process (Carlon, 1979; Warrington, 1981) proved very effective and enabled the profitable treatment of large tonnages of the low-grade disseminated ores that formed the bulk of the deposits in the Alderley district. Warrington (1981) suggested, from recorded and estimated output figures (Warrington, 1981, fig. 4), that copper-ore production between 1857 and 1877 may have been about 250 000 tons, from which about 3100 tons of copper were recovered. No output records exist for earlier periods, and output in the early 20th century, when acid-leaching was also used, was very small (Warrington, 1981, fig. 6). Small quantities of lead ore were produced between 1859 and 1861, and in 1918; until 1864, concentrates containing cobalt and nickel were produced.

Mining took place at Mottram St Andrew in the 19th century, and possibly earlier, but ceased in 1865. From 1860 the acid-leaching process adopted at the Alderley Edge mines was used; records are fragmentary but output was on a much smaller scale. Unlike the Alderley Edge mines, that at Mottram St Andrew suffered from water ingress and proved unprofitable. It has, however, a place in the annals of chemistry and mineralogy as being the source of mine residues on which research that established the valency of vanadium was carried out (Roscoe, 1868), and as the site for which mottramite, a lead-copper-vanadate, was named (Roscoe, 1876). There is, however, debate as to whether specimens Roscoe based this mineral upon originated from the eponymous site, or from one in north Shropshire (Braithwaite, 1994). Manning (1991) incorrectly cited Mottram St Andrew as the type locality for roscoelite, a second vanadium mineral named by Roscoe (1876).

Interpretation

The sediments that host mineralization in the Alderley district are of continental, part-aeolian and part-fluvial, origin. They were deposited in the Cheshire Basin during a phase of active rifting that commenced in Permian times and continued through the Triassic and into the Jurassic, allowing the basin to accommodate considerable thicknesses of deposits of those ages (Chadwick *et al.,* 1999; Warrington *et al.,* 1999).

The orebody at Engine Vein may be interpreted as the result of ponding of mineralizing fluids in the footwall of a fault that formed a barrier to lateral, up-dip migration below mudstones in the Engine Vein Conglomerate Member that acted as aquicludes and prevented vertical migration (Plant *et al.,* 1999a, p. 212, fig. 136a).

The nature of the Wood Mine workings reflects the discontinuous nature of the orebtidies in the Wood Mine Conglomerate Member. This is attributable to the presence of laterally persistent mudstone aquicludes that prevented vertical migration of mineralizing fluids, and of beds that contain quantities of mudstone debris and were partial barriers to such migration. Some ore-bodies are confined to one cycle whereas others extend through several cycles (Warrington, 1965, map 3). Convex fronts to the orebodies (e.g. Warrington, 1965, fig. 113) are consistent with fluid flow away from faults. Orebodies in the northern and central parts of the mine may, like those in the footwall at Engine Vein, reflect ponding of fluids against faults, in contrast to those at the south which reflect fluid movement up-dip, away from the fault, in its hangingwall (Plant *et al.,* 1999a, p. 212, fig. 136b).

The form of the West Mine workings reflects the comparatively homogeneous nature of the aeolian sandstone host-rock which, in marked contrast to that in Wood Mine, is almost devoid of mudstone aquicludes. Though faults influence their overall disposition, many of the orebodies in West Mine extend up-dip in the hangingwalls of the major faults (Milodowski *et al.,* 1999, fig. 93; Plant *et al,* 1999a, fig. 136c-e), and mineral fabrics are consistent with migration of fluids away from the faults (Plant *et al.,* 1999a, p. 212).

The mineralization in the Alderley district was considered to be syngenetic (i.e. deposited contemporaneously with the host sediments) (Dewey and Eastwood, 1925, and earlier authors) or epigenetic (i.e. introduced subsequently; e.g. Taylor *et al.,* 1963; Warrington, 1965; Carlon, 1979). A process involving epigenesis followed by syngenesis was invoked by Mohr (1964a). Warrington (1965) originally advocated a magmatic source for mineralizing fluids but, by 1977 (in Warrington, 1980b), had envisaged one involving chloride-rich intrastratal brines, a view reached independently by Carlon (1979, citing unpublished work, 1975). Warrington (1980b, fig. 1) demonstrated that the Alderley Horst formed a structural trap for fluids migrating through the Sherwood Sandstone Group formations beneath an impermeable cover of Mercia Mudstone Group mudstones. Warrington (1980b) proposed that the brines became enriched in metallic ions by leaching sediments through which they migrated, with an additional or alternative source of minerals being fluids of more deep-seated origin permeating the sand stones and mixing with intrastratal brines, possibly during rift-related tectonic activity that Mohr (1964a) considered potentially relevant to the Alderley mineralization and which affected Britain in the early Mesozoic, with faulting in the Cheshire Basin, and the creation of structures such as the Alderley Horst, occurring then. Enhanced geothermal activity associated with rifting may have induced or stimulated migration of mineral-bearing fluids into the horst, where minerals were deposited in a reducing environment, possibly created by hydrocarbons migrating into the classical hydrocarbon trap formed by that structure (Warrington, 1980b). This basic scenario has been adopted and developed by succeeding workers (Holmes *et al.,* 1983; Naylor *et al.,* 1989; Rowe *et al.,* 1993; Rowe and Burley, 1997; Milodowski *et al.,* 1999; Plant *et al.,* 1999a).

Ixer and Vaughan (1982), in the first paragenesis for the Alderley mineralization, proposed a four-stage, polyphase origin. Authigenic anatase and quartz overgrowths with bravoite, pyrite and chalcopyrite developed in the earliest stages of sandstone host-rock diagenesis. In the third stage, primary sulphides formed vein-fillings and intragranular cements in and adjacent to faults. A paragenetic sequence of: bravoite and nickel–cobalt–iron sulpharsenides pyrite – chalcopyrite – sphalerite – galena was reported from Stormy Point, Engine Vein and Wood Mine. In the final stage these sulphides were largely replaced by secondary species, or by carbonates and sulphates that enclose vestiges of the primary minerals. The relationship of mineralization to diagenesis recognized in this work has been emphasized by Holmes *et al.* (1983) and subsequent workers.

The first fluid-inclusion data from Cheshire Basin ore deposits (Naylor *et al.,* 1989) indicated that the mineralizing fluid was a basinal brine (cf. Carlon, 1979; Warrington, 1980b) with a salinity of 9–22 wt% NaCI equivalent and a temperature of 60°–70°C. Sulphur isotope data from barite (Naylor *et al.,* 1989) indicated that the sulphate came from Mercia Mudstone Group evaporites, and comparable isotope values from sulphide minerals suggested that they resulted from the reduction of sulphate-bearing fluids from the same source; this reduction was considered to result from bacteriogenic action or interaction with hydrocarbons (cf. Warrington, 1980b). Metcalfe *et al.* (1993) presented a hydrogeochemical model involving mixing of a reducing fluid from a deep-seated, probably Carboniferous, source, with red-bed formation water. This reproduced the main features of the Alderley ore deposits, with a requirement of only 3–4% of the total fluid being from the deep source. Rowe and Burley (1997) invoked a comparable fluid mixing process but suggested that the sulphate-rich brine originated from either the Mercia Mudstone Group or from Permian evaporites in the Manchester Marls Formation, underlying the Sherwood Sandstone Group.

The earliest attempt at dating the Alderley mineralization isotopically, using galena (Moorbath, 1962), gave an age of 210 ± 60 Ma (mid-Permian to late Jurassic). The structural-trap scenario of Warrington (1980b) implied a maximum Mid-Triassic (Anisian) age, after the lower Mercia Mudstone Group formations were deposited, forming a seal above the Sherwood Sandstone Group. Rowe and Burley (1997) concluded, from studies at Engine Vein and Wood Mine, that mineralization post-dated faulting, and suggested that primary mineralization occurred during late Mesozoic burial or Tertiary uplift. Alteration to secondary species by supergene oxidizing groundwaters, and the migration of mobile products away from fault-related primary mineralization sites, therefore occurred later in the Tertiary.

The latest study of the Alderley mineralization was in a multidisciplinary investigation of the Cheshire Basin (Plant *et al.,* 1999b) in which a four-stage metallogenic model, commencing with remobilization of metals by breakdown of parent minerals during eodiagenesis of the Triassic succession, was proposed. During a complex mesodiagenesis (Milodowski *et al.,* 1999), successive phases of density-driven fluid expulsion from the Mercia Mudstone Group into the Sherwood Sandstone Group occurred. Early fluids were sulphate-rich and resulted in sandstones in the latter group being tightly cemented with anhydrite. Later fluids were metalliferous brines that flowed through that group towards basin-bounding faults where mixing with small amounts of reducing fluids, probably sourced by Carboniferous rocks, caused precipitation of the polymetallic assemblage; contrary to Rowe and Burley's (1997) conclusion, this was regarded as occurring in latest Triassic to Early Jurassic times, between *c.* 205 Ma and 175 Ma. The primary mineralization was complex and episodic and, contrary to Rowe and Burley's (1997) view, was associated with faulting and fracturing; a paragenesis reported from West Mine (Milodowski *et al.,* 1999) differs from those of Ixer and Vaughan (1982) and Naylor *et al.* (1989) from other Alderley sites. The primary assemblage was extensively altered after 65 Ma, during telodiagenesis following post-Cretaceous basin inversion.

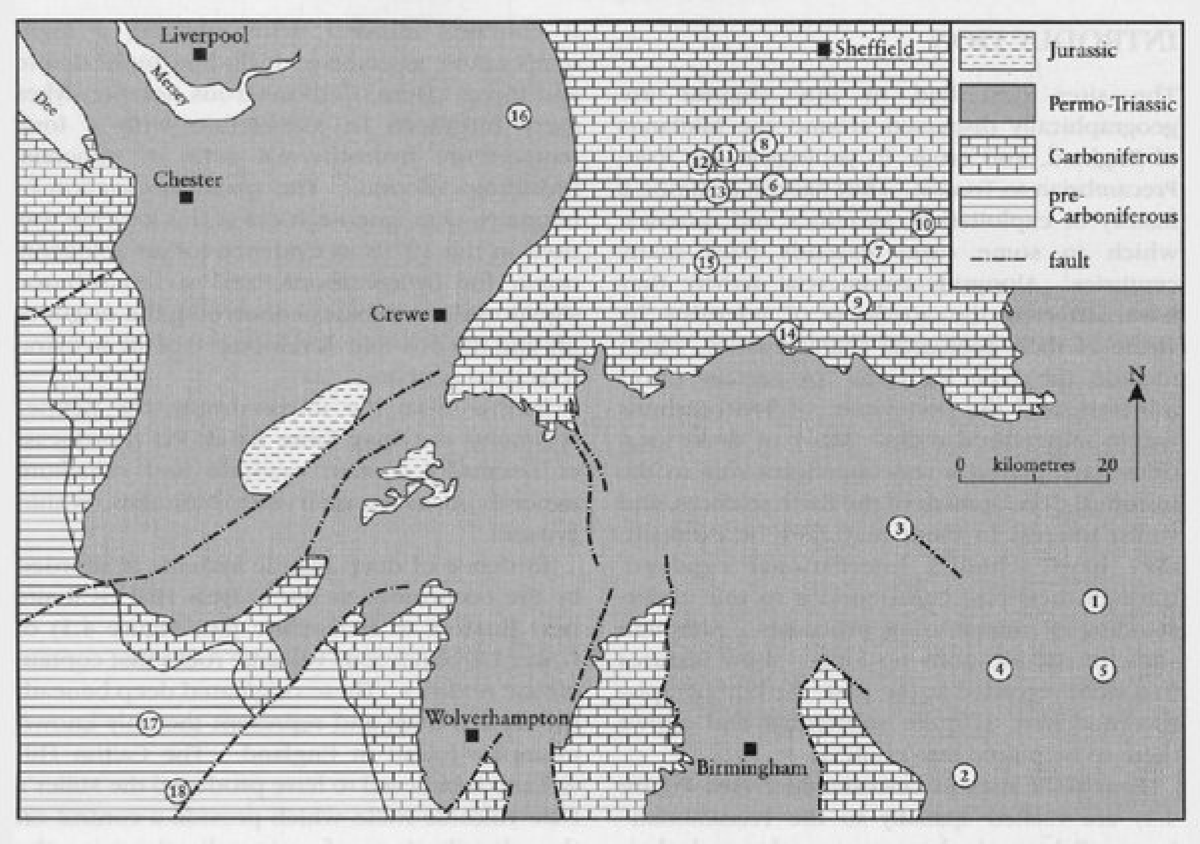
Conclusions

The Alderley Edge mining district contains an extensive and uniquely accessible example of a copper-dominated polymetallic mineralization hosted by red-bed sedimentary rocks of late Early to early Mid-Triassic age. Host rocks are predominantly aeolian and fluvial arenaceous deposits, mainly members of the Helsby Sandstone Formation. It is the largest and most extensively studied and documented of such occurrences in Britain. Weathered outcrops of parts of the ore-bearing succession are complemented by extensive sections in more than 15 km of mine workings in which the influence of structure and the character of different host-rocks on the form and size of the orebodies may be appreciated in a three-dimensional sense in an unweathered condition.

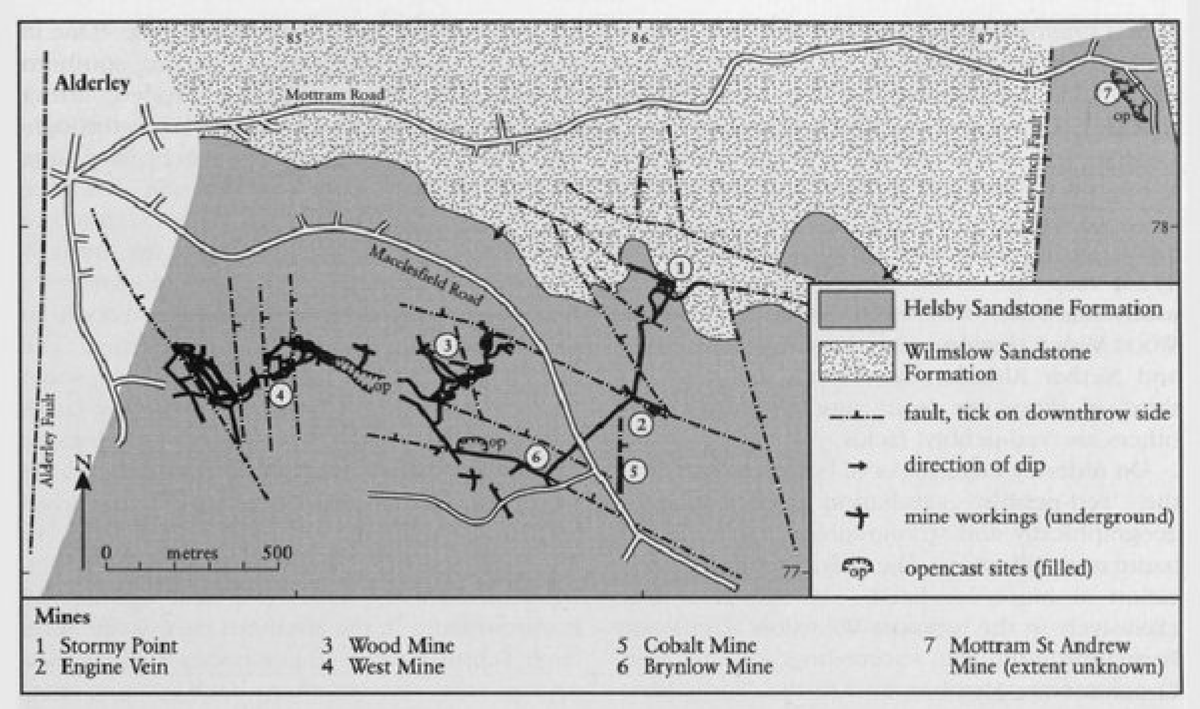
The mineralization was originally regarded as syngenetic but is now considered to be epigenetic. An origin from intrastratal brines, rather than fluids of magmatic origin, was proposed in the late 1970s, and has been substantiated by more-recent research involving fluid-inclusion, isotope and other studies; a paragenesis has been established. Mineralization occurs in a structural trap, the Alderley Horst, capped by the impermeable Mercia Mudstone Group. Metals were sourced by dissolution of detrital grains during migration of low-temperature brines through Triassic formations, and additionally, or alternatively, from Carboniferous shales, and were precipitated in an organic-rich reducing environment. Primary mineralization includes geographically and stratigraphically widespread barite and metallic sulphides localized around faults, and may be of latest Triassic to Early Jurassic age. The bulk of the mineral assemblage comprises secondary species produced by oxidizing groundwaters acting on primary minerals and migrating away from faults to produce sandstone-hosted disseminations in Tertiary times. The full mineral assemblage is exceptionally diverse and comprises over 60 species.

The site is a geological Site of Special Scientific Interest (SSSI) and is of national and international importance for educational and scientific purposes. Examples of this type of mineralization elsewhere in Britain are on a smaller scale; most have limited or no access, as is the case with similar deposits hosted by Triassic sediments elsewhere in Europe (e.g. those of Maubach–Mechernich in Germany). The district is important for indications of early mining and was a source of cobalt ore in the early 18th century and a major producer of copper ore in the mid-18th and 19th centuries. Work that established the valency of vanadium was carried out on mine residues from Mottram St Andrew Mine, and the mineral mottramite is named for that locality.

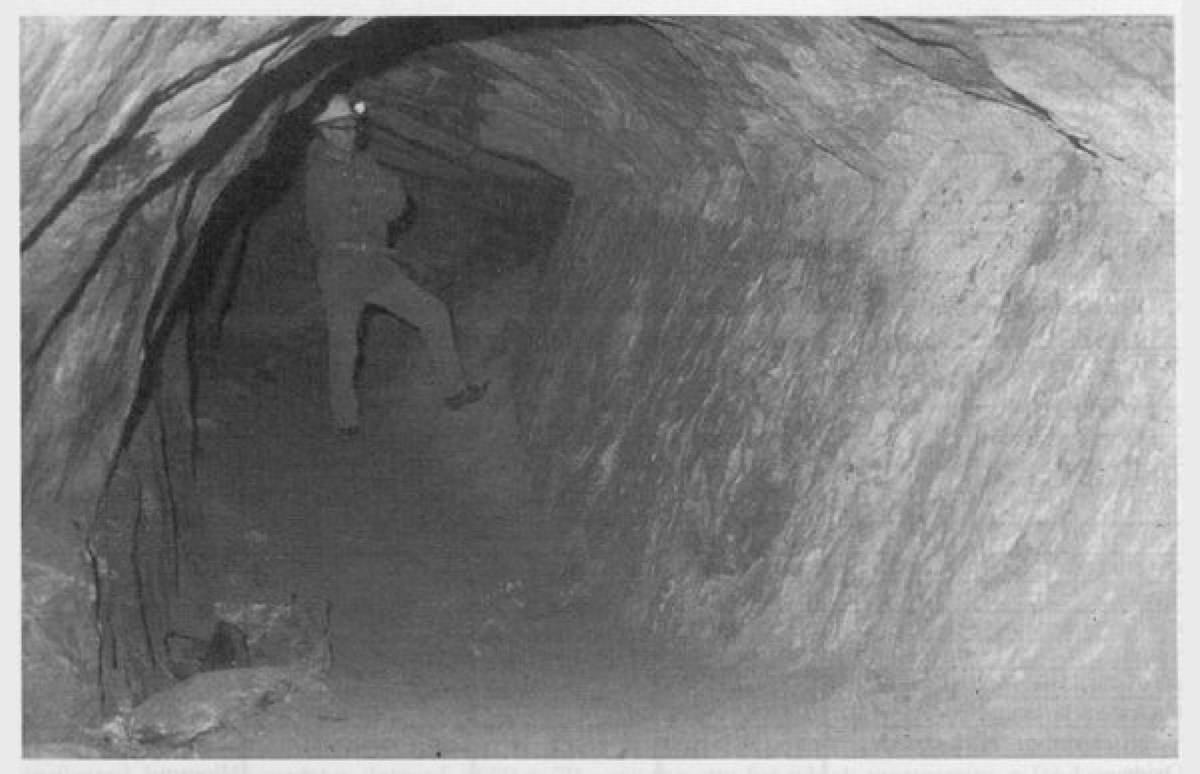
References



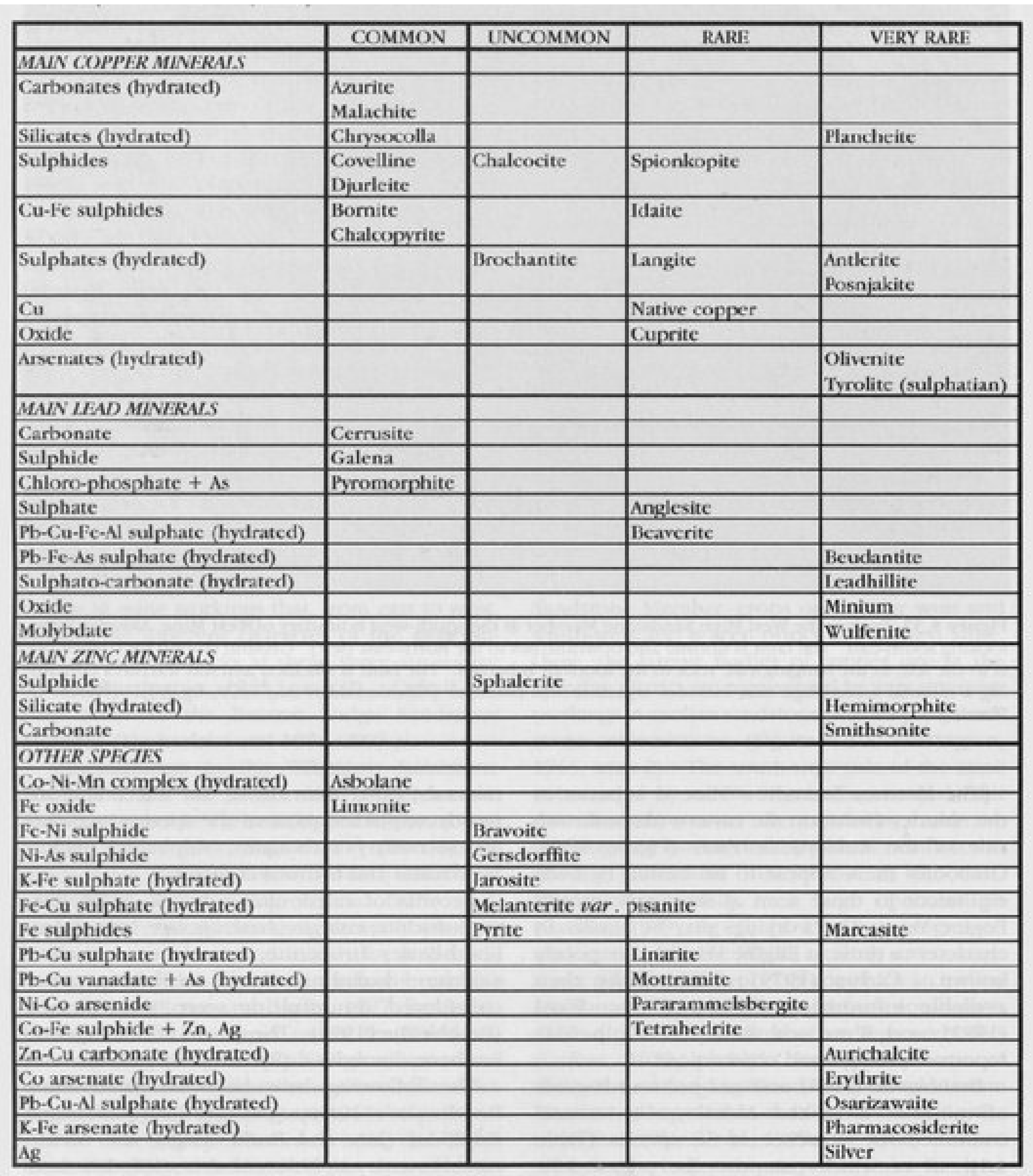
(Figure 4.1) Map of the geological sites reported in this chapter showing simplified major geological boundaries and faults. 1- Castle Hill Quarry; 2 — Croft Quarry; 3 — Newhurst Quarry; 4 — Warren Quarry; 5 — Gipsy Lane Brick Pit; 6 — Calton Hill; 7 — Masson Hill Mines; 8 — Dirtlow Rake and Pindale; 9 — Bage Mine; 10 — Fall Hill Quarry; 11 — Treak Cliff; 12 — Windy Knoll; 13 — Portway Gravel Pits; 14 — ICurkham's Silica Sandpits; 15 — Ecton Copper Mines; 16 — Alderley Edge District; 17 — Snailbeach Mine; 18 — Huglith Mine.



(Figure 4.30) The Alderley Edge mining district: simplified solid geology with distribution of mine sites and workings. After Warrington (1965, maps 1, 2; 1980b, fig. 2), incorporating more-recent underground observations.



(Figure 4.31) Fault in the West Mine Sandstone Member at the south-west boundary of West Mine, Alderley Edge, looking south-east. The fault is normal and downthrows to the north-east (left). Ground stoped for copper ore is to the left, in the hangingwall; rock in the footwall is barren. The fault is silicified and has fractures containing a mineral assemblage that includes argentite and cinnabar (Milodowski et al., 1999, fig. 93). (Photo: G. Warrington, 1979).



	COMMON	UNCOMMON	RARE	VERY RARE
MAIN COPPER MINERALS				
Carbonates (hydrated)	Azurite Malachite			
Silicates (hydrated)	Chrysocolla			Plancheite
Sulphides	Covelline Djurleite	Chalcocite	Spionkopite	
Cu-Fe sulphides	Bornite Chalcopyrite		Idaite	
Sulphates (hydrated)		Brochantite	Langite	Antlerite Posnjakite
Cu			Native copper	
Oxide			Cuprite	
Arsenates (hydrated)				Olivenite Tyrolite (sulphatian)
MAIN LEAD MINERALS				
Carbonate	Cerrusite			
Sulphide	Galena			
Chloro-phosphate + As	Pyromorphite			
Sulphate			Anglesite	
Pb-Cu-Fe-Al sulphate (hydrated)			Beaverite	
Pb-Fe-As sulphate (hydrated)				Beudantite
Sulphato-carbonate (hydrated)				Leadhillite
Oxide				Minium
Molybdate				Wulfenite
MAIN ZINC MINERALS				
Sulphide		Sphalerite		
Silicate (hydrated)				Hemimorphite
Carbonate				Smithsonite
OTHER SPECIES				
Co-Ni-Mn complex (hydrated)	Asbolane			
Fe oxide	Limonite			
Fe-Ni sulphide		Bravoite		
Ni-As sulphide		Gersdorffite		
K-Fe sulphate (hydrated)		Jarosite		
Fe-Cu sulphate (hydrated)		Melanterite *var.* pisanite		
Fe sulphides		Pyrite		Marcasite
Pb-Cu sulphate (hydrated)			Linarite	
Pb-Cu vanadate + As (hydrated)			Mottramite	
Ni-Co arsenide			Pararammelsbergite	
Co-Fe sulphide + Zn, Ag			Tetrahedrite	
Zn-Cu carbonate (hydrated)				Aurichalcite
Co arsenate (hydrated)				Erythrite
Pb-Cu-Al sulphate (hydrated)				Osarizawaite
K-Fe arsenate (hydrated)				Pharmacosiderite
Ag				Silver

(Table 4.1) Confirmed occurrences and relative abundances of ore minerals from the Alderley Edge mining district (from Braithwaite, 1994).