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Mineralization in the Triassic rocks of the Cheshire Basin with particular reference to Alderley Edge, Cheshire, and Clive, Shropshire

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WARRINGTON, G. (2012). Mineralization in the Triassic rocks of the Cheshire Basin with particular reference to Alderley Edge, Cheshire, and Clive, Shropshire. *Proceedings of the Shropshire Geological Society*, **17**, 33–39. In the Cheshire Basin barite and, locally, a copper-dominated polymetallic mineralization occurs in Triassic fluvial and aeolian deposits. The mineralization is epigenetic and has a complex paragenesis; primary polymetallic minerals have been largely altered to secondary species. Ore body form and disposition was influenced by faults and by host-rock character, with mudstones that formed barriers to fluid migration present in fluvial deposits but not in aeolian deposits.

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INTRODUCTION

The Cheshire Basin is an asymmetric graben that resulted from E-W extension after the Variscan earth movements. It accommodated a thick succession of Permian, Triassic and younger Mesozoic rocks that was partially eroded after uplift in late Cretaceous times and now crops out over much of Cheshire and north Shropshire, in an area some 100 km from north to south and 60 km from east to west (Plant *et al*., 1999a). The fullest succession is preserved in the south of the basin where the Prees borehole commenced in the Lower Jurassic and entered Palaeozoic rocks at a depth of 3600 m.

The Triassic succession includes the Sherwood Sandstone, Mercia Mudstone and Penarth groups. The Sherwood Sandstone includes, in ascending order, the Kinnerton Sandstone, Chester Pebble Beds, Wilmslow Sandstone and Helsby Sandstone formations. The Helsby Sandstone is the principal sedimentary host for mineralization which consists of widespread occurrences of barite and more localised copper-dominated polymetallic ore deposits. The latter were mined at a number of sites in Cheshire and north Shropshire (Figure 1). The principal site was the Alderley Edge–Mottram St Andrew district *c*. 20 km south of Manchester (Dewey & Eastwood, 1925; Taylor *et al*., 1963; Mohr, 1964; Warrington, 1965, 1980a, 1981, 2010; 2012; Carlon, 1979; Plant *et al*., 1999b).

Other, smaller, mines and trials were at Bickerton, west Cheshire (Poole & Whiteman, 1966; Warrington, 1980b, 1995; Carlon, 1981),

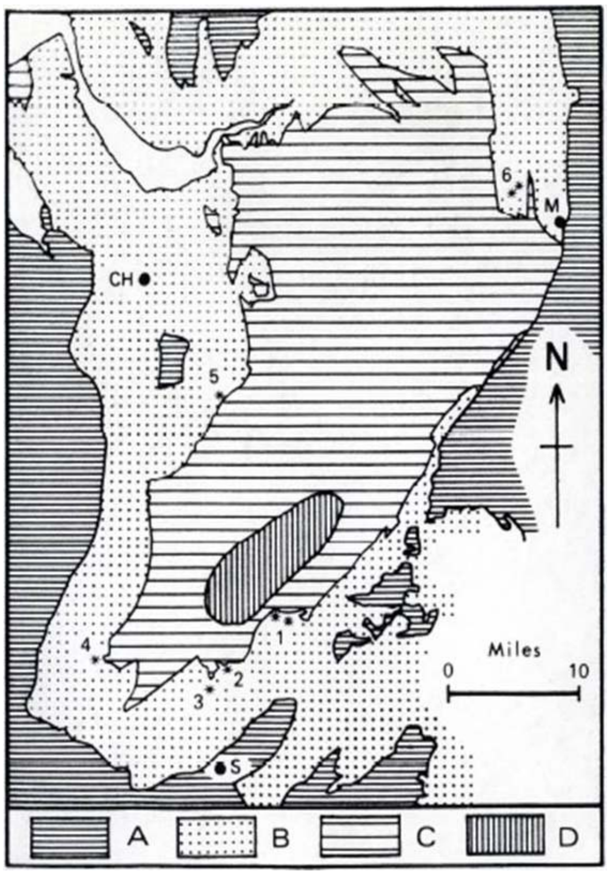

Figure 1. Locations of non-ferrous ore deposits in Triassic rocks in the Cheshire Basin (after Warrington, 1980b, map 1, in which the geology was based, with permission, on Institute of Geological Sciences 1: 625000 map, 3rd edition, solid, 1979).

Mine sites: 1 – Hawkstone district; 2 – Clive and Yorton; 3 - Pim Hill; 4 – Eardiston; 5 – Bickerton; 6 – Alderley Edge and Mottram St Andrew.

Other localities: M – Macclesfield; CH – Chester; S – Shrewsbury.

Ornament: A – pre-Permian rocks; B – Sherwood Sandstone Group (Permian and Triassic); C – Mercia Mudstone and Penarth groups (Triassic); D – Jurassic rocks.

and in north Shropshire, at Eardiston, Pim Hill, Yorton, Clive, Wixhill, Hawkstone and Bearstone (Pocock & Wray, 1925; Warrington, 1980b, 1995; Carlon, 1981; Rees & Wilson, 1998; Plant *et al*., 1999b; Rayner, 2007; Shaw, 2009). Alderley Edge and Clive, the principal sites where the mineralization can be studied *in situ* in accessible workings, are the subjects of this account.

ALDERLEY EDGE, CHESHIRE

Alderley Edge is a prominent topographic feature with a N-facing scarp and a gently sloping south side. It consists of Sherwood Sandstone formations that crop out in a 3 km-wide horst situated between major N-S-trending faults (Warrington, 1981; Plant *et al*., 1999b, fig. 134). The eastern side of the horst is *c*. 5 km west of the Red Rock Fault, near the northern end of the Wem-Bridgmere-Red Rock Fault system which marks the east side of the Cheshire Basin. The Wilmslow Sandstone, a largely aeolian formation, crops out on the scarp and is overlain unconformably by the Helsby Sandstone which caps the scarp and includes fluvial and aeolian members. The southwesterly dip is slightly steeper than the slope of the land surface on the south side and members in the latter formation therefore crop out progressively down that slope. The Mercia Mudstone Group formerly covered the sandstones in the horst.

Within the horst, WNW-ESE-trending normal faults downthrow beds to the northeast, and other, more minor faults, trend NW-SE and N-S. Barite mineralization is widespread; polymetallic mineralization is more localised and occurs largely in three members in the Helsby Sandstone and, sparingly, in the highest beds of the underlying Wilmslow Sandstone. The mineralization and

Figure 2. Mudstone bed with mudcracks in section and seen from the underside in the roof of workings, Engine Vein, Alderley Edge (photo: G. Warrington).

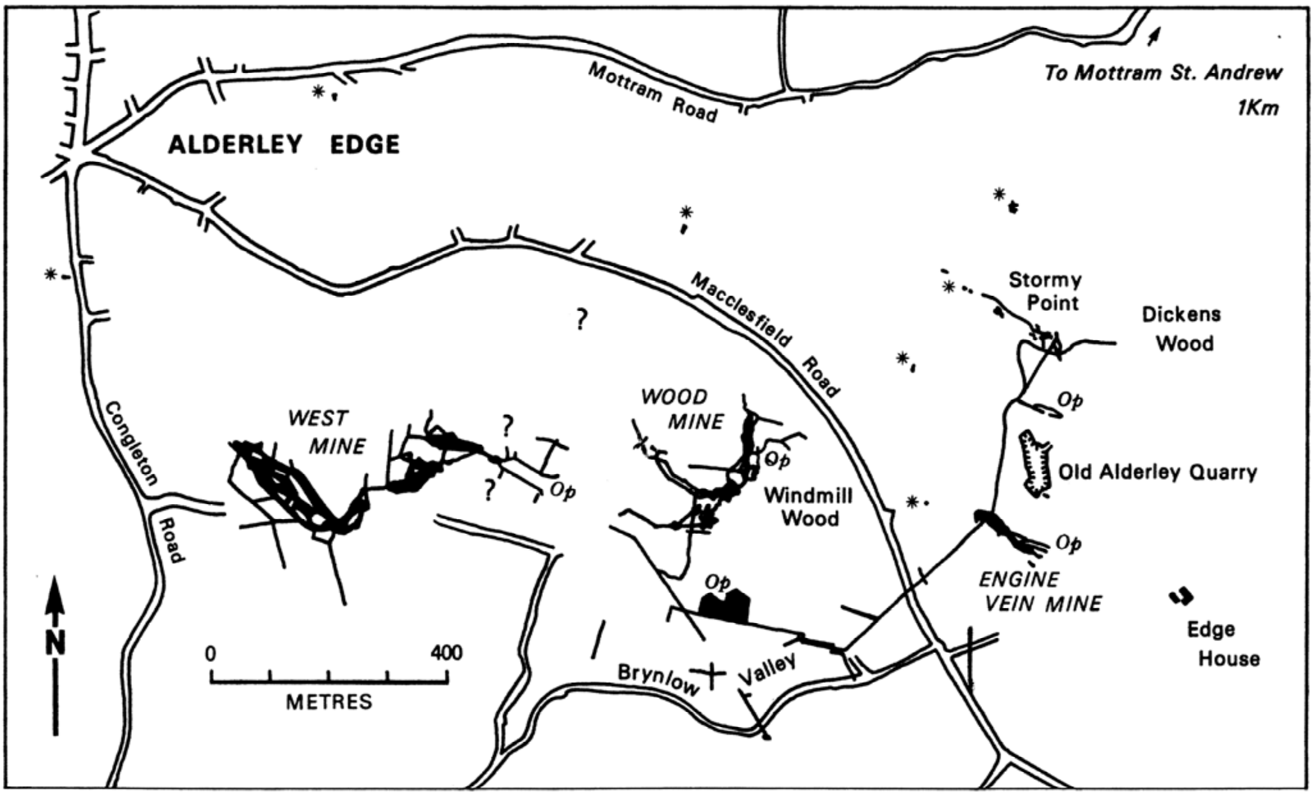

Figure 3. Distribution of mine workings at Alderley Edge (after Warrington, 1981, fig.2). *Op* – opencast workings (mostly infilled); * - minor workings; ? – areas of possible workings.

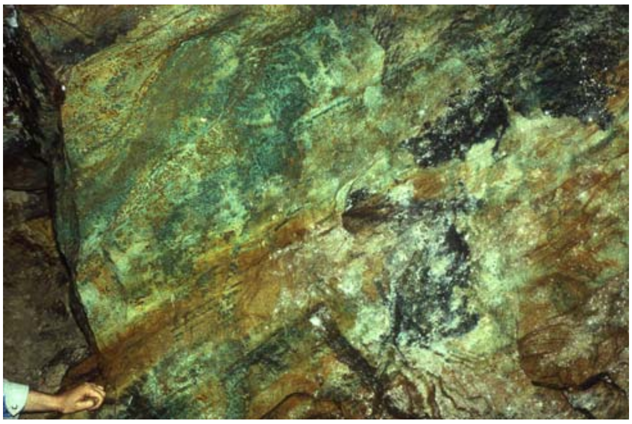

Figure 4. Dissemination of malachite and other secondary copper minerals in aeolian sandstone, West Mine, Alderley Edge (photo: G. Warrington).

Figure 5. Fault plane (left) and associated fault zone with barite (pink) and galena (grey), Engine Vein, Alderley Edge; workings extend into sandstones in the footwall to the right (photo: G. Warrington).

sedimentary features of the host-rocks (Figure 2) can be studied in 3-D in unweathered sections in at least 13 km of disused mine workings that fall broadly into three groups (Figure 3). From east to west these give access to successively higher levels in the sequence, with the character of the mineralization at each differing according to the host-rock facies and structural control; over 60 mineral species have been recorded. The mines were worked principally for copper ores (Figure 4), but small amounts of lead (Figure 5) and cobalt ores were also produced (Warrington, 1981). The site is the only one of its kind to feature in the Geological Conservation Review (Warrington, 2010). It is of unique importance for scientific and educational purposes and is, appropriately, a Geological SSSI (Site of Special Scientific Interest).

CLIVE, SHROPSHIRE

At Clive the aeolian Grinshill Sandstone (Thompson, 1993), equivalent to the Helsby Sandstone at Alderley, is overlain by the Tarporley Siltstone, the lowest Mercia Mudstone formation. Barite mineralization is widespread in this area, and polymetallic mineralization occurs and has been worked or investigated at a number of sites associated with faults that trend between nearly N-S and NE-SW (Plant *et al*., 1999b, fig. 137). The area is *c*. 3 km south of the Wem Fault, part of the Wem-Bridgmere-Red Rock Fault system, here at the southeastern margin of the Cheshire Basin.

The Clive mine is small in comparison with those at Alderley. The known workings, on two levels, extend for less than 400 m along a normal fault that downthrows west. The ore body was in the hanging wall of the fault; it was mined at the upper level in a stope that is some 300 m long and up to 10 m high, but generally only *c*. 5 m wide (Figure 6). The lower level was used for tramming ore sent down chutes from the stope; at a depth of *c*. 35 m it connects with a shaft that extends down to *c*. 65 m and is used to supply water.

The mine was worked principally for copper ore but some cobalt ore was also recovered. Few traces of the former remain but in the northern part of the mine black specks of cobalt and manganese oxides in white sandstone produce what has been termed ‘pepper and salt’ rock. Spectacular *liesegang* structures are developed in places (Figure 7).

NATURE AND ORIGIN OF THE MINERALIZATION

At Alderley Edge, mines in the east are in the Wilmslow Sandstone and the lowest Helsby Sandstone unit, the fluvial Engine Vein

Conglomerate Member; they extend along WNW-ESE-trending faults and are narrow. They were worked principally for lead ore (*galena*: Figure 5), but copper ore was mined in the footwall at Engine Vein where mineralizing fluids that migrated up-dip were trapped against a fault and below mudstones in the basal Helsby Sandstone member. A thin aeolian unit separates that from the next highest ore-bearing unit. This was exploited farther west, in Wood Mine where large but irregular bodies of copper ore occurred in a succession of eight or nine fining-upward fluvial sedimentary cycles that formed in migrating river channels.

In these cycles coarse, pebbly sandstones pass up through finer sandstones to a mudstone at the top; this was typically partially or completely eroded as a result of channel migration at the inception of the next cycle. The mudstones and beds containing their eroded debris (Figure 8) formed complete or partial barriers that influenced fluid migration within this sequence, and the form and disposition of the resulting ore-bodies. The succeeding West Mine Sandstone is the highest ore-bearing unit, and was worked farther west; it is a relatively homogeneous aeolian deposit that hosted the largest bodies of copper ore in the area (Figure 9).

At Clive mineralizing fluids that migrated up-dip were trapped in a hanging-wall situation (Milodowski *et al.*, 1999, fig. 93), against a fault and below the Tarporley Siltstone which is seen in the roof of the workings in the northern part of the mine (Anon., 2001).

Figure 6. Upper level, Clive Mine, looking north; fault to the right of workings in the hanging wall (photo: G. Warrington).

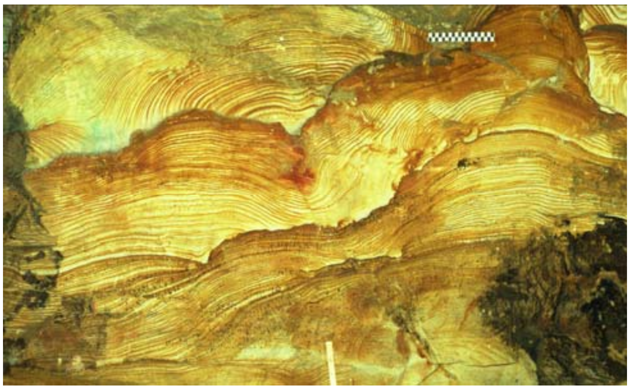

Figure 7. *Liesegang*e in aeolian sandstone, upper level, Clive Mine. The banding is caused by the precipitation of minerals (in this example, iron oxide) from fluids moving in successive phases through the host-rock (photo: G. Warrington).

Figure 8. A concentration of mudstone intraclasts in the basal part of a fining-upward fluvial sedimentary cycle, Engine Vein, Alderley Edge (photo: G. Warrington).

The mineral assemblage consists largely of secondary species and has been most fully documented from Alderley Edge where Braithwaite (1994) confirmed the presence of 52 species, 48 of which comprised the polymetallic assemblage. Subsequently, this list has been amended by other workers and up to 10 other minerals added (Warrington, 2010). The assemblage from Clive (Milodowski *et al.*, 1999) is less well documented.

The principal copper minerals are hydrated carbonates (*malachite*, *azurite*) and the hydrated silicate (*chrysocolla*). Sulphides include *covelline*, *djurleite*, *bornite* and *chalcopyrite*, and some *chalcocite*, but are comparatively rare. Also recorded are hydrated sulphates and arsenates, the oxide (*cuprite*), and native copper.

The principal lead minerals are the sulphide (*galena*) and the carbonate (*cerrusite*). Also recorded are the arsenical chloro-phosphate *pyromorphite* and hydrated complexes with other elements, including copper, arsenic, iron, aluminium and vanadium. The oxide (*minium*) and molybdate (*wulfenite*) have been recorded.

Zinc minerals include the sulphide (*sphalerite*), hydrated silicate (*hemimorphite*) and carbonate (*smithsonite*) but are uncommon.

Cobalt occurs principally with nickel and manganese in a hydrated complex (*asbolane*) but is also present in an hydrated arsenate (*erythrite*), with nickel and arsenic in an arsenide (*pararammelsbergite*) and sulphides (*cobaltite*, *siegenite*), and with iron and zinc in a sulphide (*tetrahedrite*). Nickel occurs in sulphides, with iron (*bravoite*) and arsenic (*gersdorffite*). Iron is present in the sulphide (*pyrite*), the oxide and hydrated oxide, and in hydrated sulphates. *Cinnabar*, (mercury sulphide), *argentite* (silver sulphide), a silver selenide (at Clive), and gold have also been recorded.

The mineralization was thought to be of syngenetic origin (deposited with the host sediments; e.g. Dewey & Eastwood, 1925, and earlier authors) but is now regarded as epigenetic (introduced subsequently; e.g. Taylor *et al*., 1963). Mohr (1964) proposed a process involving epigenesis followed by syngenesis. Warrington (1965) originally proposed that the mineralizing fluids were of magmatic origin but, by 1977 (see Warrington, 1980a), had envisaged that they were chloride-rich intrastratal brines, a view reached independently by Carlon (1979, from unpublished work). Warrington (1980a) demonstrated that the Alderley Horst was a potential trap for such fluids migrating through the Sherwood Sandstone beneath the cover of Mercia Mudstone. The brines leached metallic ions from minerals in sediments they passed through, with an additional or alternative source of minerals being fluids of more deep-seated origin. When trapped in the horst minerals were deposited in a reducing environment, possibly created by hydrocarbons that migrated into the same structure. The involvement of intrastratal brines in the origin of the sediment-hosted mineralization in the Cheshire Basin has been adopted and developed by subsequent workers (e.g. Holmes *et al*., 1983; Naylor *et al*., 1989; Rowe & Burley, 1997; Plant *et al*., 1999b).

The paragenesis, or order in which the minerals formed, was first studied at Alderley Edge (Ixer & Vaughan, 1982). A four-stage, polyphase origin was proposed. In early diagenesis of the sandstone host-rock authigenic *anatase* and *quartz* overgrowths with *bravoite*, *pyrite* and *chalcopyrite* developed. In the third phase primary sulphides formed vein-fillings and intergranular cements in and adjacent to faults in the order *bravoite* and Ni-Co-Fe sulpharsenides – *pyrite* – *chalcopyrite* – *sphalerite* – *galena*. In the final phase these were replaced by secondary minerals, or carbonates and sulphates that enclose vestiges of the primary minerals. The relationship of mineralization to diagenesis recognised in this work has been emphasised by Holmes *et al*. (1983) and subsequent workers.

A study of fluid inclusions (Naylor *et al*., 1989) confirmed that the mineralizing fluid was a basinal brine and indicated that this had a salinity of 9-22 wt% NaCl equivalent and a temperature of 60°C to 70°C. A study of sulphur isotopes in barite (Naylor *et al*., 1989) indicated that the sulphate was derived from evaporites in the Mercia Mudstone; comparable results from sulphide minerals suggested an origin from the reduction of sulphate-bearing fluids from the same source, with reduction resulting from bacteriogenic action or interaction with hydrocarbons.

An attempt at the isotopic dating of *galena* from Alderley (Moorbath, 1962) gave an age of 210 ± 60 million years (mid-Permian to late Jurassic). The structural trap scenario (Warrington, 1980a) implies a maximum age of Anisian (early Mid-Triassic), after deposition of the Mercia Mudstone which formed a seal above the Sherwood Sandstone in the Alderley Horst. Rowe and Burley (1997) suggested that primary mineralization was post-faulting and occurred during late Mesozoic burial or Tertiary uplift, with oxidising groundwaters causing alteration to secondary minerals later in the Tertiary.

In the most recent study of the mineralization (Milodowski *et al*., 1999) a four-stage metallogenic model has been proposed. Remobilisation of metals by breakdown of parent minerals during eodiagenesis was followed by a complex mesodiagenesis in which fluids were expelled from the Mercia Mudstone into the Sherwood Sandstone. In the early stages these fluids were sulphate-rich and resulted in the sandstones in the latter group being cemented with anhydrite. Later fluids were metalliferous brines that migrated towards basin-bounding faults where mixing with small amounts of reducing fluids, possibly sourced from Carboniferous rocks, caused precipitation of the polymetallic assemblage. This primary mineralization was complex and episodic; contrary to the views of Rowe and Burley (1997), it was considered to be of latest Triassic to Early Jurassic age, and associated with faulting and fracturing. It was extensively altered during telogenesis after post-Cretaceous basin inversion.

Figure 9. Part of a stope left after the extraction of a large body of copper ore hosted by aeolian sandstone, West Mine, Alderley Edge (photo: G. Warrington).

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REFERENCES

Anon. 2001. Clive Copper Mine 10th June 2001. *Below*, **2001**(2), 8-9.

Braithwaite, R.S.W. (1994). Mineralogy of the Alderley Edge – Mottram St Andrew area, Cheshire, England. *Journal of the Russell Society*, **5**, 91-102.

Carlon, C.J. (1979). *The Alderley Edge Mines*. Altrincham: John Sherratt & Son Ltd, 144pp.

Carlon, C.J. (1981). The Gallantry Bank copper mine, Bickerton, Cheshire: with a review of mining in the Triassic rocks of the Shropshire – Cheshire Basin. *British Mining*, **16**, 50pp.

Dewey, H. & Eastwood, T. (1925). Copper ores of the Midlands, Wales, the Lake District and the Isle of Man. *Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Great Britain*, **30**. London: HMSO, v+87pp.

Holmes, I., Chambers, A.D., Ixer, R.A., Turner, P. & Vaughan, D.J. (1983). Diagenetic processes and the mineralization in the Triassic of central England. *Mineralium Deposita*, **18**, 365-377.

Ixer, R.A. & Vaughan, D.J. (1982). The primary ore mineralogy of the Alderley Edge deposit, Cheshire. *Mineralogical Magazine*, **46**, 485-492.

Milodowski, A.E., Strong, G.E., Shepherd, T.J., Spiro, B., Kemp, S.J., Hyslop, E.K., Jones, D.G., Leng, M.J., Haslam, H.W., Bradley, A.D., Nicholson, R.A. & Warrington, G. (1999). Diagenesis of the Permo-Triassic rocks. Pp.125-175 *in* Plant, J.A., *et al*. (eds), 1999a (*q.v.*).

Mohr, P.A. (1964). On the copper-mineralised sandstones of Alderley Edge, England, and of Chercher, Ethiopia, and the problem of their genesis. An essay on red bed copper deposits. *Contributions from the Geophysical Observatory, Faculty of Science, Haile Sellassie I University, Addis Ababa, Ethiopia*, Series A, **4**, 59pp.

Moorbath, S. (1962). Lead isotope abundance studies on mineral occurrences in the British Isles and their geological significance. *Philosophical Transactions of the Royal Society of London*, **A.254**, 295-360.

Naylor, H., Turner, P., Vaughan, D.J., Boyce, A.J. & Fallick, A.E. (1989). Genetic studies of red-bed mineralization in the Triassic of the Cheshire basin, northwest England. *Journal of the Geological Society, London*, **146**, 685-699.

Plant, J.A., Ball, D.F., Bradley, A.D., Chadwick, R.A., Evans, D.J., Jones, D.G., Kirby, G.A., Milodowski, A.E., Nicholson, R.A., Shepherd, T.J., Smith, N.J.P., Warrington, G. & Wilson, A.A. (1999b). Resources of the basin: base metals, industrial mineral, hydrocarbons and groundwater. Pp.210-239 *in* Plant, J.A., *et al*. (eds), 1999a (q.v.).

Plant, J.A., Jones, D.G. & Haslam, H.W. (eds) (1999a). *The Cheshire Basin - basin evolution, fluid movement & mineral resources in a Permo-Triassic rift setting*. Keyworth, Nottingham: British Geological Survey, xvii+263 pp..

Pocock, R.W. & Wray, D.A. (1925). The geology of the country around Wem (Sheet 138, England). *Memoirs of the Geological Survey of Great Britain*. London: HMSO, vi+125pp.

Poole, E.G. & Whiteman, A.J. (1966). Geology of the country around Nantwich and Whitchurch (Sheet 122, England and Wales). *Memoirs of the Geological Survey of Great Britain*. London: HMSO, viii+154pp.

Rayner, C. (2007). A Geological Trail around Hawkstone Park. *Proceedings of the Shropshire Geological Society*, **12**, 70-78.

Rees, J.G. & Wilson, A.A. (1998). Geology of the country around Stoke-on-Trent (Sheet 123, England and Wales). *Memoirs of the British Geological Survey*. London: The Stationery Office, x+152pp.

Rowe, J. & Burley, S.D. (1997). Faulting and porosity modification of the Sherwood Sandstone at Alderley Edge, northeastern Cheshire: an exhumed example of fault-related diagenesis. *Geological Society, London, Special Publications*, **124**, 325-352.

Shaw, M. (2009). *The Lead, Copper and Barytes Mines of Shropshire*. Logaston Press, 310 pp.

Taylor, B.J., Price, R.H. & Trotter, F.M. (1963). Geology of the country around Stockport and Knutsford (Sheet 98, England and Wales). *Memoirs of the Geological Survey of Great Britain*. London: HMSO, viii+183pp.

Thompson, D.B. (1993). The Grinshill sandstones and flagstones. *Shropshire Naturalist*, **2**, 16-25.

Warrington, G. (1965). The metalliferous mining district of Alderley Edge, Cheshire. *Mercian Geologist*, **1**, 111-129.

Warrington, G. (1980a). The Alderley Edge mining district. *Amateur Geologist*, **8**, 4-13.

Warrington, G. (1980b). Non-ferrous mining in north Shropshire and Cheshire. *Shropshire Caving & Mining Club Journal*, **1979**, 9-20.

Warrington, G. (1981). The copper mines of Alderley Edge and Mottram St Andrew, Cheshire. *Journal of the Chester Archaeological Society*, **64**, 47-73.

Warrington, G. (1995). North Shropshire Copper Mines. Pp. 19-26 *in* Pearce, A. (ed.) *Mining in Shropshire*. Shrewsbury: Shropshire Books (Shropshire County Council).

Warrington, G. (2010). Alderley Edge district, Cheshire. Pp.182-190 *in* Bevins, R.E., Young, B., Mason, J.S., Manning, D.A.C. & Symes, R.F. (eds) *Mineralization of England and Wales*. Geological Conservation Review Series **36**. Peterborough: Joint Nature Conservation Committee.

Warrington, G. (2012). The legacy of mining at Alderley Edge. *Mercian Geologist*, **18**, 75-76.

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