Mineralization of England and Wales

R.E. Bevins
Department of Geology, National Museum Wales, Cardiff

B. Young
Department of Earth Sciences, University of Durham
(formerly British Geological Survey)

J.S. Mason
Department of Geology, National Museum Wales, Cardiff

D.A.C. Manning
Institute for Research on Environment and Sustainability, Newcastle University

and

R.F. Symes
Geologist/Mineralogist, Sidmouth

with contributions from
R.A.D. Pattrick (University of Manchester)
A. Clark (Mineral Solutions Ltd)
A. Thurston (Mineral Solutions Ltd)
J. Vetterlein (Mineral Solutions Ltd)
J. Aumônier (The Mineral Industry Research Organisation (MIRO))
M.L. White (Mineral Solutions Ltd)
G. Warrington (formerly British Geological Survey)

Based in part on primary work by Dr L. Haynes

GCR Editors: L.P. Thomas and E.L. Durham

Chapter 6

The Mendip Hills

R.F. Symes

INTRODUCTION

Geological setting

This chapter covers the sites located within the Mendip Hills and associated areas (see Figure 6.1). The Mendip Hills area consists of a series of ridges of Palaeozoic rocks reaching a maximum height of 300 m and extending WNW from Frome in Somerset to Brean Down, near Weston-super-Mare on the Bristol Channel.

The structure is controlled by four major en-echelon periclinal folds with a dominant east–west axis. The folding is related to the various phases of the Armorican Orogeny. The ridges consist mainly of Carboniferous Limestone which forms the dip-slopes, steeper on the northern limbs, reaching near-vertical in places. Sedimentary rocks of Devonian age form the core of most of the anticlines, as in the Blackdown, North Hill and Pen Hill structures. The Palaeozoic rocks are overlain unconformably by rocks of Triassic and Jurassic age. During the folding of the region a system of faults and joints were developed. Many of these fractures eventually became pathways for fluid movement leading to a varied assemblage of minerals (see Figure 6.2).

Mineralization

Mining and quarrying on the Mendip Hills began long before the Roman occupation of Britain. Gough (1967) suggested that Mendip lead was worked as far back as the 2nd and 3rd century BC. However it is the exploitation of the lead ores from the Mendip region by the Romans that made the region famous. Lead from the Mendips area made a major contribution to the plumbing in the villas of Pompeii, and lead ingots stamped with Latin inscriptions are known to have been exported from the Charterhouse area in AD49. Both mining of the lead ores and their smelting took place in the region.

According to the Roman historian Pliny (23–79 AD), Britain became the chief source of lead in the Roman Empire, and much of this came from the Mendip region. After the Romans departed, the industry declined until lead production began to increase in the 15th century, rose to a peak in the 17th century but then declined again, until ceasing altogether in 1908. Green (1958) suggested that some 100 000 tons of metallic lead was obtained from the Mendip region.

Zinc ores were also mined in the Mendips. The ore mineral was normally smithsonite (the zinc carbonate) rather than sphalerite, the primary sulphide. The carbonate ore was first worked in the 16th century, with production ceasing in the 19th century.

Despite the former dominance of galena, the primary lead sulphide ore, the Mendips are recognized importantly as a source of four differing mineralization assemblages. The interplay of fluids associated with the main phases of mineralization led subsequently to an assemblage of secondary minerals unique to the Mendip Hills. The four types of mineralization are: (1) lead and zinc ores; (2) iron and manganese ores; (3) evaporites such as gypsum, halite and celestine; and (4) secondary lead and copper minerals.

Despite the lack of active metalliferous mining, the quarrying industry, which is active in this area, continues to reveal temporary but important sections for study. Most of the original orefield is now overgrown 'gruffy ground', a local term for hummocky ground caused by surface workings for lead ore. Reviews covering aspects of the orefield are extensive, with important papers being those by Dewey (1921), Green (1958), and Ford (1976). The remarkable suite of secondary minerals has been described by Spencer and Mountain (1923), Symes and Embrey (1977), and Alabaster (1982), while recently several new mineral species and hence type localities have been described (see later).

An authoritative overview of the geological interpretation of many of the important mineral sites in the Mendip Hills region was given by Stanton (1982), while an outline of several of the sites of mineralogical importance in the area was described by Symes (1985).

It is from sites described in Stanton's report, combined with the unpublished work of Haynes (pers. comm.) and the findings of Symes (1985) that the site descriptions in this chapter are based.

Lead and zinc ores

The ancient lead-zinc orefield of the Mendip Hills was described in detail by Green (1958). The mineral assemblage consists of galena, sphalerite and pyrite, associated with calcite,
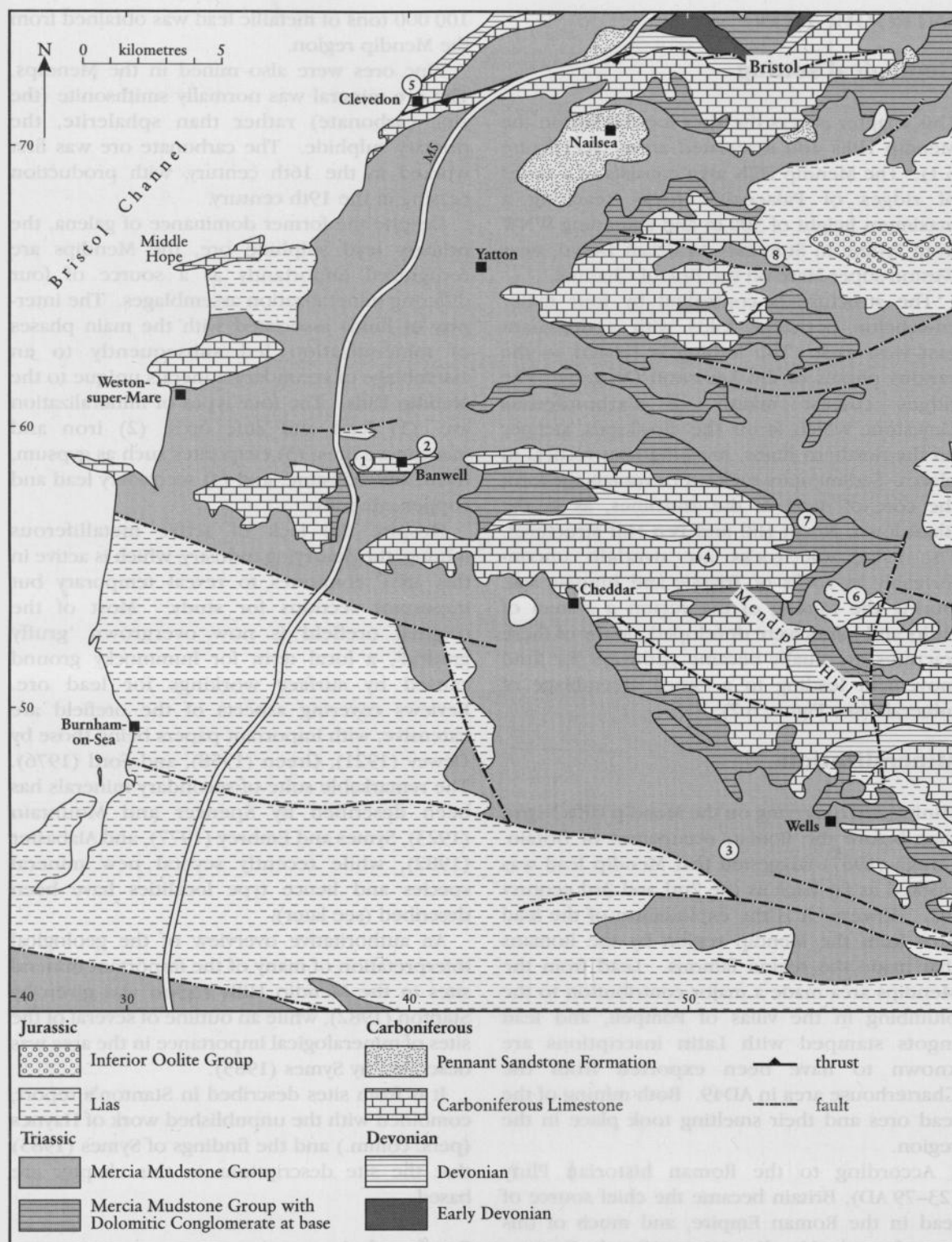
Figure 6.1 Map showing the locations of the GCR sites in the Mendips: 1 – **Banwell Caves**; 2 – **Banwell Ochre Caves**; 3 – **Ben Knowle**; 4 – **Charterhouse Lead Orefield**; 5 – **Clevedon Shore**; 6 – **Wurt Pit**; 7 – **Compton Martin Ochre Mine**; 8 – **Hartcliff Rocks Quarry**.
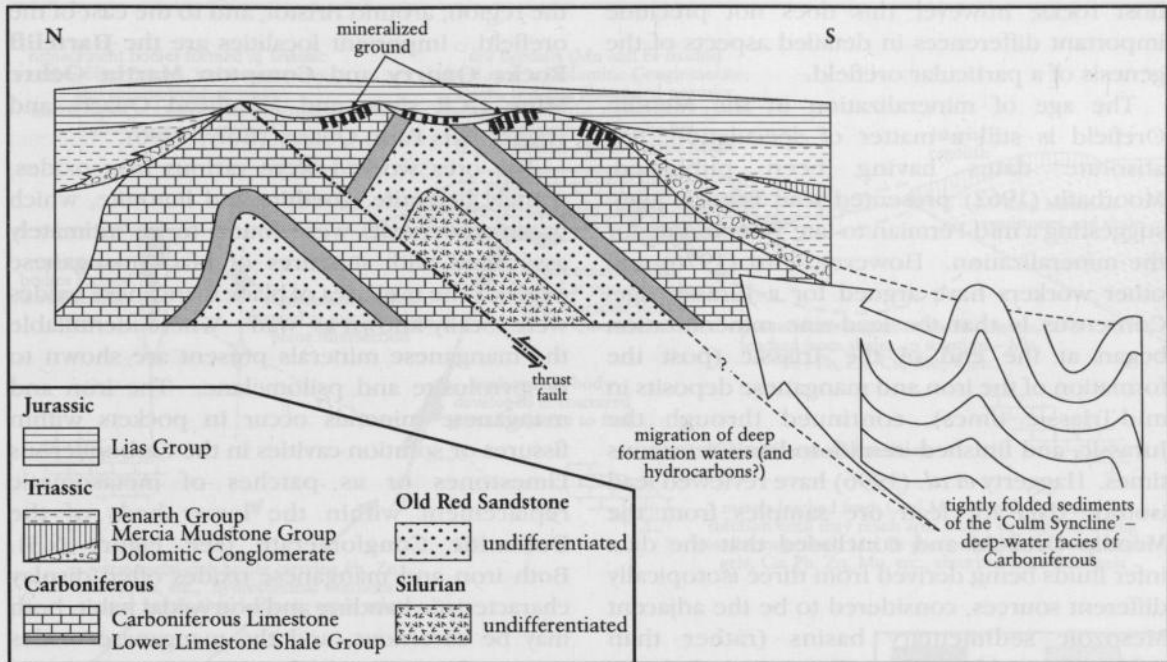
Figure 6.2 Diagrammatic cross-section of the Mendip Hills and the Culm Syncline, showing possible migration route of deep formation waters up-dip. Based on Ford (1976), and Alabaster (1982).

barite, barytocelestine and rare fluorite, as seen at the **Charterhouse Lead Orefield** GCR site. Smithsonite ('calamine' or 'dry bone ore') was the main ore of zinc, and although previously it had been believed to be of primary origin it is now considered to be of secondary origin.

The minerals occur in a series of small parallel veins and as fissure-fillings often associated with neptunian dykes. They were once economically important in the Carboniferous Limestone and Triassic Dolomitic Conglomerate, although veins are also found in the younger beds of Jurassic age (Alabaster, 1982). Veins and masses of identical mineralogy occur to the west of the orefield, at Steepholm in the Bristol Channel (Whittaker and Green, 1983), to the north-west at the **Clevedon Shore** GCR site (Ixer, 1986; Ixer *et al.*, 1993), to the north-east in the Chipping Sodbury Quarries (Rankin and Stanley, unpublished report), and across the Severn Estuary at the **Machen Quarry** GCR site (see GCR site report, Chapter 5).

Fluorite is only sparingly found associated with the Pb-Zn ores (Smith, 1973). At several localities barite was an important gangue

mineral, as for example at the **Banwell Caves** GCR site, and also occurs along with calcite filling minor veins. Copper minerals are rare in the main Mendip Orefield, although copper minerals were worked previously in the Quantock Hills, to the south-west. Fine specimens of azurite and malachite can be found in mineral collections from the Cannington and Bin Combe areas.

Although not now well-exposed, the Mendip lead-zinc ores have been extensively studied, and recent models make comparisons with other occurrences of carbonate-hosted lead-zinc mineralization, particularly with those of Mississippi Valley-type (MVT), including those of the Northern and Southern Pennines and the Halkyn Mountain–Minera district of north-east Wales, described in chapters 3, 4 and 5 of this volume, and also by Ixer and Vaughan (1993). Models related to this type of mineralization are based on the migration of diagenetically formed metalliferous fluids from adjacent sedimentary basins. It is clearly established that these deposits were formed by the deposition of the minerals from hot (50°–200°C) saline, aqueous solutions some time after the lithification of the

host rocks; however this does not preclude important differences in detailed aspects of the genesis of a particular orefield.

The age of mineralization in the Mendip Orefield is still a matter of speculation, few absolute dates having been published. Moorbath (1962) presented lead isotope ages, suggesting a mid-Permian to late Triassic date for the mineralization. However, Ford (1976) and other workers have argued for a Jurassic age. Consensus is that the lead-zinc mineralization began at the end of the Triassic (post the formation of the iron and manganese deposits in mid-Triassic times), continued through the Jurassic, and finished in mid- to late Cretaceous times. Haggerty *et al.* (1996) have reviewed lead isotope data for lead ore samples from the Mendip Orefield and concluded that the data infer fluids being derived from three isotopically different sources, considered to be the adjacent Mesozoic sedimentary basins (rather than Carboniferous basins). These included the Wessex Basin, the Central Somerset Basin and the Bristol Channel Basin.

The Harptree Beds, exposed in the central Mendips, are silicified Jurassic limestones (Lias and Inferior Oolite), which contain galena, sphalerite and barite in small amounts, and are best studied at the **Wurt Pit** GCR site. Green and Welch (1965) commented that the Harptree Beds appear to be the result of metasomatic replacement by chert of late or post-Inferior Oolite age. It was originally thought that this silicification phase was a separate late mineralizing event. However, there is now good reason to assume that on the basis of the fact that the Harptree Beds are always located close to areas of lead-zinc mineralization (Stanton, 1982) they were silicified at about the same time as mineralization.

Iron and manganese ores

Exploitation of the manganese and iron ores in the Mendip Orefield has always been on a small scale because although the sporadic deposits are quite extensive the iron ore tended to be too siliceous for easy smelting, and extraction has centred on those localities where the mineral was found to be useful as a pigment, for example in the Winford area. The manganese ores were primarily worked for use in pottery glazes.

These small supergene iron and manganese deposits are more widespread to the north of the region, around Bristol, and to the east of the orefield. Important localities are the **Hartcliff Rocks Quarry** and **Compton Martin Ochre Mine** GCR sites, and Merehead Quarry and Higher Pitts Farm Quarry (Burr, 1996).

The ores worked were various iron oxides, namely hematite, goethite and limonite, which in many deposits were found to be intimately associated with mixtures of black manganese oxides. The mixtures of black manganese oxides were locally known as 'wad'. Where identifiable the manganese minerals present are shown to be pyrolusite and psilomelane. The iron and manganese minerals occur in pockets within fissures or solution cavities in the Carboniferous Limestones or as patches of metasomatic replacement within the lower beds of the Dolomitic Conglomerate (see Figure 6.3). Both iron and manganese oxides often display characteristic banding and botryoidal habit: both may be cavernous, and the manganese oxides commonly occur as pods.

Still exposed in the low adit walls, the iron and manganese minerals of the Higher Pitts Farm Quarry have recently been described by Burr (1996). Iron ores were worked from this locality for some three years in the 1890s, and the manganese pods provided fine examples of the secondary lead-copper oxychloride assemblage. At the **Compton Martin Ochre Mine** GCR site a hematite-rich conglomerate has been mined for red ochre, providing the largest and best-preserved example of the red ochre deposits of the Mendip area.

In many of the mineralized Triassic fissures in the eastern Mendips region, the Fe-Mn mineralization is truncated by the Inferior Oolite unconformity.

Green and Welch (1965) noted that the emplacement of the hematite pre-dated the lead-zinc mineralization. However, the formation of the ores was probably partially due to descending iron-rich solutions during Triassic times, both the iron and manganese being derived from the leaching of pre-existing sediments by weathering under semi-arid conditions. Spatial distribution of the ore deposits appears to have been controlled by the distribution of suitable replacement environments within the Dolomitic Conglomerate and Carboniferous Limestone, the relative amounts of iron and manganese being determined by the chemical environment at the site of precipitation and the chemistry of the mineralizing solutions
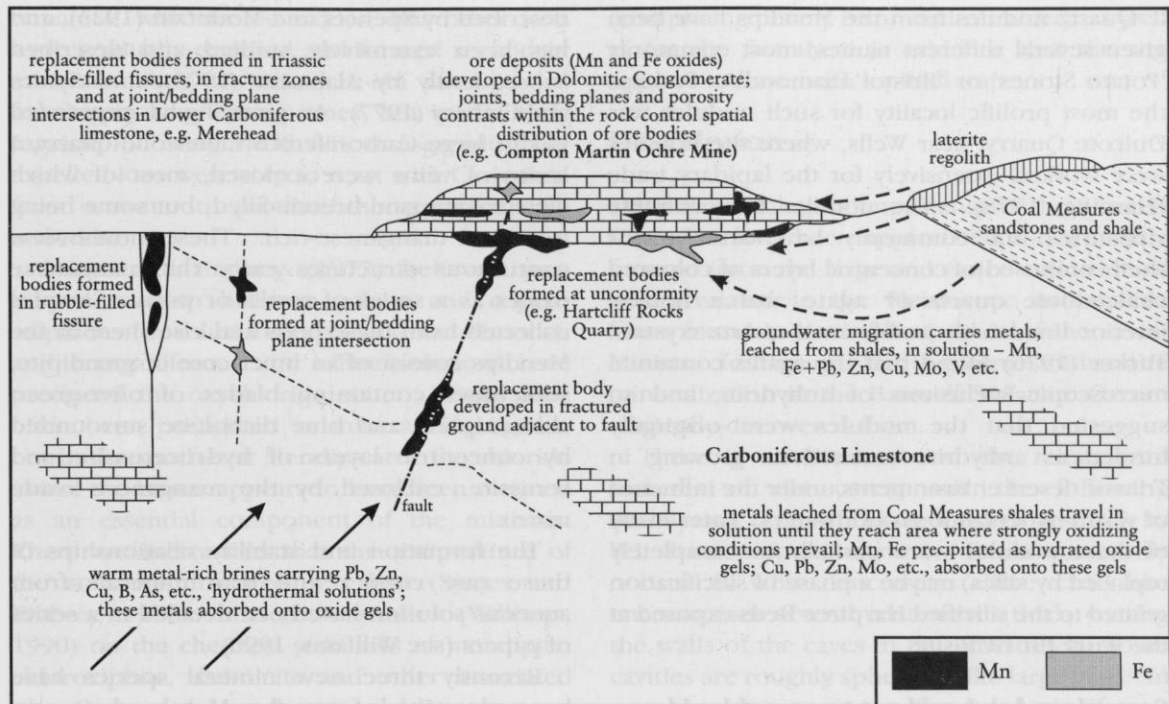
Figure 6.3 Manganese-iron mineralization in the Mendip Orefield. After Alabaster (1982).

themselves. However, Ford (1976) considered the iron ores to be of a gossanous character, derived from weathered pyrite, in late Tertiary times. The manganese ores, although being of limited distribution compared to the iron ores, invariably contain small amounts of secondary lead minerals, commonly cerussite, hydro-cerussite and mendipite, as well as a range of rare secondary lead minerals (see below).

Iron minerals are often associated with neptunian dykes and calcite-bearing veins (filled by comb-crystallized calcite); however neptunian dykes of proven Jurassic age commonly transect the Fe-Mn ores, proving an earlier age for the mineralization.

Evaporites

In parts of Somerset and Avon, Triassic sedimentary rocks contain horizons rich in gypsum. Bands of this mineral are particularly well-exposed in the cliff sections of Aust and Blue Anchor Point near Minehead. A considerable salt field of Triassic age has been proven in the Central Somerset Basin from borehole evidence (Whitaker, 1972). As such these occurrences provide information on the varying palaeo-environment of Triassic times.

However, perhaps most interesting has been the working over the last century of celestine from the Mercia Mudstone Group around Bristol and several localities throughout the Mendips. Most of the workings are now filled in, but traces of gypsum and celestine with green mudstone fragments often occur in surface rubble, as at the **Ben Knowle** GCR site. The celestine occurred as nodules or irregular masses in the Mercia Mudstone Group rocks. In the past, partially hollow nodules were found containing fine groups of pale-blue crystals.

Nickless *et al*. (1976) described the celestine deposits of the Bristol area. They considered the celestine to be diagenetic after gypsum or anhydrite, the primary minerals probably forming in supra-tidal environments. Strontium may have been derived from the conversion of aragonite to calcite in underlying limestones of Carboniferous age.

Nodules and geodes from the Mendip Hills have been known, described and collected for a few hundred years. Such nodules and geodes occur in conglomerates and marls of Triassic age and are found over an area from Bristol to Wells. Here the Triassic sedimentary rocks rest unconformably on the folded and eroded rocks of Silurian, Devonian and Carboniferous age.

Quartz nodules from the Mendips have been given several different names, most commonly 'Potato Stones' or 'Bristol Diamonds'. Perhaps the most prolific locality for such nodules was Dulcote Quarry, near Wells, where the nodules were worked extensively for the lapidary trade (Harding, 1978). The nodules have variable structures but commonly have an exterior shell composed of concentric layers of coloured chalcedonic quartz or agate and a hollow interior lined with well-formed quartz crystals. Tucker (1976) found that the agates contained microscopic inclusions of anhydrite, and so suggested that the nodules were originally formed as anhydrite concretions growing in Triassic desert environments under the influence of warm hypersaline groundwaters. Later many of these nodules were partially or completely replaced by silica, maybe a phase of silicification related to the silicified Harptree Beds exposed at the **Wurt Pit** GCR site.

Secondary lead and copper oxychloride minerals and associated mineral assemblages

The oxychloride mineral mendipite was collected from the Mendips long before it was recognized and described as a distinct species. Figured specimens of mendipite survive in old collections; several specimens of mendipite are in the Woodward Collection (1665–1728), now in the Sedgwick Museum, Cambridge. Early specimens were also in the collection of Thomas Pennant (1762–1798), now in the Natural History Museum, and a specimen of mendipite was figured by Rashleigh (1797). Spencer and Mountain (1923) described the new species chloroxiphite, which remains unique to the Mendip Hills, and diaboléite, associated with manganese and iron ores from Higher Pitts Mine, near Priddy. Examples of secondary lead minerals such as cerussite and hydrocerussite have been described from many localities, but it is from the extensive quarrying activity from Merehead Quarry (ST 691 442) that the most extensive vein type-deposits have been described (Symes and Embrey, 1977).

At Merehead Quarry the secondary minerals occur scattered throughout the manganese ores, often intermixed with calcite and, usually, cerussite and hydrocerussite. Associated with this assemblage occurs a further range of rare secondary minerals. This assemblage was first described by Spencer and Mountain (1923), and has been extensively studied and described subsequently by Alabaster (1975), and Symes and Embrey (1977). As quarrying has proceeded in this large Carboniferous Limestone quarry, a series of veins were exposed, most of which were calcite- and breccia-filled, but some being iron- and manganese-rich. These more-or-less continuous structures carry the manganese oxides as a series of swells or pods. Samples collected from these pods and elsewhere in the Mendips consist of an inner core of mendipite, sometimes containing blades of olive-green chloroxiphite and blue diaboléite surrounded by concentric layers of hydrocerussite and cerussite, enclosed by the manganese oxide matrix.

The formation and stability relationships of these rare copper and lead minerals from aqueous solution have been detailed in a series of papers (see Williams, 1990).

Recently three new mineral species have been described from the Merehead Quarry manganese-rich assemblage. Detailed compositional and X-ray crystallographic studies have shown these rare secondary minerals to have most interesting structures (Welch *et al.*, 1996). These three new minerals are:

parkinsonite (Symes *et al.*, 1994)
mereheadite (Welch *et al.*, 1998)
symesite (Welch *et al.*, 2000)

The structures of the layered lead oxychlorides are based on an alternation of litharge PbO layers and sheets of Cl atoms. The main feature of interest is the wide diversity of elements that partially substitute for Pb, namely Si, P, As, V, Mo and W (see Welch *et al.*, 1996). Charge balance is provided by Cl, which forms layers between the PbO-like sheets.

Alabaster (1975, 1982) described the formation of manganese ores at Merehead Quarry. He proposed that Fe and Mn in dilute acid solution, derived from weathering of Coal Measures strata, passed into fissures in the Carboniferous Limestone and Dolomitic Conglomerate during Triassic times. They were precipitated as hydrated oxide gels filling the fissures and replacing the wall-rocks. The Mn oxide gels adsorbed Pb, Cu, Mo, Ba and other cations from ambient solutions, while the Fe oxides adsorbed anions such as Si, As, and P. When gels slowly consolidated and crystallized, the Si

remained with the Fe oxides, but other ions were gradually expelled and formed secondary minerals filling cavities. Fe-Mn ores ceased forming in late Triassic times, but in the early Jurassic, following the Rhaetic transgression, the expelled ions were able to react with Cl derived from seawater to produce the rare oxyhalide minerals.

Symes and Embrey (1977) believed prolonged reaction between galena and copper sulphides (or solutions rich in Cu and Pb ions), and manganiferous and saline solutions have produced the oxychloride suite. Brines have often been postulated as mineralizing agents, but in the south-east Mendips area the chloride ion of the brines appears to have been retained as an essential component of the minerals. There are indications that the temperature of the solutions involved was low (Symes and Embrey, 1977). Extensive studies (Williams, 1990) on the chemical stabilities of mendipite, chloroxiphite, diaboléite and other associated phases have been determined in aqueous solution at 282°K (Humphreys *et al.*, 1980; Abdul-Samad *et al.*, 1982), and these studies have shown that small variations in concentration and other chemical parameters of the solutions may determine which members of the assemblage are formed. The Mendip mineral occurrences are critical in providing the natural analogues against which to test these experimental investigations.

BANWELL CAVES, AVON (ST 383 588)

Introduction

Banwell Caves are situated 5 km east of Weston-super-Mare, at the western end of the Banwell Hill limestone ridge (see Figure 6.1). Two sets of caves in limestones of Carboniferous age are mineralogically important, namely Banwell Bone Caves and Banwell Stalactite Cavern.

The principal mineral interest, namely barite mineralization, is well exposed as encrustations in the roof and on the walls and as vein fillings in association with minor amounts of galena, smithsonite, limonite and 'yellow ochre', and can also be closely studied from several loose blocks on the cave floor.

The site is also of particular importance for its uniquely rich Pleistocene bone assemblage (comprising mainly bison and reindeer), as well as for the fact there is evidence that the site appears to have been a pitfall trap.

Description

The palaeontological importance of the Banwell Caves has long been appreciated and is mainly focused upon the large and varied collection of bones related to the Pleistocene mammalian fauna found in the infilling sands of the caves. Miners following barite-galena-smithsonite mineralization in the Banwell Stalactite Cavern originally discovered them.

There is no literature on the mineralized features of the caves, and the following description represents unpublished research by W.I. Stanton (pers. comm.). Barite commonly occurs as white micro-crystalline chalk-like encrustations several centimetres thick, coating the walls of the caves in the limestones. Some cavities are roughly spherical, like large vugs. In one, the barite covers a floor deposit of grey, silty, horizontally laminated sediment that has been lithified by calcite impregnation. Other cavities follow bedding planes, and the barite in these varies from thin flat lodes parallel to the bedding, to thicker lodes in which the mineral occurs in association with sandy sediment that shows cross-bedding in places.

In a maze of very narrow mine-workings beneath the entrance to the Banwell Stalactite Cavern, barite forms impure vein-fillings up to 0.6 m thick, dipping at about 40° (see Figure 6.4). The mineral here is soft and earthy, and contains streaks and breccias of grey silty or clayey sediment that was apparently being deposited at the same time. There are small 'eyes' of galena in the barite, pinkish-brown films of smithsonite ('calamine'), and some limonite and yellow ochre.

The barite-coated vugs and lodes in parts of the Stalactite Cavern guided later phreatic cave development, which has enlarged them in some places and bypassed them in others. In enlarged cavities, fragments of an insoluble mineral crust have previously fallen to the floor and formed residual barite-rich cave earths. At one point, about 2 m into the Stalactite Cavern, there is a thin vertical vein of plastic blue-grey clay, possibly a Rhaetian or Jurassic neptunian dyke, and related to the grey sediment that accompanies the barite in some of the deposits.

Figure 6.4 A vein of mineralization in the roof of Banwell Bone Cave. (Photo: Natural England.)

Interpretation

Green (1958) described the ancient lead-zinc orefield of the central Mendips in detail. The deposits worked contained galena, sphalerite and pyrite associated with the gangue minerals calcite, barite and rarely fluorite. Smithsonite was the main ore of zinc, although in the Mendips this is thought to be of secondary origin, being derived from the oxidation of primary sphalerite by the action of groundwaters. Barite occurs sporadically throughout the Mendips as a gangue mineral. Such occurrences are assumed to be products of the same mineralization of Mississippi Valley-type (Ixer and Vaughan, 1993), and occur in close time and space relationship with the sulphides, although the barite may also occur as late-stage vein infill associated with, or cutting, neptunian dykes.

There is some evidence from this locality that mineralization and associated sedimentation may be contemporaneous, and of a Jurassic age rather similar to other recorded Jurassic-age mineralization throughout the Mendips. Some comparisons can be made with the recent discovery and studies on layered Pb-Zn-Ba/Sr mineralization found in former cave environments in the Carboniferous Limestone of the Chipping Sodbury quarries (Rankin, pers. comm.).

Conclusions

The Banwell Caves provide readily accessible exposures of barite mineralization of the Mendip Orefield. The predominant barite mineralization found in the Banwell Caves has features characteristic of the main phase of the Mendips Pb-Zn-Ba mineralization, but the barite at this site is in greater abundance and variety than at any other location in the Mendip Hills. Associated clays and silts appear to have been deposited at the same time as the mineralization.

BANWELL OCHRE CAVES, AVON (ST 407 593)

Introduction

Banwell Ochre Caves are situated 2.5 km east of the **Banwell Caves** GCR site, to the east of Banwell (see Figure 6.1). The ochre caves are important for the extensive yellow ochre workings that they contain. They have been chosen as the type site for yellow ochre and limonite because they are open and fairly extensive, and a variety of ochre types and iron hydroxides can be examined *in situ*, allowing the genesis of the ochre and iron deposits to be investigated. There is no literature

on the mineralogy of the Banwell Ochre Caves, and the following description is therefore based on unpublished material from W.I. Stanton (pers. comm.).

Description

Banwell Ochre Caves consists of five groups of natural phreatic tunnels in Carboniferous Limestone, from which the ferruginous floor deposits have been partly removed. They were worked for their content of yellow ochre from 1935 to 1950, and some evidence of mining remains.

The floor deposits were up to 5 m thick and consisted largely of unsorted stony earth and clay, including a variable proportion of yellow ochre and brown limonites. In one cave laminated deposits of fine sand, composed of well-rounded quartz grains, appear to be interstratified with the stony earth. In an unconfirmed report, late Pleistocene bones were found in the stony earth layers in one of the caves.

The brown limonites mostly occur as lumps up to 0.5 m in size, with a rough stalactitic, coralline, cellular, porous or encrusting internal structure. Formed by the oxidation of pyrite, either *in situ* or by deposition from iron sulphate or carbonate solutions, the lumps of brown limonite are broken pieces of larger masses. In two of the caves, residual accumulations of these lumps, 5 m or more across, occupy depressions in the limestone surface below the subsoil, or fill-fissures penetrating deep into the limestone. Being effectively insoluble in the present climate, they are working downwards as the limestone surface is lowered by dissolution. Where the fissures connect with the caves, the lumps have slumped down to form debris-cones on the cave floor. Cones of this type are present in several caves, containing not only limonite and ochre, but normal stony soil as well, which followed the iron ores down the hole.

The limonites are always accompanied by yellow ochre (soft amorphous $Fe_2O_3.H_2O$, brilliant yellow in colour) which appears to be partly primary, formed by direct oxidation of pyrite, and partly secondary, formed by weathering of limonite. The miners removed the ochre and ochreous earth, leaving the limonite in heaps on the cave floor.

In the highest cave, stalactitic limonite and ochre appear to have encrusted the cave roof in the gap above a nearly complete sediment fill.

Chunks and crusts of the minerals peeled off, creating a very ferruginous breccoid top layer to the sediments.

Interpretation

The largest cave group, consisting of two large galleries, was never filled to the roof with sediment. Most of the floor deposits, up to 4 m thick, have been removed, although some remain exposed. They consist of an unsorted breccia of various, relatively insoluble materials ranging from limonite and yellow ochre to grey clay, sand and marl. The top surface of the floor deposits was virtually level. In this case, the deposits appear to consist of insoluble material that accumulated while the caves were being developed by slow-moving phreatic water, probably in middle or later Pleistocene times.

There is evidence, therefore, of at least two phases of limonite and ochre accumulation in the caves; one beneath the water-table as the passages were forming, and a second much later in the form of subaerial stalactitic and mass-flow deposits invading the caves. The original source of the iron in both cases would have been oxidizing pyrite masses above the water-table.

Conclusions

The five caves found at the Banwell Ochre Caves GCR site contain the most extensive accessible yellow ochre workings in the Mendip Hills area. A wide variety of ochre types and iron hydroxides (limonites) can be examined *in situ*, and the evidence of their accumulation as residual ore-bodies associated with Pleistocene sediments is demonstrable.

BEN KNOWLE, SOMERSET (ST 513 450)

Introduction

For more than 100 years, up until relatively recently, Britain was a major world producer of celestine ($SrSO_4$). Economic deposits are almost entirely limited to the Triassic Mercia Mudstone Group and underlying rocks of the Bristol district and southern Mendip Hills (see Figure 6.5). Mining of the Somerset deposits ceased in 1914, and later operations were limited to an area around Yate, north-east of Bristol. Working
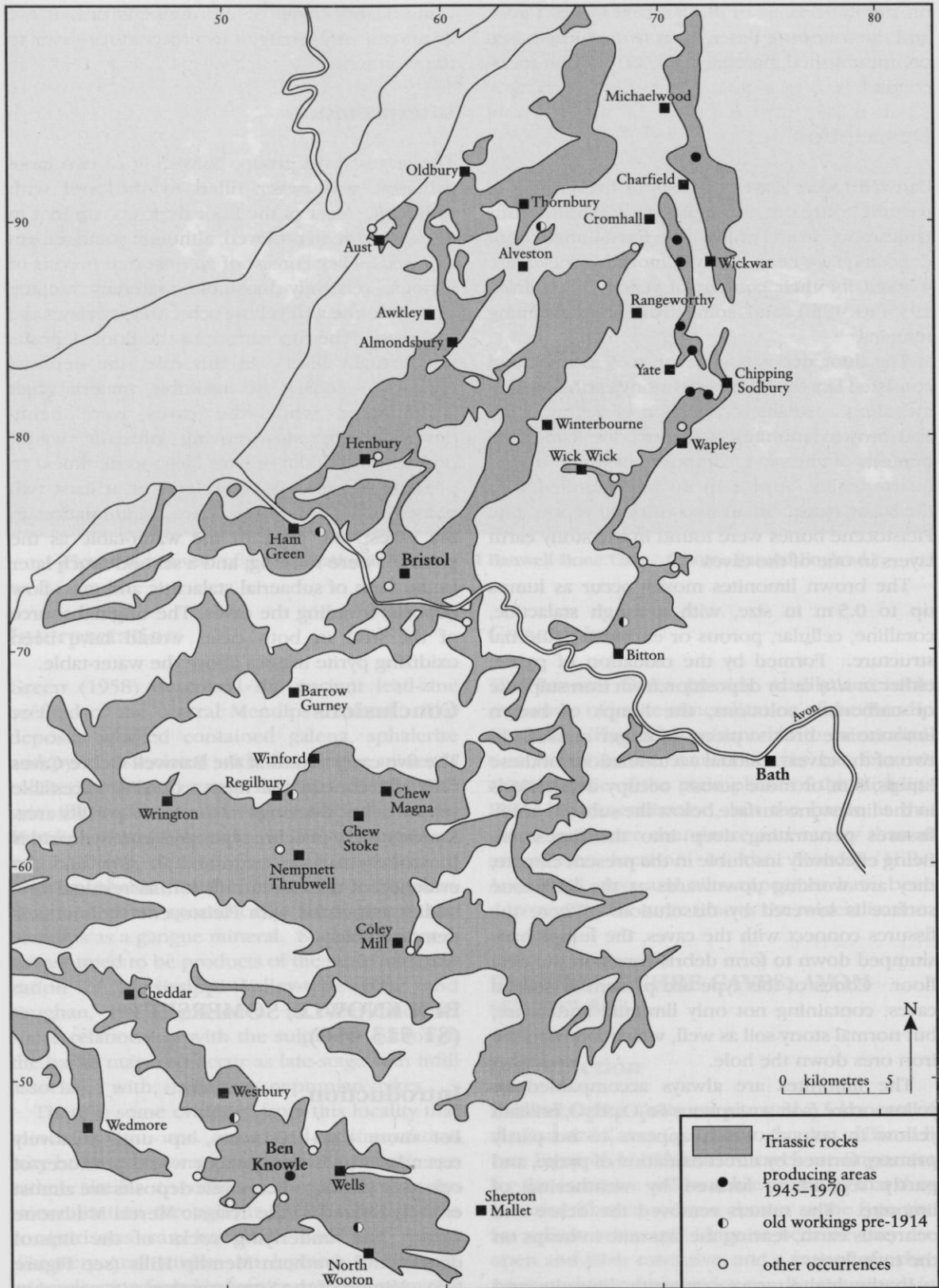
Figure 6.5 Celestine map of the Mendips showing the locality of the Ben Knowle GCR site. Based on Thomas (1973), and Nickless *et al.* (1976).

of these deposits has now also ceased. In the Yate area celestine occurred as a more-or-less continuous bed, occurring below a 5–10 m over-burden. South of the Mendips celestine was often found as field surface rubble and was dug from the underlying red marls, usually as celestine nodules. These nodules, found most often in the 'Tea Green Marl' (part of the Mercia Mudstone Group), were often associated with calcite and were especially common in the Dinder–Dulcote area, ESE of Wells (Symes, 1985).

Natural outcrops of celestine in Britain are now rare. The Ben Knowle GCR site is especially instructive in that contacts between celestine and the host rock ('Tea Green Marl') can be seen, and there are continuous exposures of 'Red Marl' and 'Tea Green Marl' on the escarpment nearby that illustrate the stratigraphical setting of the mineral deposit.

Description

Celestine at the Ben Knowle GCR site occurs on the side of a hill 3 km WSW of Wells. Here the mineral occurrence can be studied at several places in natural exposures in gullies and paths. At these small temporary sections the contact with the host rocks can be studied. The celestine is hosted in the 'Tea Green Marl', of which there are continuous exposures on the nearby escarpment. Celestine in the Somerset/Avon

area is either disseminated throughout the rock or occurs as discrete veins, sometimes forming large crystalline nodules (see Figure 6.6) and cavity infills, these having formed sometimes as a direct deposit from seawater or sometimes as a secondary replacement (see Figure 6.7).

The description below is based on the unpub-lished studies of W.I. Stanton (pers. comm.). The site includes the steep narrow ridge at the west end of the hill-top. It is here, at the western end of the field, that lumps of celestine up to 0.4 m in size project through the soil in a cattle path along the ridge top, and in another at the top of the escarpment on the north side, beside the hedge. Occasional lumps of the mineral may also be found at all levels on the north escarpment, having slipped down from the out-crop on the hill-top.

At this site the mineral is translucent to brilliant white, and occurs as irregularly shaped, sometimes cavernous masses with a sugary micro-crystalline texture. In some specimens it is interbanded with greenish marl or clayey marl, or it forms nodules or replacement masses in the host marl.

The 'Tea Green Marl' occurs as a layer some 10 m thick on top of this part of the hill. It mostly consists of soft greenish-grey mudstone and marl, with occasional thin beds of harder limestone. Some 300 m farther east, on the north escarpment of Ben Knowle (outside of the

Figure 6.6 Celestine nodules at Bristol Minerals Production Plant. From various sites. (Photo: R.F. Symes.)
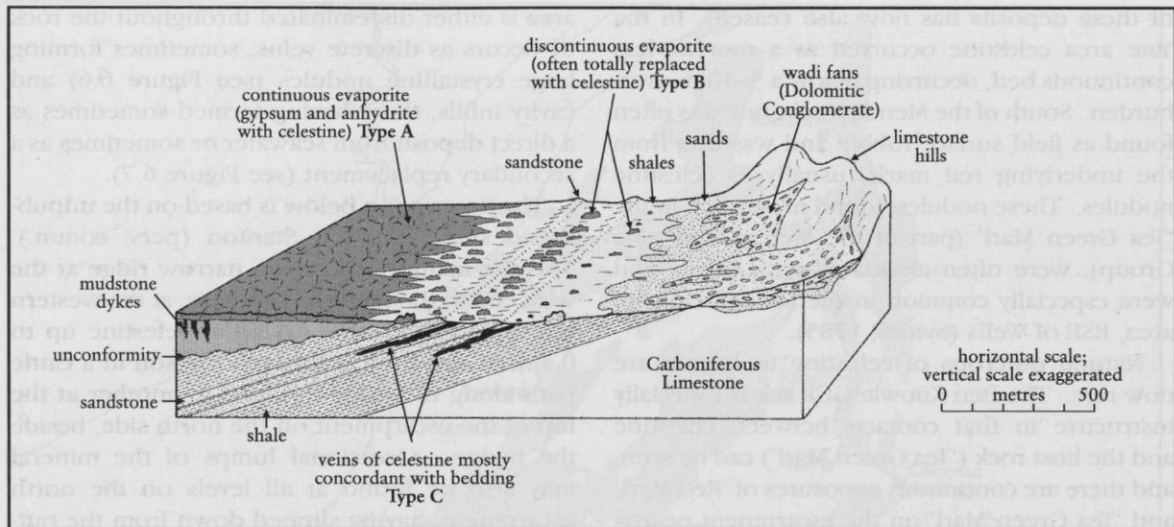
Figure 6.7 The horizontal and vertical relationships between the modes of celestine occurrence in the Mercia Mudstone Group of the Bristol/Mendip area. After Nickless *et al.* (1976).

GCR site area), there are erosion gullies in which the marls are seen to overlie about 15 m of soft red marls, which contain no celestine. The strata are subhorizontal and slightly affected by cambering.

Elsewhere in the Mendip region celestine has been found in the 'Tea Green Marl' at this stratigraphical level, and also at lower levels in the 'Red Marl' and Dolomitic Conglomerate, all of Triassic age. In the latter, where it fills small cavities, it is sometimes very coarsely crystalline.

Interpretation

In parts of Somerset and Avon the Triassic sedimentary strata locally contain horizons rich in evaporite minerals such as halite and gypsum, while sometimes in the Mercia Mudstone Group deposits of celestine are found. Nickless *et al.* (1976) described in detail the celestine deposits of the Bristol area and considered the celestine to be diagenetic after gypsum and/or anhydrite. Although the primary minerals probably formed in a supra-tidal environment, the strontium could have been derived from the conversion of aragonite to calcite in the Carboniferous Limestone, trace amounts of Sr being released into interstitial pore-fluids on this conversion. It has also been suggested that it is due to local discharge by thermal springs of Sr-rich fluids, subsequently concentrated in evaporite lagoons from which celestine was eventually precipitated. This theory is sometimes supported by the presence of barium in the celestine. However, in whichever way the strontium is introduced into the environment, the concentration of celestine appears to be associated with evaporitic lagoons.

Conclusions

The Ben Knowle site provides small but important instructive sections of, what is now rare, in-situ celestine mineralization within the Mercia Mudstone Group, of Triassic age. Its position and size precludes commercial working.

CHARTERHOUSE LEAD OREFIELD, SOMERSET (ST 506 553)

Introduction

The Mendips (a name probably derived from the medieval term 'Myne-deepes') have been the scene of mining for some two thousand years, and were a major source of lead to the Roman Empire.

The large area of worked ground which forms the Charterhouse Lead Orefield GCR site is the finest remaining example of the Mendip lead orefield (see Figure 6.8). A historical account of the orefield has been presented by Gough (1930), whilst a detailed geological context was presented by Green (1958). The western end of the Charterhouse–Lamb's Leer orefield provides the best features of the lead
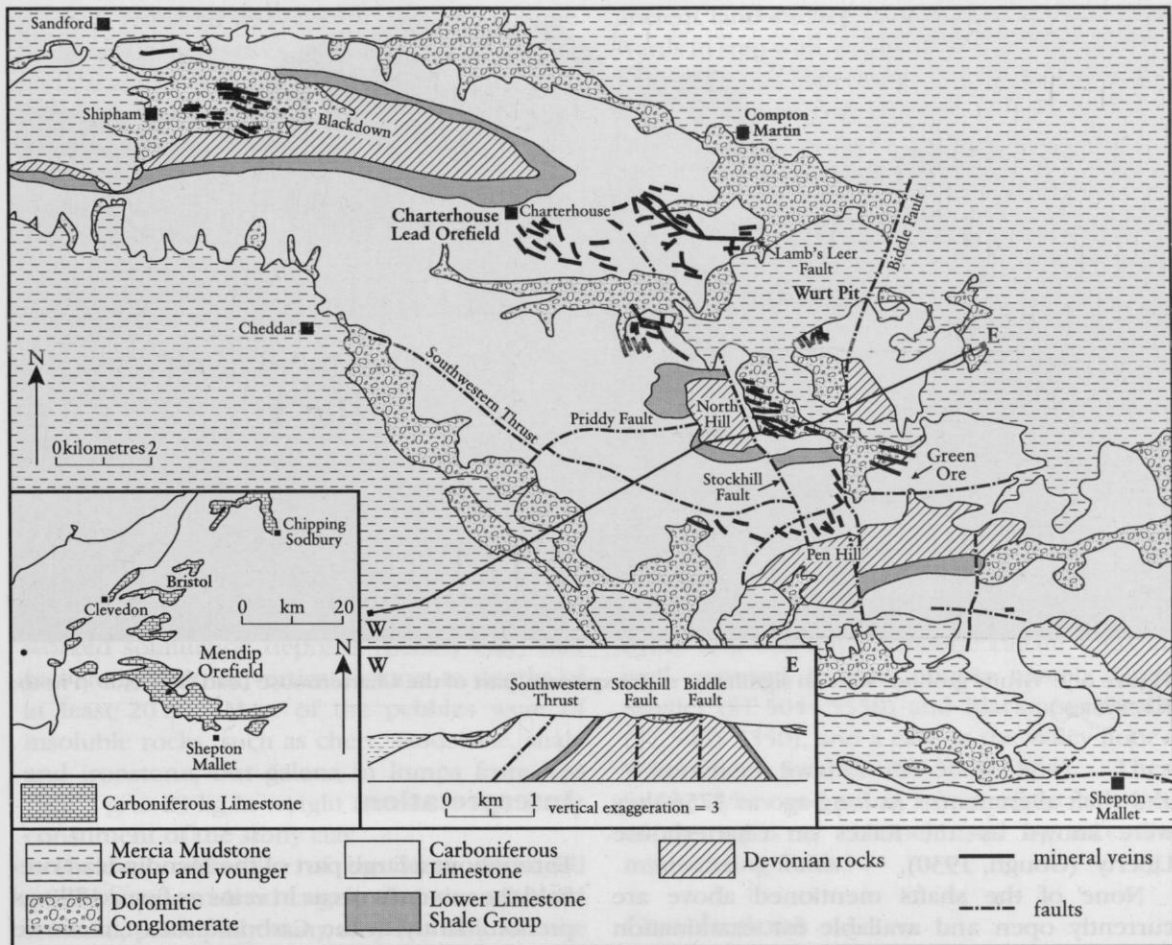
Figure 6.8 Outline map of the Mendip Orefield showing the location of the Charterhouse Lead Orefield, **Wurt Pit** and **Compton Martin Ochre Mine** GCR sites. Based on Ford (1976), and Pattrick and Poyla (1993).

mineralization and workings. Although surface exposure is now poor, the surface mining features ('rakes' and 'gruffy ground') (see Figure 6.9) are well preserved, and clearly show the forms and trends of the mineral veins, in this instance often as worked-out residual orebodies. Parts of some caves and mines (shafts) are still accessible, and although overgrown can demonstrate the nature of the residual ore deposits and the neptunian dykes that hosted the primary minerals. Of these the Grebe Swallet Mine (Stanton, 1991) provides the best evidence of mineralization. Ancient slags containing metallic lead litter the site in smelter areas, gravels and caves. The area was mined from pre-Roman times up to the 19th century. The Roman Charterhouse workings have been described by Elkington in Branigan and Fowler (1976).

Description

Much of this account of the Charterhouse ore-field is based on the publication of Stanton (1981) and his related unpublished works. In the south and west parts of the area, sharply defined sub-parallel veins trend between SSE and ESE, marked by rows of shafts spaced some 10 m apart along the bottoms of narrow shallow trenches. The veins are separated by 20–40 m of barren ground. Crossing the centre of the area in an east to ESE direction is a remarkable belt of closely packed shafts that seem to indicate the presence of several parallel and branching veins only about 5 m apart. In the north of the area are four huge trenches, up to 300 m long, 20 m wide and 10 m deep, the finest examples of their kind on Mendip. They trend east to SSE and are crossed and interconnected by smaller trenches

Figure 6.9 'Gruffy ground' with no significant rock exposure, part of the Charterhouse Lead Orefield. (Photo: R.F. Symes.)

and shaft alignments. As long ago as 1756 they were known as 'the Rakes on Charterhouse Liberty' (Gough, 1930).

None of the shafts mentioned above are currently open and available for examination (see later discussion of Grebe Swallet Mine). They appear to be aligned along vertical or steeply dipping veins. The irregularity and lateral impersistence of individual veins is a clear feature, explaining why planned methodical mining, of the kind that was normal for lead mining in Derbyshire, was not possible in the Mendip Orefield.

There is some evidence that veins die out, or become less productive, as their surface outcrop is followed down the side of valleys. If so, it illustrates the shallow nature of the Mendip ore. Contemporary writers quoted by Gough (1930) observed that it seldom paid to work the Charterhouse veins deeper than 40–60 m, a view that was confirmed when Cornish miners sank deep trial-shafts between 1845 and 1870.

A number of lead-bearing minerals have been reported from the Charterhouse Lead Orefield, including galena, cerussite and pyromorphite. The zinc carbonate mineral smithsonite occurs locally, along with sphalerite and pyrite and the associated gangue minerals calcite and barite.

Interpretation

Throughout a large part of the Mendip lead ore-field the minerals occur in veins as fissure-fillings predominantly in the Carboniferous Limestone and Triassic Dolomitic Conglomerate, although mineralization is known to occur in much younger rocks of Inferior Oolite (Jurassic) age. The deposits worked contained galena and sphalerite (smithsonite was the main ore of zinc), associated with gangue minerals pyrite, calcite, barite and rare fluorite. Extensive recent studies have made strong comparisons with worldwide occurrences of carbonate-hosted lead-zinc mineralization of the Mississippi Valley-type (Ixer and Vaughan, 1993). This model is based on the migration of diagenetically formed metalliferous fluids from adjacent sedimentary basins, possibly associated with intrastratal brines as ore-transporting fluids. However, there are strong indications that much of the upper part of the Charterhouse Lead Orefield was of a residual-ore-type, although it is supposed that at depth 'normal' veins of primary galena and gangue minerals were originally infilling the rakes in the solid Carboniferous Limestone.

The Charterhouse rakes are confined to the hill-top. They have no associated waste tips, which indicates that the volume of ore-bearing

material removed was equal to the void volume of the rakes themselves. Such huge shallow ore-bodies are most likely to be residual deposits, being the products of secondary enrichment processes acting during Pleistocene and Holocene times, when the limestone plateau of the Mendip area was lowered 50 m or more by dissolution (Barrington and Stanton, 1977). Pliny's comment on the abundant superficial lead ore of Britain may well have referred specifically to Mendip, the only British Carboniferous Limestone orefield that escaped the glaciations which elsewhere may have scraped away any shallow residual deposits present.

It might be expected that the primary lead mineral, galena, would oxidize to cerussite during the process of superficial enrichment, but a cave excavation in the north-west corner of the area, in the valley floor, has shown other-wise. At this site, miners searching for galena worked solifluction deposits (pebbly clay) that had sludged down vertical fissures to depths of at least 20 m. Most of the pebbles were of insoluble rocks, such as chert, sandstone, shale and ironstone, but galena in lumps from less than 1 g to 23 kg in weight formed a significant constituent of the stony clay.

Residual orebodies of the kind envisaged would have consisted largely of unconsolidated material, principally stony, silty and clay, like the solifluction deposits of Grebe Swallet. The walls of the rakes provide evidence that such a fill existed where, as is sometimes seen, they are pitted with large solution pockets like those found in the walls of clay-filled fissures in quarries. Nowhere in the rakes are there traces of gangue minerals adhering to the rock walls, or other signs that veins of 'normal' kind were present near the ground surface.

It is believed that normal veins of galena and gangue minerals enclosed in solid rock were originally present in the rakes and in the 50 m or more of limestone that, since the late Tertiary or early Pleistocene, have been removed by dissolution from above the present ground surface. Indeed it is probable that all the lead orefields of the Mendips high plateau were likely to have consisted of secondary residual deposits similar to Charterhouse. The galena and other insoluble minerals in these steep to vertical veins, together with the insoluble fractions of the limestone and dyke rocks, along with such foreign materials as wind-blown silt, stones from sandstone outcrops and relic material from the ancient land surface, would have moved down-wards in step with, or ahead of, the wasting of the Carboniferous Limestone. Such material would then have been concentrated and preserved in the faults and fissures of the rakes. The evidence from Grebe Swallet suggests that similar residual deposits occupied the upper sections of the narrower veins of the area as well.

In the southern area of the rakes, the presence or absence of chert beds in the lime-stone cliffs trace several east–west faults. The dip of the bedding varies considerably, mainly in detached limestone pillars, which may have sagged into the residual orebodies, or have been undercut by mining activity. Neptunian dykes of Upper Triassic and Lower Lias (Downside Stone) age, formed when fissures opened under tension, are present in the other rakes, as can be seen by the nature of the debris around shaft mouths. Neptunian dykes and coarsely crystalline calcite veins are well exposed in two mines, namely Grebe Swallet (ST 5044 5550) and Blackmoor Swallet (ST 5055 5550), and a cave in the valley floor at Waterwheel Swallet (ST 5048 5564). These faults, dykes and veins are excellent examples of the types of channel used by ascending mineralizing fluids.

Conclusions

Charterhouse Lead Orefield is the finest remaining example of the once extensive Mendip lead ore-fields. Having been little altered since mining, the nature of the original worked rakes and other associated workings are still clearly seen. Evidence from the important Grebe Swallet Mine is indicative of the residual nature to at least the upper parts of the orebody. The site provides much opportunity for further study of the relationship of residual orebodies to 'normal' vein infill types.

CLEVEDON SHORE, AVON (ST 402 719)

Introduction

At Clevedon, adjacent to the pier (see Figure 6.10), a mineralized fault and the associated country rocks contain a primary barite-sulphide assemblage and a variety of secondary minerals. The geological setting and mineralogy of the

Figure 6.10 Photo of Clevedon Pier at the Clevedon Shore GCR site. (Photo: Natural England.)

mineralized fault has been studied and described by Starkey (1984, 1986), and an ore mineral paragenesis was given by Ixer (1986) (see Figure 6.11), and by Ixer *et al.* (1993). As well as the assemblage of primary and secondary sulphides, an interesting suite of secondary alteration minerals (including phosgenite, beudantite and cotunnite) can be studied.

Description

The coast at Clevedon exposes a section through the Portishead Formation of Devonian age and the overlying Carboniferous Lower Limestone Shale Group, this being on the south-east side of the Clevedon–Portishead Anticline. At the north end of the beach the formations are faulted against the Triassic Dolomitic Conglomerate. A mineralized E–W-trending fault and fault plane is marked by a prominent low cliff-face running out to sea. This face exhibits traces of barite mineralization with minor amounts of galena, and green and yellow secondary copper and lead minerals. The fault can be traced across the promenade and road to a small mineralized exposure in the bank close to the public conveniences.

On the beach close to the cliff-face and west of the Pier Head are many large boulders of the Dolomitic Conglomerate (up to 1 m across) carrying prominently banded barite. The boulders appear to be derived by erosion along the fault. At various states of the tide many small barite pebbles (up to 10 cm across) are exposed within the beach mud, and where mineralized these show a higher degree of secondary alteration.

The vein filling is predominantly pale-cream to pink, banded barite. Some cavities contain barite of 'cockscomb' habit. Bands of chalcopyrite crystals intergrown with tennantite and sphalerite are found in the barite. Galena occurs as euhedral crystal sections and irregular masses up to 5 cm across, and carries minute tetrahedrite inclusions along grain boundaries. It is surrounded sequentially by partial or complete rims of pyrite and marcasite, a second generation of chalcopyrite and tennantite, and later inclusion-free, dark sphalerite and minor enargite. Alteration has led to the formation of idaite and covellite accompanied by native Cu and a native As-Ag alloy (Ixer, 1986). The development of botroyoidal galena and colloform pyrite may also be secondary. A number of yellow, green, brown and colour-

Barite
Hematite
Chalcopyrite
Tennantite
Galena
Tetrahedrite
Bornite
Pyrite
Marcasite
Enargite
Sphalerite
'Idaite'
'CuS'
Late pyrite

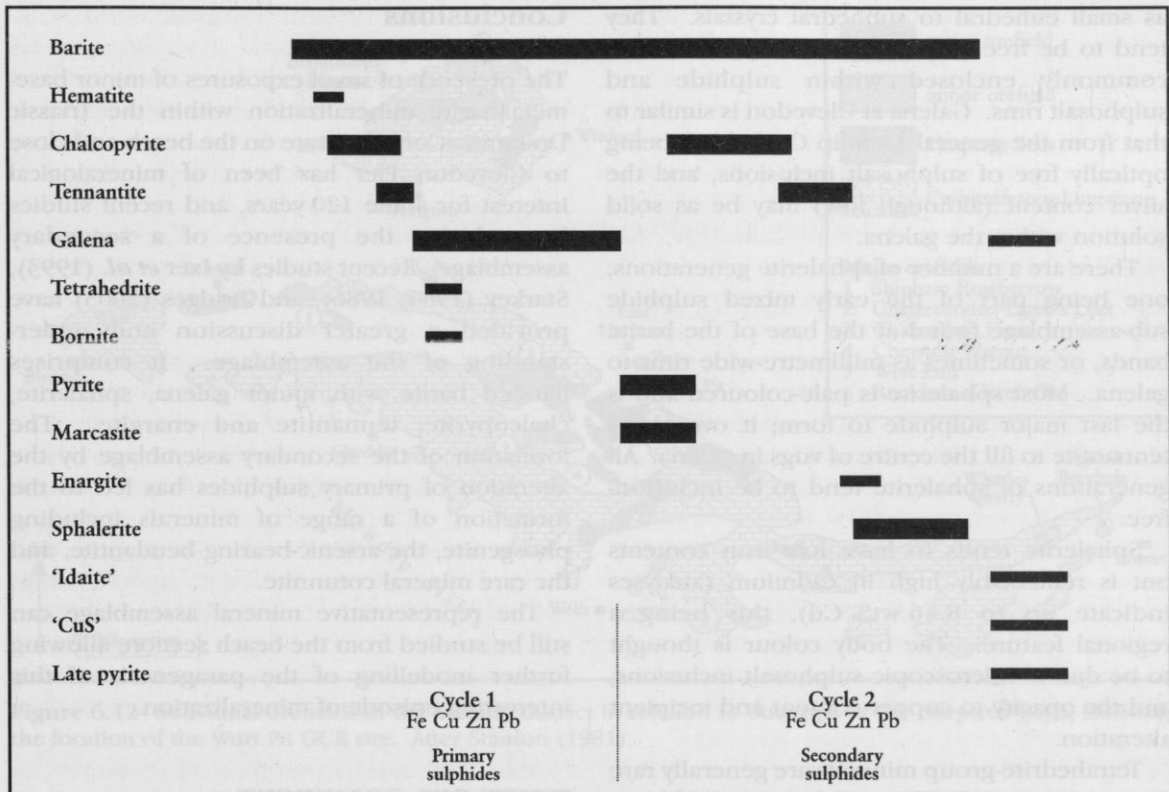| Cycle 1 | Cycle 2 |
| Fe Cu Zn Pb | Fe Cu Zn Pb |
| Primary sulphides | Secondary sulphides |

Figure 6.11 Paragenesis of the mineralization at Clevedon Shore. After Ixer (1986).

less secondary minerals include beudantite, brochantite, phosgenite, cerussite and anglesite (Starkey, 1984, 1986; Bridges, 2003).

Interpretation

Vein-style mineralization at Clevedon cross-cuts limestone breccias (Triassic Dolomitic Conglomerate). The mineralization at Clevedon belongs to the widespread but minor lead-zinc-copper mineralization of the Bristol area (Alabaster, 1989), and has many features in common with the mineralization of the Mendip Orefield, which is considered to be Mississippi Valley-type mineralization. The major mineralogy in all cases is of galena-sphalerite-barite accompanied by minor amounts of chalcopyrite, pyrite, marcasite and bornite.

At Clevedon pale-cream to pink barite, in strongly developed rhythmic bands, is the most abundant hydrothermal mineral in the vein assemblage. Chemical analyses show it to have very high strontium contents (10.7–11.6 wt% Sr). High Sr values in the barite can be equated with the mineralization recently recorded from

Chipping Sodbury (Rankin, pers. comm.). The very high values of Sr in the barite are remarkable, but probably reflect the fact that the Bristol area constitutes one of the world's classic celestine orefields. Minor amounts of lead, copper, and zinc sulphides and sulphosalts are present within the barite as rare, small disseminations. Detailed studies of the mineralogy and mineral chemistry presented by Ixer *et al*. (1993) have provided a paragenesis for the primary mineral assemblage within a single barite band.

In decreasing order of abundance the main opaque minerals are galena, chalcopyrite and sphalerite, which are accompanied by minor amounts of tennantite, pyrite, marcasite and hematite, while trace amounts of bornite and enargite are also present. Alteration of the primary sulphides to secondary digenite and covellite is widespread. An 'idaite-like' mineral accompanies chalcopyrite, and some tennantite shows features suggesting it is an alteration product of chalcopyrite.

Galena is the earliest phase to crystallize in the polymetallic sulphide bands, where it occurs

as small euhedral to subhedral crystals. They tend to be free of primary inclusions, and are commonly enclosed within sulphide and sulphosalt rims. Galena at Clevedon is similar to that from the general Mendip Orefield in being optically free of sulphosalt inclusions, and the silver content (although low) may be as solid solution within the galena.

There are a number of sphalerite generations, one being part of the early mixed sulphide sub-assemblage found at the base of the barite bands, or sometimes as millimetre-wide rims to galena. Most sphalerite is pale-coloured and is the last major sulphide to form; it overgrows tennantite to fill the centre of vugs in galena. All generations of sphalerite tend to be inclusion-free.

Sphalerite tends to have low iron contents but is remarkably high in cadmium (analyses indicate up to 8.46 wt% Cd), this being a regional feature. The body colour is thought to be due to microscopic sulphosalt inclusions, and the opacity to copper content and incipient alteration.

Tetrahedrite-group minerals are generally rare in the Mendips. The sulphosalts, including tennanite, from Clevedon are notably silver-poor and tend to have similar arsenic: antimony ratios. The presence of phosgenite and other secondary minerals were reported by Starkey (1984), and the intimate association of beudantite with oxidized tennantite-tetrahedrite and galena by Starkey (1986). At Clevedon, beudantite is locally common and seems to occur where tennantite (As-bearing) has undergone alteration in association with oxidizing pyrite-marcasite and galena.

Bridges (2003) more recently described the presence of cotunnite from a single pebble in mud on the foreshore at Clevedon. This represented only the second occurrence of cotunnite in the British Isles.

The lack of a comparable mineralogy and mineral chemistry from the Mendip Orefield makes it hard to assess the overall importance of the Clevedon mineralization. At the Clevedon Pier section upward-moving fluids of hydrothermal origin may represent a single event associated with late-stage Jurassic mineralization, or the complex mineralization may have formed from a small, localized feeder of mainstream mineralization through the fault system.

Conclusions

The presence of small exposures of minor base-metal-barite mineralization within the Triassic Dolomitic Conglomerate on the beach and close to Clevedon Pier has been of mineralogical interest for some 120 years, and recent studies have shown the presence of a secondary assemblage. Recent studies by Ixer *et al*. (1993), Starkey (1984, 1986), and Bridges (2003) have provided a greater discussion and understanding of the assemblage. It comprises banded barite with minor galena, sphalerite, chalcopyrite, tennantite and enargite. The formation of the secondary assemblage by the alteration of primary sulphides has led to the formation of a range of minerals including phosgenite, the arsenic-bearing beudantite, and the rare mineral cotunnite.

The representative mineral assemblage can still be studied from the beach section, allowing further modelling of the paragenesis of this interesting episode of mineralization.

WURT PIT, SOMERSET (ST 559 539)

Introduction

The Wurt Pit GCR site is a large cup-shaped depression, 15 m deep and 45 m in diameter, located on a gentle slope of the Mendip plateau. The site lies some 2 km south-west of the village of East Harptree (see Figure 6.12) and is readily accessible by road. Geomorphologically important, the pit is essentially a karst-collapse feature probably formed due to the collapse of a cave system in the underlying Carboniferous Limestone. The 'Pit' exposes mineralized Harptree Beds, thought to be of an early Jurassic age. Unfortunately the Harptree Beds usually occur as a jumbled mass of residual chert blocks and boulders, and stratigraphical relationships are unclear. However, at this site, a 4 m-thick succession of Lower Lias limestones has been completely altered to chert by hydrothermal silicification genetically linked to the Mendip lead-zinc mineralization. The beds locally contain small quantities of limonite and yellow ochre, barite, sphalerite and galena.
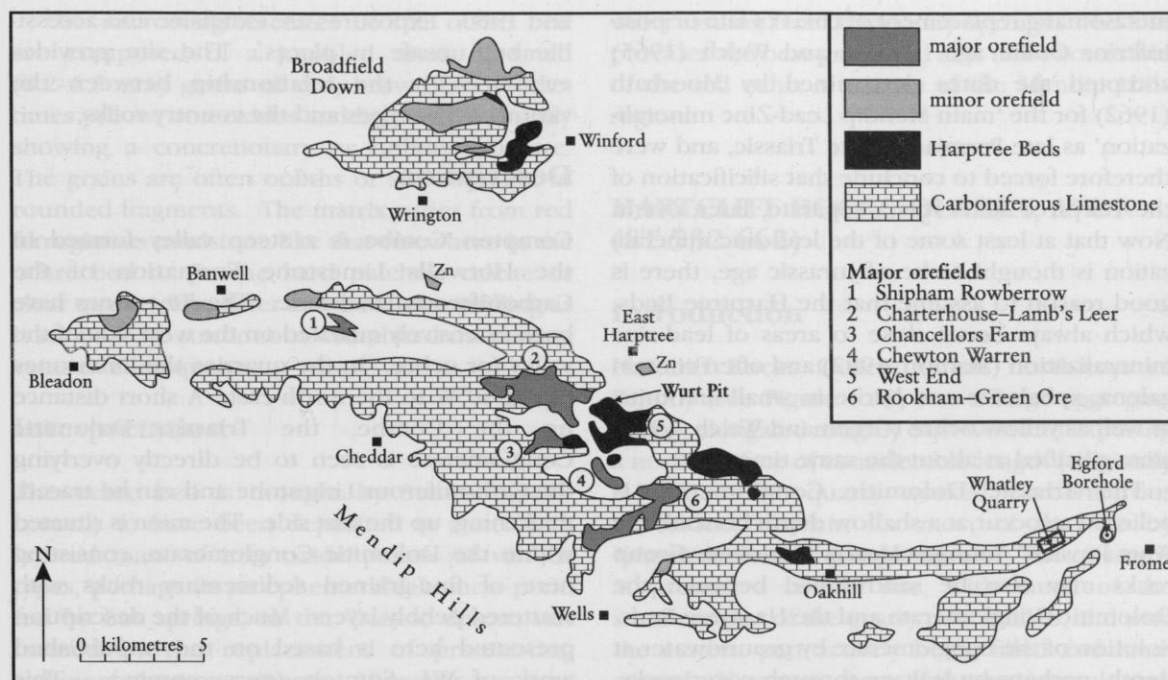
Legend:
- major orefield
- minor orefield
- Harptree Beds
- Carboniferous Limestone

Major orefields
1 Shipham Rowberrow
2 Charterhouse–Lamb's Leer
3 Chancellors Farm
4 Chewton Warren
5 West End
6 Rookham–Green Ore

Figure 6.12 Individual orefields of the Mendip district in relation to outcrops of the Harptree Beds, showing the location of the Wurt Pit GCR site. After Stanton (1981).

Description

The Harptree Beds of the central Mendip area comprise limestones of Lias to Inferior Oolite age that were altered to chert by hydrothermal silicification, more-or-less contemporaneously with the lead-zinc mineralization. Over most of the outcrops silicification was patchy, and subsequent weathering has leached away the calcium carbonate and left a residual mass of clay and jumbled chert blocks. At Wurt Pit, however, a succession of Lower Lias limestones 4 m thick was completely silicified.

Wurt Pit is a natural circular sink-hole 15 m deep and 45 m in diameter. The horizontal chert-beds form a continuous cliff around one-third of the circumference near the rim as well as cropping out at intervals around the remainder of the depression. Below this structure, fallen blocks of chert make for steep rocky slopes down to the bottom of the sink-hole.

The chert is micro-crystalline, grey to black when fresh, but which weathers to a rusty-brown. Bedding and contained fossils are faithfully preserved in some outcrops, while in others the rock appears to be a massive replacement breccia, retaining nothing of the original structure. Cracks in the weathered chert contain films of limonite and yellow ochre, and the same minerals occur as cellular masses filling small cavities. Green and Welch (1965) quoted some early writers' descriptions of ochre mines near Wurt Pit; the yellow ochre was associated with the chert. On this evidence, the Jurassic limestones were most probably slightly pyritized as well as silicified. Minor amounts of barite, sphalerite and galena are also locally present.

Interpretation

Silicification of the sedimentary rocks associated with various areas and types of mineralization has been an area of active research throughout the Mendip region. Silicification of the Harptree Beds has been the focus of these studies.

The Harptree Beds of the central Mendip area are silicified Jurassic limestones (Lias and Inferior Oolite) that have been largely decalcified. Woodward (1893) suggested that they were the products of ascending hydrothermal solutions, and Green and Welch (1965) commented that the Harptree Beds appeared to be the result of

403

metasomatic replacement of chert of late or post-Inferior Oolite age. Green and Welch (1965) accepted the dates determined by Moorbath (1962) for the 'main Mendip Lead-Zinc mineralization' as late Permian to late Triassic, and were therefore forced to conclude that silicification of the Harptree Beds was a separate, later, event. Now that at least some of the lead-zinc mineralization is thought to be of Jurassic age, there is good reason to assume that the Harptree Beds, which always occur close to areas of lead-zinc mineralization (Stanton, 1982) and often contain galena, sphalerite and barite in small amounts, as well as yellow ochre (Green and Welch, 1965) were silicified at about the same time.

The Triassic Dolomitic Conglomerate is believed to occur at a shallow depth beneath the Wurt Pit site. Younger Mercia Mudstone Group rocks may also be sandwiched between the Dolomitic Conglomerate and the Harptree Beds. Solution of the conglomerate by groundwater at depth, perhaps by leakage through cover rocks, is believed to have resulted in collapse.

Conclusions

Wurt Pit is an important geomorphological site. However, it is also of considerable geological/mineralogical importance, being the focus for the studies of the Harptree Beds of Jurassic age and their hydrothermal silicification. It is considered that this silicification was closely associated with the fluids of the main Mendip lead-zinc mineralization, and the quartz replaced anhydrite nodules (so-called 'Potato Stones' and 'Bristol Diamonds') which are found throughout the area (Tucker, 1976; Harding, 1978).

COMPTON MARTIN OCHRE MINE, SOMERSET (ST 542 567)

Introduction

This GCR site lies on the east side of Compton Combe, south of the village of Compton Martin (see Figure 6.8). At this locality, iron mineralization (red ochre) in the Triassic Dolomitic Conglomerate and the relationship between mineralization and stratigraphy were available for study underground and in surface exposures on the eastern fringe of Compton Wood. The mine is said to have been worked between 1910 and 1960. Exposures are extensive and accessible but unsafe in places. The site provides evidence for the relationship between the various ochre-types and the country rocks.

Description

Compton Combe is a steep valley formed in the Hotwells Limestone Formation of the Carboniferous Limestone. The limestones have been extensively quarried on the west side of the valley for ochre. In the quarries the limestones dip at 40°W to the north-east. A short distance up the Combe, the Triassic Dolomitic Conglomerate is seen to be directly overlying the Carboniferous Limestone and can be traced, thickening, up the east side. The mine is situated within the Dolomitic Conglomerate, consisting here of fine-grained sedimentary rocks with scattered pebbly layers. Much of the description presented here is based on the unpublished work of W.I. Stanton (pers. comm.). This locality is the largest, best-preserved and most accessible of the red-ochre workings of the Mendip area.

The ochre bed forms part of the local Dolomitic Conglomerate succession, which is coloured bright-red by disseminated hematite over a wide area of the surrounding country. The bed, about 2 m thick, dips at about 20° to the east. It consists of mudstones and pebbly sandstones, brilliant red in colour, and soft enough to be easily worked by hand, or with a pick and shovel. There is a vague internal stratification. Irregular lenses of harder material are scattered through the bed and appear to be calcite and/or quartz impregnations. The mine galleries terminate, in a southerly direction, where this harder material is so plentiful as to make the ochre bed difficult to work.

The roof bed is much harder, more calcareous and less ferruginous, but is still fine-grained. At the mine entrance the ochre bed is seen to be overlain by about 5 m of these harder beds, which are overlain in turn by conglomerates. The floor bed is never fully seen in section.

Near the mine entrance, large vugs lined with quartz crystals (geodes) are present on the west wall of the main gallery. At one point, near the south end of the workings, a small irregular calcite vein cuts the ochre bed, and contains blebs of galena. Accompanying it is a thin neptunian dyke of pale greenish-grey porcellaneous limestone.

The microconglomerates of the ochre bed are composed of a jumbled mass of small (0.2–1.5 mm) grains of red, brown, and sometimes yellow, iron oxides and hydroxides, locally showing a concretionary or oolitic structure. The grains are often ooliths or sub-rounded to rounded fragments. The matrix varies from red ferruginous mudstone like that elsewhere in the ochre bed to (in the hard patches) calcite or clear quartz. The latter may be a later infilling as it seems to be continuous with thin cross-cutting veins of clear quartz.

Interpretation

The ochre bed is thought by Stanton (pers. comm.) to have been deposited in water as a layered mass of iron oxide pellets of various types, perhaps in an ephemeral lake or a pond fed by hot springs, in the Triassic desert, not formed by the replacement of pre-existing sediments by iron minerals. However, a source of the iron from a lateritic regolith overlying the Coal Measures and infilling a karstic surface seems more likely, although certain features of the deposit are consistent with water-saturated lateritic regolith locally reworked in a spring-fed lake.

Alabaster (1982) argued that ochre is believed to represent largely an alteration product of massive iron ores. Certainly many of the varied deposits at the Compton Martin Ochre Mine GCR site have formed from a combination of mechanical transport of eroded iron ore and direct chemical precipitation of iron minerals from highly ferruginous groundwaters.

Lenses, pods and impregnations of quartz and calcite are a further feature of the Compton Martin deposit, leading to many vugs lined with quartz. Again, this phase of silicification appears to be a later event than the iron mineralization and may have been responsible for modification of the iron ores.

Conclusions

The Compton Martin deposit provides interesting comparisons with the supposed origin of the replacement iron ores at the **Hartcliff Rocks Quarry** GCR site and Winford. Exposures at Compton Martin are considered to provide evidence that iron mineralization in the Triassic rocks of the site area represents saturation of a lateritic regolith with ground-water issuing from temporary springs. The site provides the best-preserved and most accessible of the red ochre workings of the Mendip Hills region.

HARTCLIFF ROCKS QUARRY, AVON (ST 532 662)

Introduction

Hartcliff Rocks Quarry (1 km north-east of Felton) (see Figure 6.13) was a large aggregate quarry, elongated roughly east–west and exposing a northern face of considerable length (originally 0.5 km). The quarry worked Carboniferous Limestone, overlain for most of the site by Triassic Dolomitic Conglomerate. The quarry is at present a landfill site, with much of the southern part of the quarry now infilled, and with the eastern part actively being filled and land-scaped. However, some of the major geological features of the quarried northern section have been conserved, and despite being overgrown in places, with faces needing some tidying up, excellent, easily accessible geological and
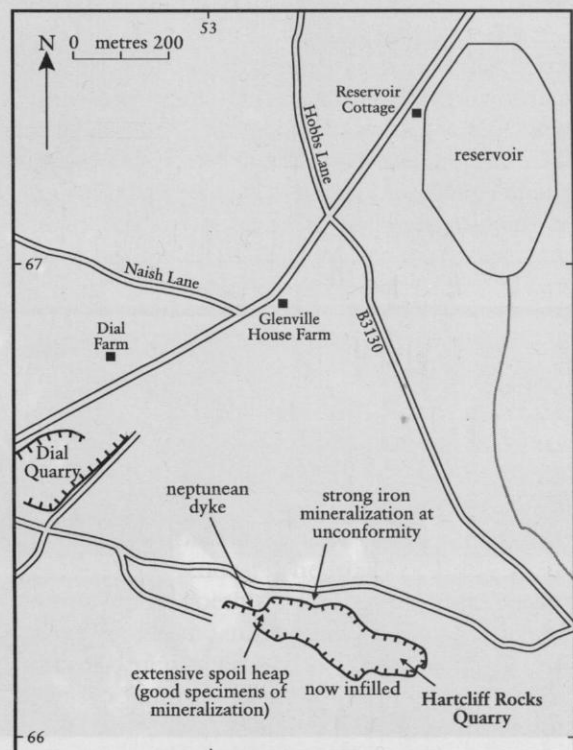

Figure 6.13 Outline map of the Hartcliff Rocks Quarry GCR site.

mineralogical features can be studied at the site (see Figure 6.14).

Description

The quarry has been cut into a ridge of the Carboniferous Limestone, part of the Broadfield Down Anticline. The section now exposed was probably part of the upper bench of the quarry. The central part of this quarried section exposes fine sections of the plane of unconformity, especially the Triassic wadi deposits overlying the Carboniferous Limestone. The wadis contain rich iron ores of a replacement type, typical of many Mendip sections. Calcite- and barite-rich mineralized veins cut through the Triassic and Carboniferous sedimentary rocks and iron ores. The plane of unconformity is sinuous, reflecting the shape of the Triassic Dolomitic Conglomerate wadis.

The Triassic and Carboniferous strata have both undergone extensive silicification associated with the replacement of massive iron oxides. The iron oxides (hematite, goethite, and limonite) are themselves siliceous. In the wadis, limestone pebbles are associated with iron oxides and sometimes show the replacement growth of crystalline quartz (so-called 'Bristol Diamonds'). The iron ores tend to be concentrated along the plane of unconformity, the Dolomitic Conglomerate being the preferred host for such mineralization. Several late-stage, minor calcite-barite veins cut through the rocks and iron mineralization. Towards the eastern end of the quarry, neptunian dykes containing some calcite and barite cross the wadi structures. However, the best-developed mineralized fissures and neptunian dykes are to be found at the extreme western end of the worked section. These are near-vertical structures up to 5 m wide, and despite being extensively overgrown the critical geological features can still be studied. The fill varies from comb-layered calcite, to minor calcite-barite veins, and iron-rich clays. Some manganese oxides have been reported to occur in these structures but are not readily visible at present.

In front of the faces of the western section a large heap of intensively mineralized rock has been preserved. The material is essentially

Figure 6.14 Close-up of iron mineralization *in situ*, north quarry wall, Hartcliff Rocks Quarry. The dark material is mainly hematite and goethite. A cavity in the massive iron mineralization has crystals of calcite, quartz and hematite deposited by late mineralized solutions in groundwaters. (Photo: Natural England.)

blocks of Dolomitic Conglomerate and Carboniferous Limestone containing the iron oxides hematite and goethite. Traces of galena, barite, calcite and quartz are also present.

Interpretation

Traces of former iron workings are widespread in the Mendip Hills area, although production was usually on a small scale. Their origins have been compared and likened to the iron ores of the Forest of Dean and South Wales (seen for example at the **Mwyndy Mine** GCR site, Chapter 5). The ores worked were iron oxides (hematite, goethite and limonite). In many instances these iron oxides were intimately associated with mixtures of earthy black manganese oxides (principally pyrolusite and psilomelane), collectively known as 'wad'.

The iron orebodies are always more extensive and continuous than the associated manganese ores, which occur in smaller pod-like structures. Such a deposit was formerly mined for iron ore at Higher Pitts Farm Quarry (ST 535 491), the ore occurring as pockets and veins associated with black earthy manganese oxides (Burr, 1996).

Iron ore deposits are recorded from faults in the Coal Measures of the Somerset and Avon Coalfield and as replacements and fissures-fills in the Carboniferous Limestone and Triassic Dolomitic Conglomerate throughout the Mendip region. These are specifically concentrated in the Hartcliff Rocks Quarry, Winford Ochre Mine and the **Compton Martin Ochre Mine** GCR site of the north Mendips (Symes, 1985). At Winford Ochre Mine (ST 535 638) some 3 km south of Hartcliff, a considerable tonnage of siliceous iron ore was mined (mainly as pigment) from similar wadi-filled deposits (Alabaster, 1982). Again at Winford it can be seen that mineralized veins carrying calcite and barite, and also a little galena, cut the iron ores. A phase of silicification is associated with the iron oxides such that dumps associated with the quarried area contain fine, clear quartz crystals ('Bristol Diamonds').

Alabaster (1982) reviewed the characteristics of all Fe-Mn deposits in the Mendips region and related them to one mineralizing event of late Triassic age. He considered that the style and age of the deposits demonstrated the following relationships:

1. in fissures, Fe and Fe/Mn mineralization is cut by Jurassic fissure-fill;
2. in east Mendip, mineralized fissures with Triassic fill are truncated by the basal Inferior Oolite (Jurassic) unconformity;
3. at various localities veins of Pb-Zn-Ba mineralization cut through both the Lower Lias and Inferior Oolite.

Green and Welch (1965) observed that the emplacement of hematite pre-dated the Pb-Zn mineralization, the hematite deposits often being cut by lead veins. They supposed that descending iron-rich solutions in Triassic basins formed the Mendip ores. However, Ford (1976) considered that the iron ores were of a gossanous character, formed by weathering, probaby in late Tertiary times. It is now generally believed that the red hematite ores were formed and concentrated, normally as replacement deposits, under hot and arid conditions in Triassic times. However, Alabaster (1982) proposed that the source of the iron and manganese was due to intense weathering, under semi-arid conditions, of pyrite- and/or siderite-bearing Carboniferous rocks, the associated manganese being primarily derived from the Upper Carboniferous shales.

Within any mineralized area, the relative amounts and distribution of iron and manganese have been determined by the chemical environment at the site of precipitation and the chemistry of the mineralizing solutions themselves, such factors as the pH and the oxidation potential being all-important.

Conclusions

Hartcliff Rocks Quarry provides excellent exposures of mineralized Triassic Dolomitic Conglomerate rocks unconformably overlying the Carboniferous Limestone. Both rock-types have undergone extensive replacement by siliceous iron oxides. The iron ores, principally hematite and goethite, are concentrated along the plane of the unconformity. Calcite-barite veins and neptunian dykes cut across the rocks and associated iron mineralization.