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The journal of British Isles topographical mineralogy

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Aims and Scope: The Journal publishes articles and reviews by both amateur and professional mineralogists dealing with all aspects of mineralogy. Contributions concerning the topographical mineralogy of the British Isles are particularly welcome. Notes for contributors were printed in the last issue.

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FRONT COVER: Vanadinite, probably from High Pirn mine, Wanlockhead, Dumfriesshire, Scotland. Orangy-brown globular aggregates up to 7 mm in size, on chalky white plumboan apatite coating pyromorphite. 50 x 27 mm. Specimen in the Sutcliffe-Greenbank Collection purchased by the Royal Museum of Scotland in 1991.

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THE RUSSELL MEDAL

The Russell Medal for 1993 has been awarded to Trevor Bridges of Ovington, Northumberland. Established last year, the medal is awarded in recognition of outstanding contributions to topographic and specimen mineralogy, site documentation, and conservation.

Trevor Bridges (right) receiving the medal from Brian Young, President of the Russell Society, at a recent field meeting in Cumbria.

Trevor needs little introduction to Society members. He was one of the Society's first members and has served in a variety of posts including Honorary President 1979-81, General Secretary, and Newsletter Editor. He was one of the initiators of the Society's first regional branch, the Northern Branch, in 1984. In the early years of the Society Trevor provided much help and encouragement to members, particularly on mineral chemistry and identification using simple techniques. He was actively involved in conservation projects at Tickow Lane and Earl Ferrers lead mines, and has done much to promote both the Society and amateur mineralogy generally through numerous other societies.

Trevor Bridges is one of Britain's leading amateur mineralogists who, over a period of many years, has carried out valuable research into British minerals, especially those of northern England. Many of the country's museums have benefited from his generous donation of numerous important specimens. He has lectured and conducted extra-mural courses on mineralogy and mineral chemistry and has published a number of papers on British minerals in scientific journals. In presenting him with the medal the Society are delighted to acknowledge the excellent and important work of an amateur, especially one so prominent in the north of England, where Sir Arthur Russell, too, made important discoveries.

EDITORIAL

It is a pleasure to open the new volume of the journal by recording the award of the second Russell Medal to Trevor Bridges (see opposite page). How appropriate that the medal was presented to him in a quarry!

Articles on British Isles topographical mineralogy are the bread-and-butter of the journal, but a large part of this somewhat unusual number is devoted to wider issues of crucial relevance to all mineralogists and mineral collectors in Britain. The last number of the journal included a report of the conference on 'Conserving Britain's Mineralogical Heritage' held in Manchester in 1992. The full proceedings are not to be published, but the Russell Society was offered, and accepted, the opportunity to print eight of the papers presented at that conference. I am greatly indebted to Richard Bevins for collecting together and editing these papers, and the Society thanks the conference organising committee for defraying the cost of printing this extra material.

Members of the Society should not underestimate the importance of the topics discussed at the Manchester meeting, nor of the need to ensure that the Russell Society continues to play a significant role in representing the interests of mineral collectors and other students of mineralogy. It is the very future of collecting that is at stake.

While we can only list and conserve what is known, many of the exciting future discoveries will undoubtedly be made at still unstudied or even uncharted sites. The importance of timely reporting in reputable journals of the results of mineralogical finds and investigations by both amateurs and professionals is stressed in several of the conference papers. Without published accounts of the mineralogy of localities, conservation bodies may not become aware of their significance or even existence, making it more likely that they will disappear as collecting sites.

The charming reminiscences of the late Robert Shrimpton with which we begin this number merely underline the contrast between the carefree collecting days of not so long ago, and the complex issues that *every* collector faces today.

George Ryback

NICK CARRUTH

MINERALOGIST

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THE STORY OF A MINERAL COLLECTION
(Part 1)

The late R.D.S. SHRIMPTON

Few, if any, ordinary mineral collectors write memoirs. These reminiscences, spanning the years 1917-80, were drawn to my attention by Mr Nigel Lowson, Head of Geography at Tonbridge School in Kent, where Robert Shrimpton was a pupil in 1918-21, and where his collection is now housed. Until he retired in 1964, Shrimpton worked as a chartered accountant of I.C.I., which took him to the Far East and various parts of Britain. It was in Britain, particularly in Cornwall and the north of England, that he did most of his collecting, starting at the age of 12 while on holiday in Cornwall. The localities he mentions will be familiar to many of our readers, and his account provides a fascinating glimpse of collecting in the mid-part of this century, when there were still mine managers and miners to talk to, and when you could spend three weeks in the Lake District without meeting another hammer-wielding collector! The collection to which Shrimpton devoted so much loving care may be unremarkable in terms of specimen quality, but it is well arranged and documented and, in its present resting place, may help to spark off an interest in minerals and earth sciences in future generations. For reasons of space the story is being printed in two instalments. I thank Roy Starkey for helping to edit Shrimpton's original typescript.

Editor

A CHANCE ENCOUNTER

When my father died in 1917 at the early age of 53, my mother was left with a considerably reduced income with which to bring up four children – myself, aged 12, John, aged 10, Ann, aged 6 and Frank, aged 4. Economy was the order of the day and at first my mother thought that a holiday by the sea would be too expensive. However, one of my mother's friends offered to rent us, for the month of August, a three-bedroom furnished house, within a few yards of the sea, at Port Gaverne, just over the hill from the fishing village of Port Isaac, on the north coast of Cornwall. The rent was to be three and a half guineas a week. So began our long love affair with Cornwall and thereafter we returned to Port Gaverne for our family holiday every year up to and including 1927.

At this time my brother John collected butterflies. One morning he announced his intention to walk up the valley from Port Gaverne in search of butterflies. I was not interested in butterflies, but I was quite willing to explore the valley and so we started off together. After a few hundred yards the valley broadened and butterflies appeared amongst some rushes by the stream. John got to work with his butterfly net and I wandered on into the next field, which sloped steeply up to the right. I noticed a heap of soil about 30 yards up the slope and, just beyond the heap, a tunnel going into the side of the hill. I entered the tunnel and walked along it until lack of light made it inadvisable to continue. Emerging again into daylight, I looked at the heap outside the tunnel. In addition to normal soil, it contained a large number of fragments of slate and something else which immediately caught my eye. It was a lump of grey metallic fibrous material accompanied by white vein quartz. I took it home and asked a local man what it was. 'Antimony', he replied. He told me that the mine up the valley was the Bodannon mine, and that there were a number of other small antimony mines in the area, although he could not say exactly where they were.

This piece of jamesonite was my first mineral specimen, and I was now eager to collect specimens of other materials from other mines. But first I had to find out where the old mines were, and none of the local residents with whom I had contact was able to help me. Eventually I purchased a copy of the Geological Survey Memoir on the Padstow-Camelford area which had been issued in 1910. It contained a schedule of mines, with brief notes on the metals they produced, but no indication of the precise locations. For this information I had to wait until I was able to obtain copies of the Special Reports on the Mineral Resources of Great Britain, a series of which was issued by the Geological Survey during the period 1919 to 1927.

EARLY DAYS IN CORNWALL

During the next few years I did what collecting I could in the area within walking or cycling distance of Port Gaverne. When we arrived for our holiday in 1918 I noticed, when I looked up the valley, the top of a chimney which had certainly not been there in the previous year. I took an early opportunity to investigate and about a mile from Port Gaverne, a little way beyond Bodannon mine but on the other side of the stream, I discovered Treore mine, which was being worked for arsenic – a commodity then much in demand for war purposes. The mineral being mined was arsenopyrite. On arrival at the surface the ore was crushed and then roasted in a small furnace, yielding arsenious oxide vapour which was led up the hillside through a long brick-built chamber terminating in the chimney that I had seen from Port Gaverne. The arsenious oxide was deposited on the inside walls of the chamber as a white powder which was collected periodically by men wearing face masks, packed in barrels, and despatched to the various users.

In addition to the arsenic lode there was also an antimony lode, the minerals from which were thrown on to the mine dumps because there was then no market for them. From these dumps I obtained, over the next few years, both arsenopyrite and various antimony minerals, including jamesonite, boulangerite and bournonite.

When I first visited Treore mine, the mine manager was quite happy for me to take what specimens I wanted from the mine dumps. In the course of our conversation he told me he and his men had obtained small quantities of gold from the stream which flowed down the valley. For this purpose they had diverted the stream for a short distance and worked the stream bed dry. He had sent some of this gold dust to the Natural History Museum in South Kensington. In later years, when I was an articled clerk in London, I used to visit the Mineral Gallery of the Natural History Museum from time to time and there – sure enough – was a small glass phial containing gold dust which was stated to have come from Treore Creek.

Treore mine had been opened to provide arsenic for war purposes. By 1920 it had been shut down and, so far as I know, was never reopened. Now that I had the place to myself I decided that I, too, should try my hand at panning for gold, and I purchased a 'prospector's pan' in London. Armed with this and a small shovel I walked to the mine and chose a spot where there was a miniature beach of sand at a bend in the stream. I shovelled this sand into the pan, half filled it with water and swilled the mixture in the time-honoured way so that the lighter particles of sand would be thrown over the side of the pan leaving behind, hopefully, particles of gold. Alas, no such particles appeared but I can always say that, like so many prospectors in so many countries, I too have panned for gold.

Our favourite places along the coast for picnics and bathing were Barrett's Zawn, about 3 miles east of Port Gaverne, and Lundy Bay, about the same distance to the west. In Barrett's Zawn I discovered nests of crystals of arsenopyrite in the slate cliffs on the east side of the bay, but there was no sign of a mineral vein. On the way to Lundy Bay we had to pass along the seaward side of a wall which had been largely built of material from the waste dumps of an old copper mine which, years later, I discovered to have been Gilson's Cove mine. From this wall I collected, over the years, good specimens of chalcopyrite and galena. I never found the actual mine.

Other mines from which I collected specimens during the early 1920s were Treburgett and Pengenna mines near Port Isaac Road railway station, and Trevinnick mine about a mile ESE of St Endellion Church. From Treburgett Mine, which was still working when I first visited it, I obtained good specimens of galena, pyrite and ankerite. From the dumps of the old Pengenna mine I obtained clusters of leaf-shaped crystals of siderite, and from Trevinnick mine clusters of pale green barrel-shaped crystals of pyromorphite. The furthest point which I reached by bicycle was Buttern Hill mine on the northern edge of Bodmin Moor. This mine had been worked for tungsten during the 1914-18 war and, when I visited it, had only recently been abandoned. From the waste dumps I collected good specimens of wolframite with associated vein quartz.

During our early holidays in Cornwall my only means of transport was a bicycle, but in 1924 I acquired a second-hand motor-cycle which considerably enlarged the scope of my mineral hunts. I was now able to visit the old copper mines on the south-eastern edge of Bodmin Moor and the granite boss of Kit Hill some six miles further to the east. I found many specimens in these areas but very few with what I would call 'display potential'. My most rewarding visit during those years was to the Castle-an-Dinas mine situated on a small boss of granite about three miles ESE of St Columb Major. The granite had been penetrated by veins containing wolfram and I collected good specimens of this mineral from the mine dumps.

FORMATIVE YEARS

At this point I must leave Cornwall and refer, briefly, to the question of my career. In his will my father had set aside funds to send his sons to public school – a privilege which had been denied to him – but there were quite insufficient funds to provide for his sons to go to the sort of preparatory schools which intending public schoolboys usually attended. And so John and I went as boarders to Magdalen College School, Brackley, which provided an all-round education, largely to sons of local tradesmen and other residents, at a relatively low cost. For me this proved a great advantage because I received a good all-round education in a range of subjects, including chemistry, which I should certainly not have received at a preparatory school. In fact, chemistry became my favourite subject, and when in 1918 I went on to Tonbridge School, I had already decided that I wanted to be a mining engineer, and aimed to go to the Camborne School of Mines in Cornwall. That I did not do so arose from the fact that I was the eldest son and was expected to make money for the family. My mother turned for advice to her eldest brother, who was the Chief Engineer of the Madras and Southern Mahratta Railway, on leave from India. He poured scorn on the idea that I should become a mining engineer and said to my mother: 'Make him a chartered accountant. They always make money.'

My fate was sealed and, in January 1922, I commenced a five-year term of service as an articled clerk with a long-established firm of chartered accountants in London. For five long years I became, in effect, a human adding and ticking machine, but my work as a junior audit clerk visiting various companies did, in fact, provide two mineral specimens for my collection. At the offices of the Bertam Consolidated Rubber Co. in the City I saw a few sacks containing rock samples and asked what they were. I was told they had been collected by a prospector in Malaya and were supposed to contain gold, and I was allowed to take any specimen I wanted for my collection. I selected the best specimen of the lot – a nice piece of white vein quartz with scales of yellow metallic gold. At the offices of the Agent-General for Western Australia in the Strand, specimens of the minerals found in that territory were displayed, including a large one of white, silky chrysotile asbestos, and the Agent-General was good enough to give me a specimen of this mineral.

I received two more gifts of minerals during these years in London. Jack Irwin, with whose parents I often played tennis, came to visit them in 1926. He had just qualified from the Camborne School of Mines and was about to leave England to take a post in Malaya. He had with him a few mineral specimens which he had acquired during his time in Cornwall and these he now gave to me. They included nice specimens of covellite, hematite, 'smoky' crystalline quartz, a single transparent pyramidally terminated crystal of quartz, and a large group of sheaves of brown platy biotite mica.

Since I could not myself become a mining engineer I decided to obtain some qualification in the field of mining and metallurgy, so that I might still be able to enter the mineral industry through the accountancy back door. I therefore enrolled at the Sir John Cass Technical Institute for a course in the Metallurgy of Non-ferrous Metals during the winter of 1925/26. On this course I met one young man who gave me a nice specimen of lazurite ('lapis lazuli') for my collection. He could not tell me the origin of the specimen, but it almost certainly came from Afghanistan.

Also in 1926 I became a member of the Geologists' Association, but I attended only one field meeting, at Godalming in Surrey. On this meeting I obtained a specimen of shining black goethite, although I have no record of the precise location from which it came.

NEW HORIZONS

Having passed my Final Accountancy examination in May 1927, I started to look for a suitable job overseas. Eventually I accepted the offer of a job by Imperial Chemical Industries as Assistant Accountant to I.C.I. (India) Ltd in Calcutta, and I sailed for India the following January. Calcutta is situated in the middle of the Ganges delta and I made no additions to my collection while I was there. After two years I was offered the post of Secretary and Accountant to a new company to be formed in Malaya – I.C.I. (Malaya) Ltd – with its headquarters in Singapore. I returned to England in January 1930 to await instructions, with plenty of time for holidays and mineral hunts.

My mother was then having a cottage built for her on the cliff which separates Port Isaac from Port Gaverne in north Cornwall, and when the cottage was completed in March I took my mother and youngest brother to Port Isaac for the month of April, travelling in the new car which I had purchased. During this holiday I visited the old copper mines on the south-eastern edge of Bodmin Moor. From Wheal Phoenix dumps I obtained a good specimen of malachite, and from the dumps of the old South Caradon mine specimens of dark green nodular banded chlorite. Proceeding south to the lead mining area around Liskeard, I found good baryte crystals implanted on a calcareous veinstone on the dumps of Wheal Ludcott. On the return journey I visited the old Restormel iron mine near Lostwithiel, where I found nice specimens of hematite and goethite.

It was during this holiday in Cornwall that I drove to Exeter with my mother, primarily to obtain a cabinet of some kind in which to keep my minerals. In a shop in one of the back streets I found a suitable chest with 12 large drawers, priced at £5. On top of the chest was a large lump of dull red mamillary hematite which the shopkeeper agreed to let me have for nothing if I bought the chest – which I did. The specimen almost certainly came from the iron mines of west Cumbria.

In July 1930 I was sent on a temporary assignment to Java, in connection with the purchase of a Dutch company which owned a phosphate mine there. I visited all the branches of the company, including one at Medan in northern Sumatra. My visit to Medan included a week-end as the guest of the Medan office manager at Brastagi – a hill station about 40 miles from Medan. Within a mile or two was the volcano Sibajak and we climbed it during the early hours of Sunday morning. The active crater at the summit was inaccessible but, a little below, there was an old crater which contained several active solfataras. These emitted large jets of steam at high pressure and their lips were lined with thick crusts of yellow crystalline sulphur, specimens of which I collected. In December I moved to Singapore as one of the three founder members of I.C.I. (Malaya) Ltd and remained there until my first home leave in 1934. This period yielded only a single mineral specimen for my collection, from a Chinese gentleman who gave me a piece of black magnetic iron ore (magnetite) which – so he told me – came from Borneo.

In March 1934 I returned to England for six months leave, during which I met again, at her home in Solihull near Birmingham, the lady who was to become my wife. (I had first met her during my years as an articled clerk in London in the 1920s). We were married in Solihull in July, and after the wedding we drove to the Armathwaite Hall Hotel at the northern end of Bassenthwaite Lake in Cumbria. This was not the time for mineral collecting but our honeymoon did, in fact, provide me with several specimens. One of the first things I noticed on arrival at the hotel was a small collection of large-sized mineral specimens lying in a group on the ground outside the front door. When the hotel manager learnt that I was a collector of minerals he gave me the lot - a very acceptable wedding present! They included three excellent specimens of black reniform hematite and a group of off-white crystals of calcite, almost certainly from the iron mines of west Cumbria. On our way back we drove through Weardale and stopped for lunch at an inn in St John's Chapel. Here again there was a mineral specimen on show - part of a translucent cube of purple fluorite from one of the local mines - and again the proprietor gave it to me as a present.

In August we sailed from Southampton on our journey to Singapore. My second term of service here yielded no mineral specimens. For reasons which need not concern us here I resigned my post at the end of my 3-year term and returned to England in 1937 without a job. Fortunately I.C.I. was able to offer me a post in the Pensions department at its head office in Millbank, which I accepted and kept for two years. During 1938 I visited two of the northern Divisions of I.C.I. – the Alkali Division at Northwich in Cheshire, and the Billingham Division in Co. Durham. While at Northwich I was able to go down the I.C.I. rock salt mine at Winsford, and this provided me with good specimens of halite. At Billingham I was able to go down the anhydrite mine on the factory site and here I was given a specimen of grey-green massive anhydrite.

Also in 1938 my wife and I went on holiday with our children to Port Isaac, travelling by train both ways. For visiting mine dumps I took with me a second-hand bicycle which cost me just under £2. I revisited Treburgett and Pengenna mines, which had been worked intermittently during the preceding ten years. From Treburgett dumps I collected good specimens of ankerite and other minerals, and at Pengenna I found an excellent specimen of white vein quartz on which was emplanted a cluster of small crystals of bright green pyromorphite. I also discovered two localities near Port Isaac of which I had hitherto been unaware. The first of these was the old and famous Trewetha mine, or Wheal Boys, which had been worked for antimony at various times during the 19th century and earlier, and where I was able to obtain good specimens of stibnite, bournonite and jamesonite. The other previously unvisited locality was Tartar Beach, about a mile east of Port Isaac. I had passed along the cliffs overlooking this beach in previous years but had never bothered to go down to it. When I did so, I found the western end littered with vein material from which I obtained a good specimen of dolomite. On the cliffs above the beach immediately to the west I discovered rabbit holes in which stringers of grey metallic jamesonite had been exposed.

NORTHERN OUTLOOK

At the end of 1939 I was posted to Northwich in Cheshire, and moved with my family into half of a very large mansion with three floors and 12-foot ceilings. The other half was occupied by an auctioneer and his wife and, through occasional purchases at his auction sales, he made some small contributions to my mineral collection. These included two specimens of transparent cubic fluorite and two reniform nodules of hematite. There was, of course, no record of the mines from which the specimens had come.

During my six years at Northwich I made several trips to old mines, relying partly on the railways and partly on my bicycle. On day trips from Northwich I visited the old copper mines at Alderley Edge in Cheshire, the old Shropshire lead mines, the Derbyshire fluorspar mines, and the old Moel Hiraddug iron mine in Flintshire. At Alderley Edge in 1941 I obtained, from an adit of the old Wood mine, interesting specimens of Keuper sandstone impregnated with malachite and azurite. In Shropshire I obtained good specimens of galena and baryte from Snailbeach mine and good specimens of baryte from Huglith mine. Also at Huglith I found, in a wooden shed which had been the mine office, good specimens of chalcocite with a deep blue tarnish. In June 1943 I left the train at Edale in Derbyshire and cycled to the old fluorspar ('Blue John') mines a mile or so west of Castleton. Avoiding the official 'Blue John Mine' (which was, and probably still is, a trap for tourists) I made for Treak Cliff mine at the foot of Mam Tor. An adit leading into the mine from the road was completely blocked by soil and vein material but from this unpromising pile I secured excellent specimens of deep purple-blue crystalline 'Blue John'. From dumps on the opposite side of the road (the old Odin mine) I obtained groups of small colourless to pink cubes of fluorite and also a good specimen of white crystalline calcite. My last day trip, in 1945, was to Moel Hiraddug iron mine, on a hill about three miles east of St Asaph in north Wales. Here I obtained specimens of hematite. On the way back to Holywell to catch a train home, I stopped for a cursory examination of some of the waste dumps of the old Parry's mine, Halkyn. Within a few minutes I found a perfect transparent rhombohedron of calcite in which tiny crystals of chalcopyrite had been emplanted along one of the cleavage planes.

There were also holidays and other opportunities to collect minerals during the war years. A fortnight's holiday at Barmouth in Merionethshire in 1940 enabled me to cycle to the old Panorama copper mine east of Barmouth, where I obtained good specimens of chalcopyrite and pyrrhotite, and to Clogau mine which, in the past, produced not only copper but gold. However, the Clogau dumps were disappointing and I found no gold. On holiday in Anglesey in 1941 I collected a few specimens from both the ancient Parys copper mine and the more recent Rhosmynach mine, but none suitable for display. On another holiday, at Rhos near Llandudno, I took a bus to the old lead-mining area west of Llanrwst. From the waste dumps of the Hafna mine I collected 'cockscomb' crystals of marcasite, and from those at Trecastell mine, specimens of sphalerite and calcite.

In 1942 I had to visit a wartime factory producing bromine at Hayle in Cornwall. I stayed at the Carbis Bay Hotel on the west bank of the Hayle estuary, and each day took the ferry boat across the estuary to the bromine plant. I was always the only passenger and accordingly I got to know the ferryman quite well – a rugged old Cornishman who had been a miner in Chile and other countries. After our last crossing he invited me to his 'cabin', a large dark shed full of fishing gear, where he emptied a very rusty tin box on to the table. 'They are all yours', he said. 'I have no use for them any more'. 'They' included three good specimens of native copper from Chile, one of pyrite from Bolivia, and other specimens of lesser interest.

In 1943 I devoted the whole of my three weeks' annual holiday to collecting minerals in the Lake District. Having studied the Reports on the Mineral Resources of that area I decided to concentrate on the Caldbeck Fells and accordingly, with my bicycle and big black kitbag issued to me as a member of 'Dad's Army', I booked a room at an inn close to Troutbeck station. I started with Carrock mine, which had recently been worked for wolframite and scheelite, and I found many specimens of both minerals on the dumps. Several visits to these dumps produced specimens of molybdenite, pyrrhotite, arsenopyrite, dolomite, hornblende, and large crystals of quartz. These large quartz crystals had been much in demand for war purposes on account of their piezo-electric properties. A little over a mile north of Carrock mine I scratched the dumps of Roughtongill and Drygill mines, which had long been abandoned. Roughtongill was disappointing, but Drygill provided me with good specimens of pyromorphite and mimetite. Outside Caldbeck Fells I visited Force Crag mine in the heart of the hills between Derwentwater and Crummock Water. This was an old lead and zinc mine and the waste dumps provided good specimens of sphalerite and psilomelane. I also collected graphite from the old plumbago mine in Borrowdale – a large collection of small pits in the fells immediately north of Seathwaite village, from which graphite ('plumbago') had been extracted in past centuries.

There were, of course, some wet days during my stay at Troutbeck. On one of these I visited Keswick Museum, and noticed that they had lovely specimens of mimetite, pyromorphite and linarite from the Caldbeck Fells mines, but no specimens of wolframite, scheelite or molybdenite from Carrock mine. This gave me an idea and I made a bargain with the Curator – I would bring him good specimens from Carrock mine and, in return, he would give me good (but not the very best) specimens of the lead and copper minerals. I think both of us gained from the exchange. On another occasion I noticed two good specimens of calcite in the window of a jeweller's shop in Keswick and purchased them. They had come from Greenside mine near Glenridding. At the end of this holiday I returned to Northwich with the biggest and heaviest load of specimens I have ever collected at any one time.

While I was at Northwich I received three gifts of minerals from members of the I.C.I. staff. The first was a good specimen of trona from Lake Magadi in southern Kenya, where this mineral was extracted by a subsidiary company of I.C.I. Another was a good specimen of labradorite feldspar from a quarry in Labrador, Canada, from which the mineral takes its name. Finally, the manager of the bromine plant at Hayle which I had visited earlier sent to me by post a small piece of uraninite from an undisclosed Cornish locality.

In 1945 I received my largest single gift of minerals. My sister Ann had married Paul Hummel, a young doctor in the Royal Navy. Paul's father was Professor of Mining at Leeds University, who had spent a year at the Mining School at Příbram in Bohemia – then a province of Austria but now part of Czechoslovakia – where he made a collection of minerals. He had given the bulk of these to Leeds University but had kept some for himself. They had lain in the attic for over 40 years and he now presented them to me. They included outstanding specimens of stibnite and good specimens of galena, sphalerite, boulangerite, baryte and many other minerals.

(To be continued)

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ORIGIN OF THE LEADHILLITE POLYMORPHS

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The three polymorphs of $Pb_4(SO_4)(CO_3)_2(OH)_2$, i.e. leadhillite, susannite and macphersonite, occurring on the same small specimen raises questions about their mode of origin. In spite of the vast number of lead deposits throughout the world that contain both secondary anglesite and cerussite, the occurrence of the leadhillite polymorphs is extremely limited. For these polymorphs to form, a critical change in the ratio of sulphate to carbonate activities is essential. Other possible controlling factors, in association with the sulphate and carbonate activities, are pressure, temperature, and anion substitution.

INTRODUCTION

The polymorphs of $Pb_4(SO_4)(CO_3)_2(OH)_2$, i.e. leadhillite, susannite and macphersonite, occur within a few millimetres of each other on the type specimen of macphersonite from Leadhills Dod, Leadhills, Strathclyde Region, Scotland. Additionally, they form part of a secondary suite at the Argentolle mine, near Saint Prix, Saône-et-Loire, France (Livingstone and Sarp, 1984). A macphersonite crystal group (<2 cm, specimen RMS G.1991.31) from the Leadhills-Wanlockhead district contains a small quantity of adhering leadhillite. Three polymorphs occurring on the same specimen raises questions about their stabilities and ultimately their origin.

CHEMICAL RELATIONSHIPS

Garrels and Christ (1965) addressed the problem of coexisting secondary lead minerals and a simplified version of their stability field diagram is reproduced in Fig. 1. This reveals that at 25° C and one atmosphere pressure a change from sulphate to carbonate mineralogy takes place at pH 6. Anglesite and cerussite are common secondary minerals in many lead deposits throughout the world. For example, at the 79 Mine, Gila Co., Arizona, galena altered directly to cerussite, or to anglesite which became surrounded by cerussite (Keith, 1972). Leadhillite and susannite are not known from the 79 Mine. Macphersonite is known only from Leadhills-Wanlockhead (two crystals), Saint-Prix, and Caldbeck Fells in Cumbria (Cooper et al., 1988), while leadhillite and susannite also are reported from only a few localities throughout the world, a situation which contrasts markedly with the number of lead deposits. It appears that these rare polymorphs must require highly restricted conditions for their formation. Ideally, $Pb_4(SO_4)(CO_3)_2(OH)_2$ contains 7.4 wt.% SO_3 and 8.16 wt.% CO_2, whereas anglesite contains 26.4 wt.% SO_3 and cerussite 16.47 wt.% CO_2. As sulphate activity* decreases in the solutions responsible for secondary mineral formation, carbonate activity would begin to rise; thus formation conditions must lie somewhere along the anglesite-cerussite field boundary.

Using solution chemistry, Abdul-Samad et al. (1982a) obtained a series of reversible reactions, mineralogically summarised below, which were dependent upon the activity of H_2CO_3 (carbonic acid). The stability fields of these minerals must also be controlled by H_2CO_3 activity. Chemically susannite and macphersonite can be substituted for leadhillite in the simplified reactions represented below, although the equilibrium constants will be different.

anglesite ⇔ leadhillite
anglesite ⇔ hydrocerussite
leadhillite ⇔ lanarkite
leadhillite ⇔ hydrocerussite
lanarkite ⇔ hydrocerussite

In addition, Abdul-Samad *et al.* (1982b) showed that the cerussite boundary is not simple but contains an intermediate leadhillite field (Fig. 2). Phosgenite is unknown from the Leadhills-Wanlockhead orefield whereas paralaurionite has only been described in a slag assemblage of secondary minerals (Green, 1987). Cotunnite is the only lead chloride reported from the area (Temple, 1956) although it is noteworthy that some leadhillite contains up to 0.5 wt.% Cl (*author's unpublished data*).

From a chemical point of view the stability fields of all three polymorphs must lie between the anglesite and cerussite fields. It may well be that each phase has an extremely narrow stability field within the leadhillite field (Fig. 2). Low temperature formation of lanarkite, leadhillite and susannite in sea-water on ancient slags at Laurion, Greece, has been reported (Schnorrer-Köhler *et al.*, 1982a, 1982b). Further investigation may reveal the presence of macphersonite also.

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* The activity of a component is a measure of its *effective* concentration

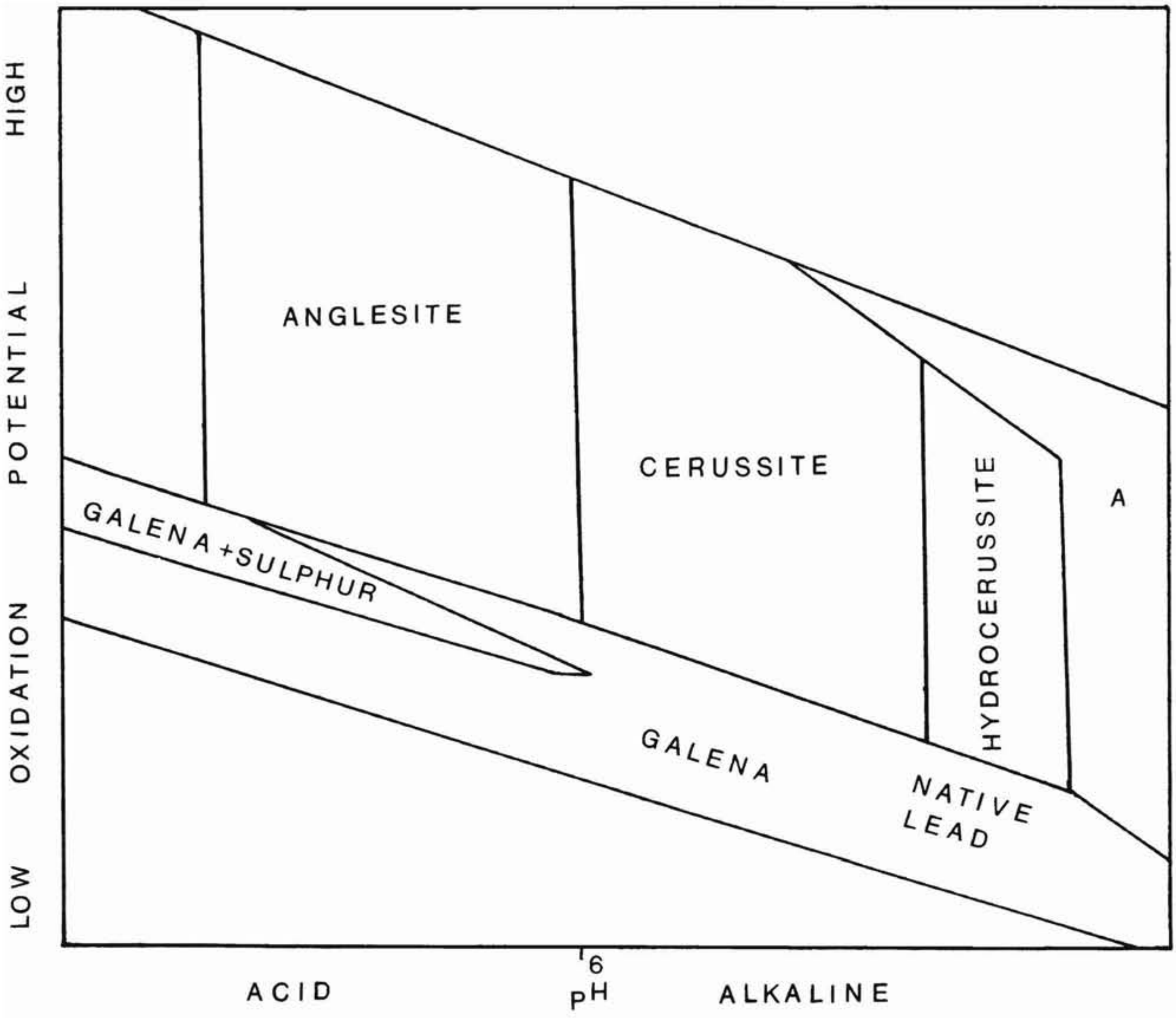

FIGURE 1. Stability fields among lead minerals in water at 25° C and 1 atmosphere pressure. A = field of lead oxides. (Adapted from Garrels and Christ, 1965).

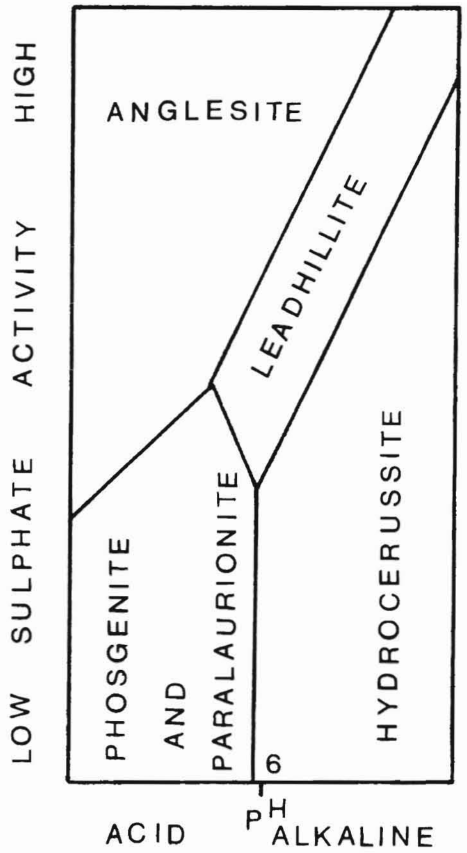

FIGURE 2. Stability fields of lead minerals with chlorine introduced into the system. (Adapted from Abdul-Samad *et al.*, 1982b).

PHYSICAL RELATIONSHIPS

In a vein system, superimposed upon the strict chemical controls outlined above, would be a temperature-pressure regime. Temperatures may vary because of an influx of new, warmer solutions from depth, or mixing with cooler percolating groundwaters. As solutions course through vein systems, throttling due to physical restrictions would increase pressures.

A metastable leadhillite phase derived by heating susannite at 35° C changes, with time, to stable leadhillite (Milodowski and Morgan, 1984). The susannite structure is the most disordered of the polymorphs although it is almost identical with that of leadhillite. Susannite, when heated from room temperature, shows the leadhillite-susannite inversion peak at 88° C (A. Livingstone, *unpublished work*) and thus may also exist as a low temperature metastable form. The hypothetical temperature-pressure phase diagram depicted in Fig. 3 shows the leadhillite, susannite and macphersonite fields, their areas corresponding to their relative abundance. It is well established that metastable phases exist close to field boundaries and thus, for three polymorphs to exist on one specimen, the pressure-temperature conditions must have been close to the triple point location. At this stage no assessment of pressures and temperatures can be made, although Leadhills-Wanlockhead primary sphalerite formed between 280 and 140° C (Temple, 1956). The formation temperatures for the leadhillite polymorphs would be considerably lower, possibly even lower than the inversion temperature.

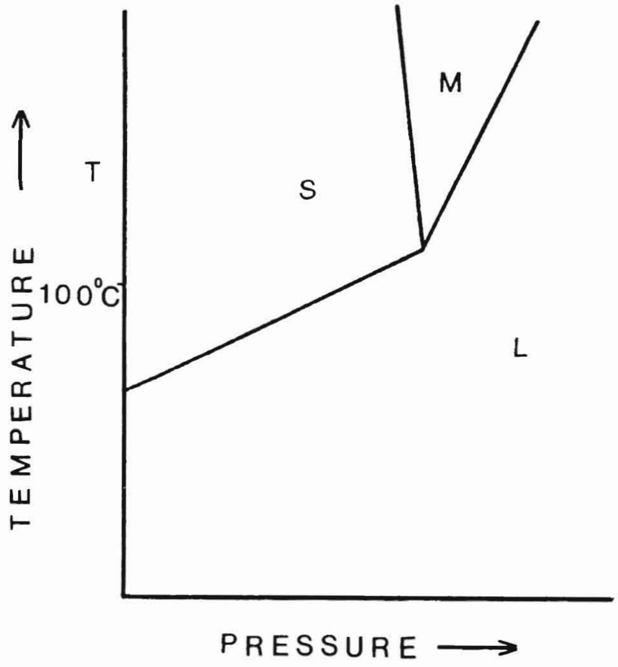

FIGURE 3. Hypothetical pressure-temperature diagram showing the fields of leadhillite (L), susannite (S) and macphersonite (M).

Another possible controlling mechanism is anion or cation substitution. The sulphate/carbonate ratios in leadhillite vary slightly owing to mutual replacement (Russell *et al.*, 1983). Although there are slight but not consistent differences in the sulphate/carbonate ratios within the analysed polymorphs, no significant differences could be detected between the species – the differences are within analytical error. Copper is the most abundant trace element detected in the polymorphs, amounting to approximately 0.1 wt.% CuO. Again, no significance can be attached to the small variations detected, and hence copper as a stabilising element cannot be considered responsible, at this stage, for determining which particular structure crystallised. If substitution is a major factor it may well be that the cation/anion ratios are critical as to which substitution controlled structure forms.

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THE OCCURRENCE OF SPHALERITE IN LEICESTERSHIRE, ENGLAND

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Sphalerite, although a relatively common mineral in Leicestershire, is nevertheless geologically restricted to the time interval of Lower Carboniferous to Lower Mesozoic. Its occurrence in the Lower Carboniferous is limited to a single locality, Earl Ferrers' mine in the little valley known as Dimminsdale, near Ashby-de-la-Zouch. It occurs in the Leicestershire Coalfield throughout the geological succession exposed there in mines and opencast coal sites, where it forms platy crystals in septarian siderite-mudstone nodules. In the Lower Mesozoic clay facies, it is also present in the septa of siderite-mudstone nodules. Localities take the form of temporary exposures, but on faunal evidence the beds from which the large majority of sphalerite-bearing nodules come range from the upper part of the Sinemurian to the *A. margaritatus* zone in the upper Pleinsbachian of the Lower Jurassic. Partial analyses for iron and cadmium are provided together with a complete bibliography of occurrences of sphalerite in the county.

INTRODUCTION

Sphalerite is quite a common mineral in Leicestershire but is restricted to the geological time interval between and including the Lower Carboniferous and the Lower Jurassic. A similar format has been chosen to describe the occurrence of sphalerite in Leicestershire to that used in a previous paper on the occurrence of galena in Leicestershire (King, 1983). The sketch-map (Fig. 1) shows the principal localities mentioned in the text.

HISTORY

The first reference to its occurrence in the county is that of Sowerby (1806, vol. 2, p. 107) in his description of hemimorphite from Dimminsdale. This ancient mine, also known by other names such as Earl Ferrers' mine and Staunton Harold, is situated 5.5 km NNE of Ashby-de-la-Zouch parish church at National Grid Reference SK 376 217. In his description, Sowerby refers to the presence there of 'the sulphuret of zinc'. Farey (1811, p.406) lists 'Staunton-Harold, Leicest.' as one of the localities where 'Black Jack, or Blende' is found, and mentions Staunton Harold twice in the 'List of mines of Lead, Zink, etc.', first (p. 257) as 'Dimsdale in Calke, adjoining Leicestershire - Lead, Black Jack', and secondly (p. 267) as 'Stanton Park, in Stanton Harold, Leicestershire - Lead, Black Jack, Pyrites'. Phillips (1823, p. 355) records blende in the mines of Earl Ferrers, and Hull (1860, p. 16) provides the first useful account of the geology of the Dimminsdale inlier, mentioning blende as one of the minerals occurring there. This is repeated, word for word, by Ansted (1866, pp. 22, 62). Hall (1868) also noted the presence of blende at Staunton Harold, although he was a little uncertain of the details of the locality.

The first record of its occurrence in Mesozoic strata is that provided by Judd (1875, p. 69). Describing a section in the blue clays of the *A. margaritatus* zone, on the north side of the main Leicester to Uppingham road in the village of Billesdon, he notes large flat septarian nodules at the base of the section. These nodules contained 'Specular iron, zinc-blende and Pyrites'. The mention of specular iron (hematite) is interesting as other workers subsequently reported it at much the same horizon elsewhere. No confirmatory evidence is forthcoming, however. Harrison (1877a, p. 39) records specular iron not only at Billesdon, but also at Ouston (Owston), Cranoe and Neville Holt. Although his description, 'thin small plates of a dark lustrous hue', could apply to specular hematite, the writer considers this to be an original mistaken identification of sphalerite, subsequently perpetuated. To the writer's knowledge, specular hematite is unknown in this Liassic environment. Furthermore, examination of mineralized septarian nodules from the localities mentioned by Harrison yielded no specular hematite, although sphalerite was abundant. Harrison (1877a, p. 16; 1877b, p. 129) also speaks of blende occurring at 'Dimmingsdale'. Woodward (1881, p.89) lists blende at Staunton Harold, and again (p. 258) at 'Diminsdale'. Woodward (1893, p.237) quotes Judd (1875), repeating the mis-identification of sphalerite as specular iron. He describes 'thin laminae of Specular Iron' occurring in the highest beds of the Lower Lias, and again in the *A. margaritatus* clays, at Cranoe, Belton and Hallaton.

Binns and Harrow (1897, p. 252) provide the first account of any value of the several minerals found in Netherseal Colliery, including sphalerite associated with siderite mudstone nodules at numerous horizons in the Coal Measures. They also provide an analysis (Zn 63.20, Fe 2.11, Ca 0.50, Mg 0.36, S 33.91, sum 100.08) and note that a 'minute yellow precipitate, too small for identification, was considered to be probably cadmium'. Harrison's account in White's Directory

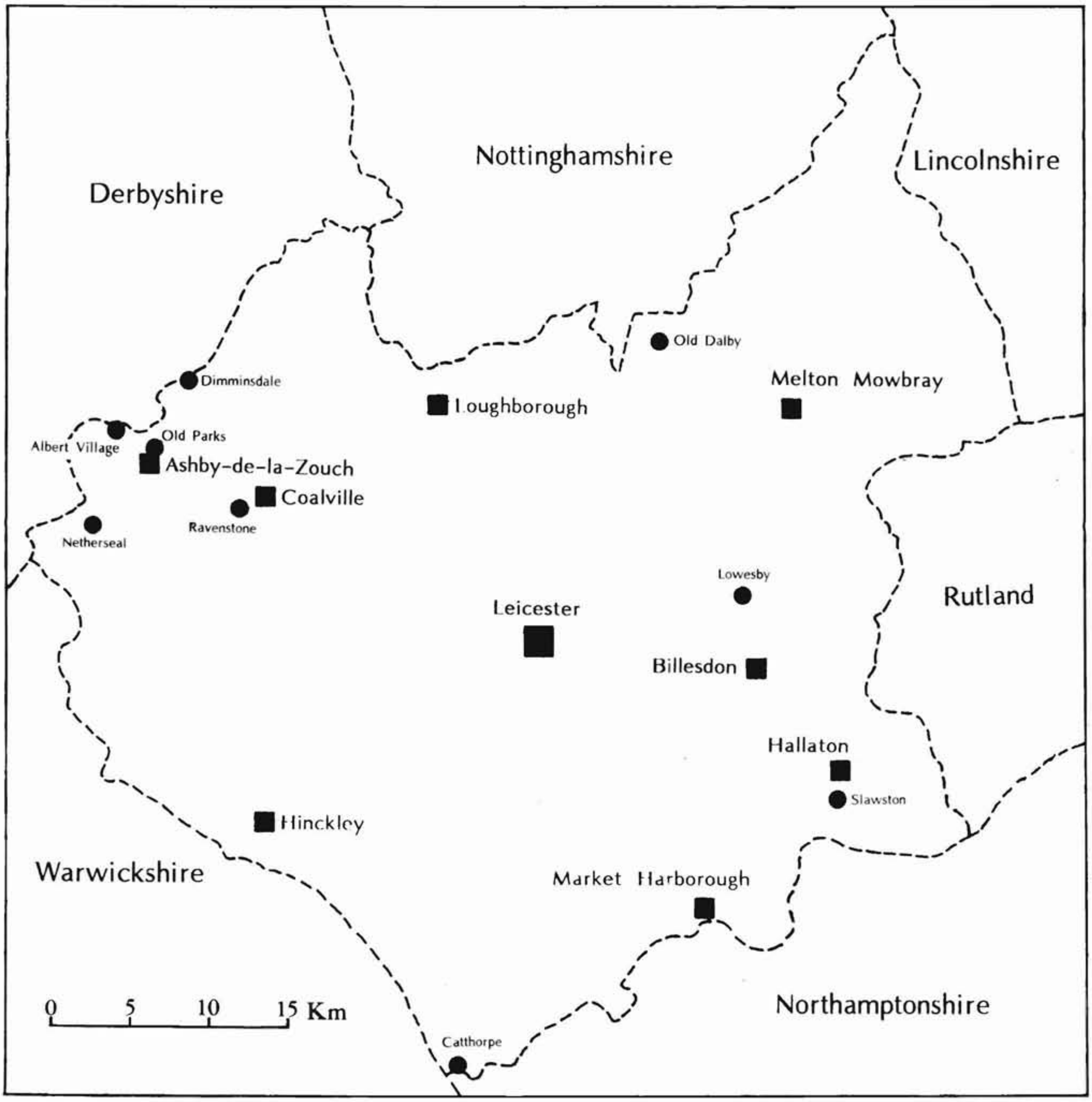

FIGURE 1. Map of Leicestershire showing sphalerite localities mentioned in the text. (Rutland was incorporated into Leicestershire in 1974).

(1877a) was repeated in Kelly's Directory (Harrison, 1904, p.11). Rudler (1905, p.178) quotes Hull's remarks (1860, p.16) on the occurrence of sphalerite at Staunton Harold, and Fox-Strangways and Horwood (1907, p.110) repeat Binns and Harrow's account at Netherseal, including the analysis. Horwood (1908, p.148) records sphalerite occurring in plant-bearing ironstone nodules in the coalfield, especially at Donisthorpe. There is a mention of blende occurring at Staunton Harold in Sylvester-Bradley and King (1963, p. 729). Sphalerite, associated with calcite and pyrite, occurred in septarian cracks within flattened siderite-mudstone nodules in a section 3 m thick of grey Lower Lias clays cropping out on the south bank of the River Welland, 1200 yards NE by N of Rockingham Church (Taylor *et al.*, 1963, p. 30). Ford (1968, p. 123) speaks of chalcopyrite and sphalerite being 'found recently in septarian nodules in fireclay near Ashby-de-la-Zouch'. King (1968, pp. 130, 132, 135) records sphalerite in very well crystallized minute but brilliant tetrahedra at Staunton Harold, and in large brilliant black plates in the Lias. One of the localities for the latter is given as the abandoned railway cutting near the site of the former Lowesby railway station. The 64th Annual Report of the Leicester City Museum for 1969-70 refers to the finding of an ironstone nodule containing sphalerite from the Middle Lias at Slawston (Accession No. 332'1970). The latest report is of sphalerite found in 1988 at the opencast coal site at Ravenstone, near Coalville (see below).

OCCURRENCE IN LOWER CARBONIFEROUS

STAUNTON HAROLD (DIMMINSDALE)

Although the sphalerite occurrence at Staunton Harold cannot compare with the magnificent development of crystallized groups from such localities as Hagg's mine at Nentsbury in Cumbria, nor with the enormous size of crystals from Leadhills in south Scotland, it is, nevertheless, a remarkable occurrence. It takes two forms, one a modification of the other. In neither case have single crystals developed and complex and multiple twinning is paramount.

The first and most common type is that of rosettes up to 4.1 mm across of tetrahedral forms, forming polycrystalline surfaces. Each rosette may be made up of a maximum of 12 individuals. The exteriors of these rosettes are quite black, but broken ones may be seen to be zoned from a central core of greyish-orange through golden to black. The variations from this are slight. The dominant forms are $\{111\}$ and $\{1\bar{1}1\}$, and all faces have a high lustre. This type is most common where the paragenetic sequence is less complicated, perhaps towards the extremity of the orebodies. Two examples of this type are lodged in the Natural History Museum in London, one labelled 'Staunton Harold, Ticknall, near Ashby-de-la-Zouch, Leicestershire. Thomas Kingsbury Colln.' (BM 1958,263), and the other collected by Sir Arthur Russell in 1940 from the reopened workings at Staunton Harold (BM 1964R,3967). Equally fine material of this same type, formerly in the British Geological Survey collections, is now also in the Natural History Museum (BM 1985MI,12353 and BM 1985MI,13033 to 13035). The City Museum at Sheffield possesses comparable fine material (I.187 and 1971.581), as does the National Museum of Wales in the King Collection (83.41G.M 5007, 83.41G.M 1283 and 83.41G.M 854).

The second, and perhaps more interesting type shows the development of polysynthetic twinning. This appears to be only the second example of macroscopic polysynthetic twinning described from the British Isles, the other being that from Gie-uisg, Caithness, north Scotland (Heddle, 1901, vol. 1, p. 22). The complex twinning described above in the first type now presents a set formula of repeated twinning on (111). Most twins are pairs, but triplets and occasionally quadruplets have been observed (Fig. 2). The surfaces of sphalerite of this type present an etched appearance to the naked eye, and are slightly undulatory or mamillated, but the individual crystal faces are planar and brilliant. In cross-section, the mamillations are seen to be made up of tabular forms radiating from a common centre, colour-zoned parallel to the outer surface. The overall colour of these remarkable surfaces is pale greyish-orange. Considerable trouble was experienced in the identification of this type, but confirmation was provided by X-ray diffraction (University of Leicester, Department of Geology, X-ray film No. 463). Several specimens are preserved, e.g. in the King Collection in the National Museum of Wales (83.41G.M 863, 83.41G.M 5005 and 83.41G.M 884); in the Natural History Museum (BM 1985Nev,209; see Fig. 3); and in the City Museum of Sheffield (1971-576 and 1971-584).

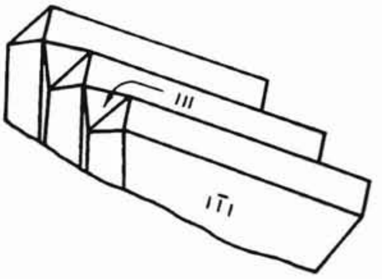

FIGURE 2. Sketch of type 2 habit of sphalerite from Staunton Harold, showing repeated twinning on (111).

FIGURE 3. Group of sphalerite crystals from Staunton Harold, repeatedly twinned on (111), associated with cubo-octahedral galena. Natural History Museum specimen (BM 1985Nev,209). Width of field 27 mm.

Electron microprobe examination of sphalerite from Staunton Harold shows that it is remarkably pure and close to the ideal composition, only a trace of iron being present in two samples, and no cadmium (G.L. McTurk, *unpublished work*).

OCCURRENCES IN THE COALFIELD

Occurrences of sphalerite in the Leicestershire coalfield are restricted to the record of Binns and Harrow (1897,

p. 252), two personal fortuitous observations, and the report of a field meeting held in 1988. Sphalerite in siderite-mudstone nodules appears to be ubiquitous at several horizons through a wide range of the Coal Measures in Leicestershire. The lack of field data simply implies lack of exposure.

RAVENSTONE

Sphalerite was observed in 1988 by members of the Russell Society when attending a field meeting at the opencast coal site at Ravenstone, 4 km west of Coalville (SK 40 13). The coal seams worked at the site were the Kilburn and Clod seams of the Lower Coal Measures.

OLD PARKS COAL PIT

A horizon rich in large septarian clay ironstone nodules, lying just above the Middle Lount Coal, was exposed in the Old Parks Coal Pit, NE of Ashby-de-la-Zouch (SK 380 183). These nodules bore proportionately large septa for the size of the nodules, most of them reaching the surface of the nodules. They were thus very brittle, and good specimens were difficult to collect. Sphalerite was the dominant mineral present, and formed large, highly lustrous, brownish-black crystalline plates, up to 3.2 mm thick and 42 mm across, lying at right angles to the septa walls. Some plates occupied the full width of a septum. The cleavage {110} was perfectly developed in these plates, and the sphalerite in these cleavages was perfectly transparent. Associated with it was clear colourless calcite, well-crystallized siderite, and films of microcrystalline kaolinite (identification confirmed by the National Coal Board, South Midland Region).

ALBERT VILLAGE PIT

Higher up the succession, in the Pottery Clay Series, a pit owned by Ellistown Pipes Ltd was opened near Albert Village (SK 301 177). In the 'Pot A' clays, septarian nodules of siderite-mudstone lie in considerable abundance 2.4 m above the Derby Coal. The septa within these nodules are barren of sulphides, but the nodules have often been cracked subsequently and sulphides have been introduced into the small-scale joints thus formed. Their development is even stronger in the non-septarian nodules. Sphalerite is the most common sulphide present, forming films up to 0.3 mm thick on the joint surfaces. Fractures and open cleavage surfaces on the sphalerite show the characteristic lustre, but the colour varies in a zonal manner, from reddish-orange next to the exterior of the nodule, to brownish-black towards the centre of the nodule. Rarely a stronger development of sphalerite occurs and veins up to 8 mm thick have been seen, containing crystals (<5 mm) showing the forms {111} and $\{1\bar{1}1\}$; they tend to be dull and malformed. Associated with the sphalerite, and obviously younger, are thin films of galena.

NETHERSEAL COLLIERY

Binns and Harrow (1897, p. 252) provided an analysis of sphalerite from Netherseal Colliery, 6.5 km south of Swadlincote. They reported 2.11% Fe and a minute yellow precipitate considered to be cadmium [sulphide] (see historical section, above). It is interesting to note that traces of cadmium have been detected by electron microprobe in sphalerite from Old Parks Pit and Albert Village, with iron below 2 wt % (G.L. McTurk, *unpublished work*).

OCCURRENCES IN MESOZOIC STRATA

As in the Coal Measures, the small number of occurrences of sphalerite observed in Mesozoic strata implies lack of exposure, and this is particularly true of the Lias, where good exposures are now rare. It occurs at many horizons, and temporary exposures often yield surprisingly good sphalerite, usually from septarian siderite-mudstone nodules. Several occurrences have been recorded and they, plus the controversial presence of 'specular iron', have already been listed in the historical section, above. Sphalerite is common in the nodules which occur in the upper part of the Sinemurian and Lower Pliensbachian, the region between the *E. raricostatum* and *U. jamesoni* zones.

Sphalerites from the localities described below were examined by electron microprobe. All showed less than 2 wt % Fe, and no trace of cadmium (G.L. McTurk, *unpublished work*).

OLD DALBY

In the railway cutting at the northern end of the Grimston Tunnel, 0.8 km SE of Old Dalby (SK 684 234), is a fine exposure of Lower Lias. Blue sandy shales, containing elliptical nodules, crop out 2.4 m up from the base of the section. These beds may be in the *E. raricostatum* zone (P.E. Kent, *personal communication*). The nodules, of various shades of dark reddish-brown, are in places septarian, the septa showing a complex paragenetic development, essentially calcite-pyrite-calcite-sphalerite. The two generations of calcite are strikingly different in colour and form, the earliest being pale brown and crystalline, the later one in white scalenohedra. The sphalerite is typical of the septarian environment, occurring in highly lustrous dark-brown plates, up to 4.3 mm across and 1.2 mm thick. Material from this locality is held in the National Museum of Wales (Field reference No. K49-30).

CATTHORPE

During the construction of the M1-M6 interchange, a 'borrow-pit' was opened near Catthorpe (SP 557 881) on the north side of the B5414 road from Catthorpe to Swinford. Faunal evidence suggests that this pit exposed Lower Lias beds lying somewhere between the *E. raricostatum* and *U. jamesoni* zones (Blake and Clements, 1988). On the NE face of the pit, a band of isolated 'cementstone' nodules was exposed, some of which were septarian in form. In the latter, primary pyrite was seen partially covered by a younger growth of a contemporaneous association of calcite and sphalerite, in plates up to 8 mm across. Material from this locality is held in the National Museum of Wales (Field reference No. K69-143 (iii)).

LOWESBY BRICKYARD

At the site of the former Lowesby Brickyard (SK 716 081), a sequence of clays and nodular ironstones, now almost completely overgrown, was formerly worked for brick and pottery clays (Judd, 1875, p. 61; Fox-Strangways, 1903, p. 27). It is thought that the beds belong to the *E. raricostatum* zone of the Lower Lias. During a preliminary examination of the site for a proposed Temporary Section meeting of the Leicester Literary and Philosophical Society, a loose flattened siderite-mudstone nodule was picked up by Dr R.G. Clements. Its exact situation in the section could not be determined, although it most likely belonged to 'Bed 6. Shales with ferruginous nodules. 6 ft' of Fox-Strangways (1903). Subsequently, a number of similarly flattened nodules were found, though not *in situ*, and 30% of those examined were found to be septariform. The septa voids were completely filled by a sequence of pyrite-calcite-sphalerite, although in some cases pyrite was absent. The sphalerite occurred as black adamantine plates, on average 7.4 mm long and 0.8 mm thick, but attractively grouped together as asterate aggregates. Cleavage plates showed that the sphalerite was translucent and reddish-orange in colour. The original nodule found by Dr Clements bore post-septarian cracks, which were occupied by fans of barian celestine (barytocelestine). This specimen is stored in the National Museum of Wales (Field reference No. K71-7).

HALLATON

A temporary exposure in the form of a deep trench was cut by British Gas in the summer of 1969, exposing many valuable sections for a very short time. In one, near Hallaton (SK 776 977), septarian nodules were found in some abundance. On faunal evidence, it is suggested that the clays in which the nodules occur are of Lower Lias age. Sphalerite was common in these septarian nodules, as black lustrous plates up to 0.8 mm thick and 4 mm long, lying randomly oriented in the colourless calcite (University of Leicester, Department of Geology, accession No. 49068).

MARKET HARBOROUGH

During the construction in 1969-70 of the new Rockingham Road bridge on the A427 at Market Harborough (SP 744 874), clays and flattened nodular limestones were exposed in the footings of the bridge. The nodular limestones, in addition to being modestly septariform, were also fossiliferous, suggesting a Lower Lias age. Their mineralogy was simple, being restricted to highly lustrous plates of black sphalerite associated with minor calcite. A specimen from this locality is lodged in the King Collection in the National Museum of Wales (83.41G.M 601, and Field reference No. K69-49).

LOWESBY AND SLAWSTON CUTTINGS

Two localities have produced abundant sphalerite from the *A. margaritatus* zone of the Middle Lias. The first was a temporary exposure in the railway cutting of the former Great Northern Line, NE of the site of the former Lowesby station (SK 735 069). Here a section was exposed by trenching in 1961, by kind permission of British Railways, who still held the property at that time. A thick sequence of blue shales and small ironstone nodules was exposed, the latter invariably septariform and filled with coarsely crystalline yellow calcite, containing embedded plates (<9 mm) of dark brown sphalerite with strikingly high lustre. A specimen from this locality is stored in the King Collection in the National Museum of Wales (83.41G.M).

A similar specimen at the same horizon and with exactly similar physical features was found in the abandoned railway cutting at Slawston. (Specimen material in Leicester City Museum, accession No. 332'1970).

DISCUSSION

The siderite-mudstone nodules present in the Upper Carboniferous and Mesozoic sediments may have been formed at an early stage in the compaction of the hosting sediments by the segregation of colloids, depending upon the relative abundance of such hydrosols of Fe, Ca and Mg within the sediments (Raiswell, 1976). The crystallization of the nodules from the outside, with desiccation of the centre, could form the septarian structure. The infilling of the septarian voids was probably affected by the crystallization of substances present in a state of supersaturation (Lindholm, 1974).

While the genesis of the sphalerite in the nodules may thus be understood, the genesis of the orebodies containing sphalerite at Staunton Harold is unclear. As there is currently no underground access to any remnant orebodies in the mine at Staunton Harold which could aid our understanding of the mineralogical processes, we are left with only two eyewitness accounts, one in the 19th century and one recent. Both lead to controversy. Furthermore, the study of material collected largely for its aesthetic value in the 18th and 19th centuries leads to a confusing and frustrating picture. Neither do the surface remains (Fig. 4) provide much mineralogical information, though they reveal a fascinating historical story.

The substrate of much specimen material is a quartzose conglomerate, a fine example of which in the Leicestershire Museums is labelled 'Carboniferous Limestone (Dolomitic) (Conglomerate) Dimminsdale and galena. 1647'. The matrix is a conglomeratic sandstone with well-rounded quartzite pebbles up 12 mm in diameter and sub-rounded clasts of reddish and

FIGURE 4. View looking north across the mining field at Staunton Harold in 1958. The fenced enclosures (A) are shafts with accompanying dumps. The gable end (B) belongs to a house converted to a laundry after the closure of the mine. The small building (C) to its right was the black powder house for the mine, relegated to use as a dry toilet after the closure.

greenish clay. The cementing agent is dolomite and red baryte. Running through the specimen are thin veinlets of calcite and galena following the lineation of the pebbles.

Hull (1860, p. 16), quoting a personal observation made to him by a Mr Bauerman of the Geological Survey, reported "the curious fact that most or all of the lodes in Dimmingsdale are formed of quartzose conglomerate or breccia, and the galena principally occurs in ribs at each side of the wall of the lode, while the crystals of the remaining minerals [including sphalerite] are formed in the druses of the veinstone. The ore is extracted in what is technically called 'pipework'".

Such descriptions are inadequate for determining the age of the conglomerate. According to a plan and section of the strata at Staunton Harold, produced by Woodhouse and Jeffcock, solicitors of Derby, to support the writ of Ferrers versus Matthews in 1853, the sulphide ores are geologically restricted to the upper 3 m of the limestone succession, the so-called 'Lead Measures'. The source of the mineralizing solutions must therefore be derived either laterally or from above, and we are left with few alternatives. The presence of conglomerate as cross-cutting bodies within the limestone succession suggests pre-Namurian cavernisation subsequently occupied by Namurian conglomerates. These could have been derived either from the 'thin pebbly grit' of Mitchell and Stubblefield (1941, p. 215), 'resting on the Carboniferous Limestone', i.e. immediately below the Namurian Limestone Shales; or from the 3.6 m of Namurian conglomerates which overlie the Lower Namurian Limestone Shales. Alternatively, the conglomerates could be of Permo-Triassic age, representing post-Carboniferous cavernisation, and equating with similar examples of Red Beds unconformably overlying Precambrian and Palaeozoic strata elsewhere in Leicestershire (King, 1991), and on a larger scale in Derbyshire, the Mendips and South Wales.

In 1939 Sir Arthur Russell visited Staunton Harold when the mine was unwatered and reopened for a short time. In a letter to the writer (12 January 1961) he reported mineralization ponded between the Namurian Shales above and the selectively dolomitised Viséan limestones below. The specimens kindly given to the writer by Sir Arthur are highly metastable marcasite nodules and may not be related to the paragenesis of which sphalerite is a member. While there is evidence of replacement of the host limestone by earlier members of the paragenesis, such as pink baryte and earlier phases of galena deposition (King, 1973, p. 102), the formation of the marcasite nodules may be outside the main paragenetic sequence and may represent a separate event related to reducing mechanisms present in the Namurian Limestones Shales.

It is unfortunate that none of these hypotheses can be tested. For this, access would have to be gained to any remnant orebodies in the mine, which at present seems highly unlikely.

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MANCHESTER MINERALS

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LEAD-ZINC-COPPER-ARSENIC-BARYTE MINERALIZATION FROM CLEVEDON, NEAR BRISTOL, ENGLAND

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Vein-style mineralization at Clevedon cross-cuts Upper Triassic limestone breccias (Dolomitic Conglomerate). It comprises banded baryte with minor galena, sphalerite, chalcopyrite, tennantite and enargite together with their alteration products. Microprobe analyses show sphalerite to be cadmium-rich, with up to 8.46 wt % Cd, and suggest that its body colour is related to the presence of microscopic sulphosalt inclusions whereas its opacity is related to copper content and incipient alteration. Baryte is strontium-rich and approaches $(Ba_{0.75}Sr_{0.25})SO_4$ in composition. The sulphosalts are silver-poor and have similar arsenic:antimony ratios, close to 3:1.

INTRODUCTION

The presence of minor base metal-baryte mineralization within dolomitic limestones close to the beach and Pier Hotel, Clevedon, Avon (ST 4015 7185) has been of mineralogical interest for over 120 years; much of this attention has centred upon the presence and range of the colourful copper and lead secondary minerals (Grenfell, 1873; Stoddart, 1877; Starkey, 1984, 1986). The primary mineral assemblage has not been described in other than brief accounts and a preliminary paragenesis is given in Ixer (1986, 1990) as part of generalized descriptions of British Mississippi Valley-type mineralization.

GEOLOGICAL SETTING

The coastline at Clevedon exposes a section through the Devonian Portishead Beds and Carboniferous Lower Limestone Shale Group, both of which are unconformably overlain by the Upper Triassic Dolomitic Conglomerate (now part of the Mercia Group). The Dolomitic Conglomerate is cut by a steeply dipping, southeast-trending (110°) mineralized fault zone approximately one metre wide. To the west of the Pier Hotel the fault plane dips 72°S and is marked by a prominent cliff face which shows traces of baryte-galena mineralization. Close to the Pier Hotel the fault lies within the Dolomitic Conglomerate, but to the east the fault throws Dolomitic Conglomerate against the Devonian Portishead Beds.

The degree of erosion and later infilling by soft sediments along the fault plane has made collection of *in situ* material and detailed mapping difficult. Locally, up to ten centimetres of rhythmically banded baryte accompanied by minor amounts of lead and copper sulphides lie along the footwall. However, most of the vein comprises angular fragments of Dolomitic Conglomerate (themselves containing Carboniferous crinoidal limestone clasts) cemented by baryte. The hanging wall calcareous sandstones are cut by thin galena stringers that have the same orientation as the main vein. Pebbles and boulders of Dolomitic Conglomerate containing banded baryte-sulphides, up to two metres in diameter and derived from the fault zone, are common on the beach below the Pier Hotel (ST 4015 7185).

COLLECTION, PETROGRAPHY AND MINERAL ANALYSIS

Representative sulphide-bearing material was collected from the beach together with *in situ* galena-bearing hanging wall sandstones. Four polished blocks and one polished thin section of material from the hanging wall sandstones and twelve polished blocks and three polished thin sections from nine examples of the sulphide-baryte mineralization were made. Routine transmitted and reflected light petrographical studies were followed by wavelength-dispersive electron microprobe analyses of copper- and zinc-bearing sulphides and sulphosalts. Quantitative analyses for Cu, Fe, Zn, Cd, Ag, Co, Ni, As, Sb and S were performed using a Cameca Camebax electron microprobe with a take-off angle of 40° and an accelerating voltage of 20 kV, using $CuSbS_2$, ZnS, FeS_2, CdS, $AgBiS_2$, Ni-metal, Co-metal, and FeAsS standards, and full ZAF correction procedures.

RESULTS

HANGING WALL SANDSTONES

The sandstone comprises angular fragments of quartz, feldspar, chert and rounded clasts of micrite together with trace amounts of zoned zircon, pale-coloured TiO_2 polymorphs and 120 µm diameter patches of very fine-grained hematite. These clastic grains are cemented and partially replaced by fine-grained carbonate but elsewhere galena, enclosing 2-10 µm diameter crystals of chalcopyrite, sphalerite, marcasite and rhombic dolomite, is intergrown with light-coloured, inclusion-free sphalerite to make a local cement. Coarser-grained galena and sphalerite fill voids, or form thin veinlets cutting the sandstone.

VEIN MINERALIZATION

Pale cream to pink baryte with strongly developed rhythmic banding is the most abundant hydrothermal mineral in the vein. Analyses show it to have very high strontium contents of 10.7-11.6 wt % Sr, equivalent to 22.4-24.3 mol. % $SrSO_4$, so making it strontiobarite with a formula close to $(Ba_{0.75}Sr_{0.25})SO_4$. Minor amounts of lead, copper and zinc sulphides and sulphosalts are present within baryte as sparse disseminations of small, up to 100 µm diameter, discrete crystals or occur within millimetre-wide sulphide-rich bands with only minor amounts of baryte.

In decreasing order of abundance the main opaque minerals are galena, chalcopyrite and sphalerite; these are accompanied by minor amounts of tennantite, pyrite, marcasite and hematite, and trace amounts of bornite and enargite. Secondary sulphides include 'idaite-like' material[1], digenite, blaubleibender covelline[2], covelline and botryoidal pyrite.

Notwithstanding the repetitive nature of the vein infilling, a suggested paragenesis for a given cycle of mineralization, modified after Ixer (1986), is given in Fig. 1. The minerals are described in detail below by their mode of occurrence and order of first appearance. Hematite is the earliest opaque phase, lying at the base of each baryte band as radiating spherical or polygonal aggregates up to 60 µm in diameter, composed of very fine-grained crystals (<<1 µm in length). Sulphides are absent from these bands.

EARLY SULPHIDES

The earliest generation of sulphides is galena-poor, minor in extent, and comprises small, up to 80 µm diameter, discrete, disseminated crystals of chalcopyrite, bornite, tennantite and sphalerite or, more rarely, intergrowths between these. Small, 5 to 20 µm diameter, crystals of pyrite and marcasite are infrequent and all of the sulphides fill voids between bladed baryte crystals. Alteration of the primary to secondary sulphides, including digenite, blaubleibender covelline and covelline, is widespread, as are limonitic and coloured carbonate pseudomorphs. An 'idaite-like' material accompanying chalcopyrite and tennantite shows textures that suggest it is an alteration product of chalcopyrite.

Table I presents microprobe analyses of sulphides and sulphosalts belonging to two mixed sulphide intergrowths, namely bornite-chalcopyrite enclosed in a copper sulphide rim, and relict chalcopyrite and tennantite intergrown with an 'idaite-like' material.

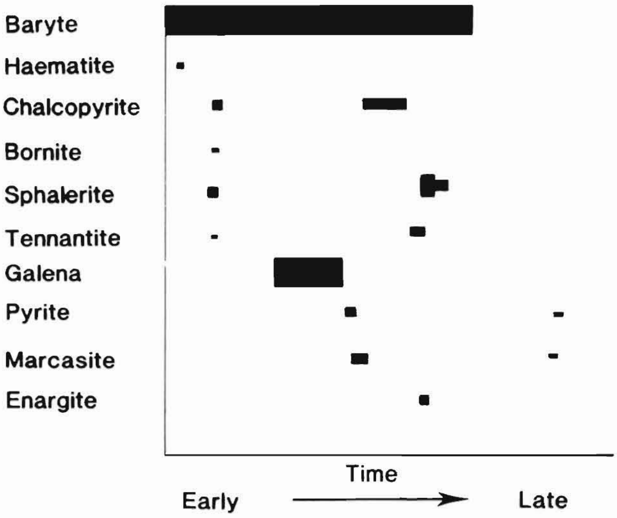

FIGURE 1. Paragenetic diagram of the primary mineral assemblage associated with a single baryte band, Clevedon. The vertical thickness of the bars is proportional to the relative amount of each mineral within the baryte band.

Bornite, carrying 10 x 1 µm long chalcopyrite spindles, is slightly sulphur-rich as compared with standard bornite and has a composition approaching that of low temperature anomalous bornite, described by Sillitoe and Clark (1969) as X-bornite. Bornite has up to 0.06 wt % Ag. The enclosing/replacing blue copper sulphide carries similar silver values, displays the optical properties of digenite and has a metal to sulphur ratio within the range of some synthetic and natural digenites (Morimoto and Gyobu, 1971; Mumme *et al.*, 1988).

An analysis of relict chalcopyrite within the 'idaite-like' material shows the chalcopyrite to be close to stoichiometric but slightly copper-enriched due to incipient alteration, and to contain up to 0.04 wt % silver. The enclosing 'idaite-like' material shows similar trace element concentrations but is slightly silver-enriched, having 0.07-0.12 wt % Ag. Despite good totals the analyses give elemental ratios that depart markedly from those given for idaite, namely Cu_3FeS_4. Analyses of two sulphosalts show them to be zinc-rich tennantite with up to 6.65 wt % Zn, up to 2.17 wt % iron, plus minor cadmium (up to 0.25 wt % Cd); they are, however, silver-poor with only 0.03 wt % Ag. One tennantite, CL10, has an As:Sb ratio of 4.69, the highest ratio of any of the tennantite analyses.

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[1] **'Idaite-like' material.** The term 'idaite-like' material is used here to describe a set of optically distinctive, fine-grained lamellar intergrowths between copper-iron sulphides ± copper sulphides that cannot be optically or chemically resolved into their constituent phases.

[2] **Blaubleibender covelline.** When viewed in reflected light in air all of the covelline group of minerals are blue and pleochroic. When viewed under oil immersion some covellines change their surface colour to purple whilst others remain blue - the latter are called blaubleibender (i.e. blue-remaining) covelline. They comprise two distinct minerals, yarrowite and spionkopite.

TABLE I. Analyses of sulphides and sulphosalts from galena-poor, altered copper-rich assemblages within baryte. (Weight %)

	Cu	Fe	Ag	Ni	Co	As	Sb	S	Total	Formula	Remarks
CL1	62.21	10.68	0.06	0.01	0.02	0.00	n.d.	25.55	98.53	$Cu_5Fe_{0.98}S_{4.07}$	Bornite with chalcopyrite spindles.
CL2	61.75	11.02	0.00	0.00	0.00	0.03	n.d.	25.74	98.54	$Cu_5Fe_{1.01}S_{4.13}$	Sulphur-rich bornite.
CL3	76.93	0.19	0.06	0.00	0.00	0.00	n.d.	22.73	99.91	$Cu_{1.71}Fe_{0.01}S$	Digenite replacing bornite-chalcopyrite.
CL4	76.13	0.65	0.05	0.00	0.01	0.03	n.d.	22.87	99.74	$Cu_{1.68}Fe_{0.02}S$	Digenite replacing bornite-chalcopyrite.
CL5	35.21	29.80	0.04	0.00	0.02	0.00	n.d.	34.07	99.14	$Cu_{1.04}Fe_{1.00}S_2$	Chalcopyrite relicts assoc. with CL6-CL9.
CL6	55.47	13.31	0.07	0.00	0.05	0.00	n.d.	31.13	100.03	$Cu_{3.60}Fe_{0.98}S_4$	'Idaite-like' material.
CL7*	56.22	13.04	0.12	0.00	0.03	0.00	n.d.	30.63	100.04	$Cu_{3.71}Fe_{0.98}S_4$	'Idaite-like' material.
CL8	54.88	13.85	0.11	0.00	0.03	0.00	n.d.	31.18	100.05	$Cu_{3.55}Fe_{1.02}S_4$	'Idaite-like' material.
CL9*	54.11	14.72	0.10	0.00	0.03	0.00	n.d.	31.22	100.18	$Cu_{3.50}Fe_{1.08}S_4$	'Idaite-like' material.

	Cu	Fe	Ag	Zn	Cd	As	Sb	S	Total	Formula	Remarks
CL10	42.76	2.17	0.01	4.68	0.20	17.09	5.91	27.40	100.22	$Cu_{10.24}Zn_{1.09}Fe_{0.59}Cd_{0.03}As_{3.47}Sb_{0.74}S_{13}$	Tennantite relict.
CL11	41.37	0.54	0.03	6.65	0.25	15.81	8.89	26.95	100.49	$Cu_{10.07}Zn_{1.57}Fe_{0.15}Cd_{0.03}As_{3.27}Sb_{1.13}S_{13}$	Tennantite relict.

* Analyses of the same grain.
n.d. = not determined.

POLYMETALLIC SULPHIDE BANDS

Galena, the most abundant sulphide in the vein, is the earliest phase to crystallize in the polymetallic sulphide bands. Euhedral to subhedral crystals, up to millimetres in diameter, are free of small (<1 µm) primary inclusions and commonly are enclosed within a series of sulphide and sulphosalt rims.

The complete sequence of later phases comprises pyrite and marcasite followed by chalcopyrite, tennantite, sphalerite, and finally enargite. Supergene alteration of galena to 5-20 µm wide rims of digenite, 'chalcocite'[3], blaubleibender covelline, covelline, cerussite, anglesite (confirmed by qualitative SEM analysis) and limonite is patchily developed. Locally, botryoidal secondary galena is accompanied by 5-20 µm diameter native copper grains, botryoidal pyrite, and 200 x 20 µm rods of a soft, white, high reflectance, isotropic metal that tarnishes quickly and is optically identified as native silver.

Minor quantities of 20-40 µm diameter, subhedral to euhedral crystals of pyrite and marcasite make up the earliest rim around galena; here pyrite forms cores to radiating marcasite crystals. However, more commonly the earliest rim, up to 250 µm wide, is chalcopyrite which encloses and replaces large, up to 200 µm long, twinned marcasite crystals, pyrite-marcasite aggregates, or small relict galena. Chalcopyrite is replaced by minor amounts of bornite or by tennantite. Supergene alteration to 'idaite-like' material, digenite, 'chalcocite', blaubleibender covelline, covelline, green copper secondary minerals, and finally limonite, is widespread. Analyses of chalcopyrite, rimmed by 'idaite-like' material, given in Table II, show chalcopyrite to have low trace element contents with silver up to 0.06 wt %; it departs very slightly from the ideal formula in being copper-rich, probably as a result of incipient alteration. 'Idaite-like' material shows variations in surface colour (brown-orange to yellow-orange), in the intensity of its strong anisotropy, and in the size and density of the enclosed chalcopyrite lamellae. Up to 40 µm wide rims of 'idaite-like' material mantle the outermost zones of chalcopyrite and hence much lies between chalcopyrite and tennantite. Texturally it can be seen to replace chalcopyrite and the rhythmical sequence galena-'idaite-like' material-tennantite is interpreted as being the result of the total pseudomorphing of chalcopyrite. 'Idaite-like' material alters to covelline and blaubleibender covelline (Table II). Analyses given in Table II show the Clevedon material is close in composition to the given formula for idaite, Cu_3FeS_4, especially analysis 7B. Comparisons with its associated chalcopyrite (analyses 6B, 6D) show an increase in silver content from 0.06 wt % maximum in chalcopyrite to 0.13 wt % in 'idaite-like' material, but little or no difference in the contents of the other trace elements, notably As.

Pale green tennantite displays orange to red internal reflections and is optically homogeneous. Much tennantite is intergrown with sphalerite and minor amounts of enargite as 200 µm wide rims (of up to 80 µm diameter crystals) about chalcopyrite. Tennantite overgrowing chalcopyrite into vugs is euhedral. Elsewhere collomorphic aggregates of tennantite reach up to 500 µm in size. Tennantite alters to digenite, blaubleibender covelline, covelline and non-opaque secondary minerals. Analyses given in Table II confirm the sulphosalt as zincian tennantite with As:Sb ratios of 3.15-1.69. Tennantites having the lowest As:Sb ratios (analyses 7E, 1F, 1H) are those that have crystallized into vugs between galena grains. Other than for zinc and iron, the tennantites have low trace element contents, with up to 0.53 wt % Cd and silver values that range from below detection limit to a maximum of 0.12 wt % Ag.

There are a number of sphalerite generations. One is part of the early, galena-poor, mixed sulphide subassemblage found at the base of the baryte bands, or locally forming up to millimetre-wide rims to galena,

[3] **'Chalcocite'.** This is used for all uncharacterized blue-white copper sulphides of the chalcocite-anilite-digenite-djurleite group of minerals.

TABLE II. Analyses of sulphosalts and sulphides associated with vugs in galena. (Weight %)

	Cu	Fe	Ag	Zn	Cd	As	Sb	S	Total	Formula	Remarks
CL12	46.56	0.41	0.09	0.00	0.16	11.54	10.69	30.71	100.16	$Cu_{3.06}Fe_{0.03}Cd_{0.01}As_{0.64}Sb_{0.37}S_4$	Enargite.[a]
CL13	47.02	0.36	0.07	0.00	0.05	14.04	7.83	30.81	100.18	$Cu_{3.08}Fe_{0.03}As_{0.78}Sb_{0.27}S_4$	Enargite.[a]
CL14	47.33	0.36	0.02	0.06	0.15	14.15	8.09	31.21	101.37	$Cu_{3.06}Fe_{0.03}Cd_{0.01}As_{0.78}Sb_{0.27}S_4$	Enargite.[a]
IE	42.00	0.51	0.10	8.06	0.24	14.79	8.25	27.05	101.00	$Cu_{10.19}Zn_{1.90}Fe_{0.14}Cd_{0.03}Ag_{0.01}As_{3.04}Sb_{1.04}S_{13}$	Tennantite.[b]
IG	40.65	0.65	0.00	6.83	0.25	15.59	8.03	27.23	99.23	$Cu_{9.79}Zn_{1.60}Fe_{0.18}Cd_{0.03}As_{3.19}Sb_{1.01}S_{13}$	Tennantite.[c]
IF	40.52	0.51	0.09	6.88	0.30	13.28	11.05	26.63	99.26	$Cu_{9.98}Zn_{1.65}Fe_{0.14}Cd_{0.04}Ag_{0.01}As_{2.78}Sb_{1.42}S_{13}$	Tennantite.[c]
IH	40.64	0.31	0.00	6.98	0.23	10.37	10.37	26.94	98.50	$Cu_{9.85}Zn_{1.65}Fe_{0.09}Cd_{0.03}As_{2.73}Sb_{1.32}S_{13}$	Tennantite.[c]
7E	40.42	0.80	0.01	5.91	0.53	12.36	11.92	26.77	98.72	$Cu_{9.91}Zn_{1.41}Fe_{0.22}Cd_{0.07}As_{2.57}Sb_{1.52}S_{13}$	Tennantite.[d]
CL20	41.22	1.04	0.09	6.67	0.24	14.04	9.01	26.71	99.02	$Cu_{10.13}Zn_{1.59}Fe_{0.29}Cd_{0.03}Ag_{0.01}As_{2.93}Sb_{1.16}S_{13}$	Tennantite.[e]
CL21	39.99	0.58	0.12	7.43	0.23	13.34	10.18	26.44	98.31	$Cu_{9.92}Zn_{1.79}Fe_{0.16}Cd_{0.03}Ag_{0.02}As_{2.81}Sb_{1.32}S_{13}$	Tennantite.[e]
8A	41.16	0.55	0.03	6.57	0.26	14.32	9.22	26.38	98.49	$Cu_{10.24}Zn_{1.59}Fe_{0.16}Cd_{0.04}As_{3.02}Sb_{1.20}S_{13}$	Tennantite.
8B	42.37	0.49	0.05	7.21	0.38	14.47	8.64	27.41	101.02	$Cu_{10.14}Zn_{1.68}Fe_{0.13}Cd_{0.05}Ag_{0.01}As_{2.94}Sb_{1.08}S_{13}$	Tennantite.

	Cu	Fe	Ag	Ni	Co	As	Sb	S	Total	Formula	Remarks
6D	35.03	28.67	0.00	0.03	0.00	0.02	n.d.	34.48	98.23	$Cu_{1.03}Fe_{0.96}S_2$	Chalcopyrite.[f]
6B	35.03	29.35	0.06	0.01	0.00	0.03	n.d.	34.61	99.09	$Cu_{1.02}Fe_{0.97}S_2$	Chalcopyrite.[f]
1A	34.26	29.99	0.00	0.03	0.00	0.01	n.d.	35.05	99.34	$Cu_{0.99}Fe_{0.98}S_2$	Chalcopyrite.[f]
7A	49.23	15.30	0.11	0.04	0.00	0.02	n.d.	34.22	98.92	$Cu_{2.90}Fe_{1.03}S_4$	'Idaite'.[g]
7B	50.55	14.35	0.12	0.05	0.00	0.00	n.d.	34.29	99.36	$Cu_{2.98}Fe_{0.96}S_4$	'Idaite'.[g]
7C	51.04	13.15	0.13	0.00	0.00	0.03	n.d.	34.23	98.58	$Cu_{3.01}Fe_{0.88}S_4$	'Idaite'.[g]
7D	49.08	14.79	0.12	0.00	0.00	0.02	n.d.	34.15	98.16	$Cu_{2.90}Fe_{1.00}S_4$	'Idaite'.[g]
6A	67.42	2.16	0.04	0.06	0.01	0.00	n.d.	29.42	99.11	$Cu_{1.16}Fe_{0.04}S$	Covelline.[h]
9A	66.34	0.07	0.01	0.05	0.01	0.00	n.d.	33.08	99.58	$Cu_{1.01}S$	Covelline.[h]

a: Enargite in chalcopyrite in galena.
b: Tennantite close to sphalerite.
c: Tennantite associated with sphalerite.
d: Tennantite in centre of cleavage + 'idaite-like' rims 7A-7D.
e: Tennantite intergrown with sphalerite CL16-CL19.
f: Chalcopyrite associated with 'idaite-like' material 7A-7D.
g: 'Idaite-like' material next to tennantite 7E along cleavage planes in galena.
h: Covelline associated with 'idaite-like' material 7A-7D.
n.d. = Not determined.

often along cleavage planes. This generation of sphalerite displays a number of different internal reflection colours (from pale yellow to dark orange and purple within domains bounded by twin planes), and is partially enclosed in thin rims of chalcopyrite and tennantite. 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 are inclusion-free except for the very minor development of 'chalcopyrite disease'[4] accompanied by very rare tennantite along growth zones of the millimetre-wide sphalerite. Initial supergene alteration of sphalerite changes its surface colour from grey to pale blue; with more extensive alteration sphalerite is replaced by blaubleibender covelline, covelline and smithsonite.

Domains within a millimetre-thick, inclusion-free sphalerite rim about galena display the full range of internal reflection colours from pale yellow to dark orange to opaque. Representative analyses of these domains are given in Table III and are graphically shown in Fig. 2, where the copper content is plotted against combined antimony and arsenic for different coloured areas. The analyses show the sphalerite to be iron-poor with a maximum of 0.22 mol. % FeS, but cadmium-rich with up to 8.46 wt % Cd. Copper values are erratic, but reach 0.92 wt % , while other trace element concentrations are low: up to 0.2 wt % Sb, 0.13 wt % As, and 0.05 wt % Ag. Fig. 2 shows a positive, approximately linear relationship between copper and combined arsenic and antimony contents. In addition, an increase in the contents of all three deepens the internal reflection colour.

Analyses of late stage, pale-coloured sphalerites intergrown with, or overgrowing, sulphosalts (all within galena) are given in Table IV, and unaltered copper-poor examples (<1.0 wt % Cu) are plotted in Fig. 2. The analyses show that these sphalerites are iron-poor (up to 0.44 mol. % FeS) and have variable amounts of cadmium (up to 7.38 wt %). Unaltered sphalerites have low copper values up to 0.77 wt %; low silver, up to 0.10 wt % (0.60 wt % Ag in specimen 1C is anomalous); and low antimony and arsenic, both up to 0.09 wt %.

Incipient alteration of sphalerite is accompanied by the loss of internal reflections, a slight increase in reflectance, and changes in surface colour from grey to blue-grey to blue. Analyses CL15, 17 and CL19 are of blue-grey altered sphalerites associated with unaltered grey sphalerites (CL16 and CL18). Comparisons between the altered and unaltered sulphides show there

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[4] **Chalcopyrite disease.** Many sphalerite crystals carry very fine-grained (<1 µm to 2 µm) blebs of chalcopyrite. Often these are crystallographically orientated within the sphalerite and so are seen lying along twin planes or growth zones. They are no longer believed to be due to exsolution processes but are a replacement phenomenon. It is called chalcopyrite disease because the sphalerite looks spotty.

TABLE III. Analyses of sphalerite showing the variation in compositions within the millimetre-wide band. (Weight %)

	Zn	Cd	Cu	Fe	Ag	As	Sb	S	Total	Formula	Internal reflection colour
3H	63.55	5.11	0.03	0.05	0.04	0.00	0.07	31.57	100.42	$Zn_{0.99}Cd_{0.05}S$	pale orange
3A	63.80	2.35	0.02	0.00	0.03	0.02	0.10	32.68	99.00	$Zn_{0.96}Cd_{0.02}S$	pale yellow
3J	64.79	4.08	0.12	0.03	0.02	0.01	0.05	31.63	100.73	$Zn_{1.01}Cd_{0.04}S$	very pale orange
3G	62.78	4.39	0.16	0.01	0.03	0.03	0.06	31.82	99.28	$Zn_{0.97}Cd_{0.04}S$	orange
3M	63.69	5.65	0.19	0.09	0.00	0.00	0.06	31.39	101.07	$Zn_{1.00}Cd_{0.05}S$	medium orange
3N	61.59	7.02	0.16	0.01	0.00	0.03	0.12	32.03	100.96	$Zn_{0.94}Cd_{0.06}S$	brown
3L	60.36	8.46	0.25	0.06	0.02	0.05	0.06	31.23	100.49	$Zn_{0.95}Cd_{0.08}S$	medium dark orange
3F	63.72	4.87	0.32	0.07	0.00	0.07	0.07	31.59	100.71	$Zn_{0.99}Cd_{0.04}Cu_{0.01}S$	dark orange
3K	66.03	1.17	0.46	0.05	0.05	0.09	0.06	32.23	100.14	$Zn_{1.01}Cd_{0.01}Cu_{0.01}S$	pale yellow
3C	63.40	2.19	0.44	0.00	0.00	0.07	0.13	32.87	99.10	$Zn_{0.95}Cd_{0.02}Cu_{0.01}S$	dark orange
3D	63.94	1.92	0.85	0.12	0.04	0.10	0.11	31.70	98.78	$Zn_{0.99}Cd_{0.02}Cu_{0.01}S$	opaque
3E	64.99	1.84	0.92	0.14	0.01	0.11	0.09	31.83	99.93	$Zn_{1.00}Cd_{0.02}Cu_{0.02}S$	opaque
3P	63.95	1.77	0.85	0.04	0.00	0.11	0.19	31.94	98.85	$Zn_{0.98}Cd_{0.02}Cu_{0.01}S$	opaque
3B	64.75	1.40	0.88	0.12	0.02	0.13	0.20	32.62	100.12	$Zn_{0.97}Cd_{0.01}Cu_{0.01}S$	opaque

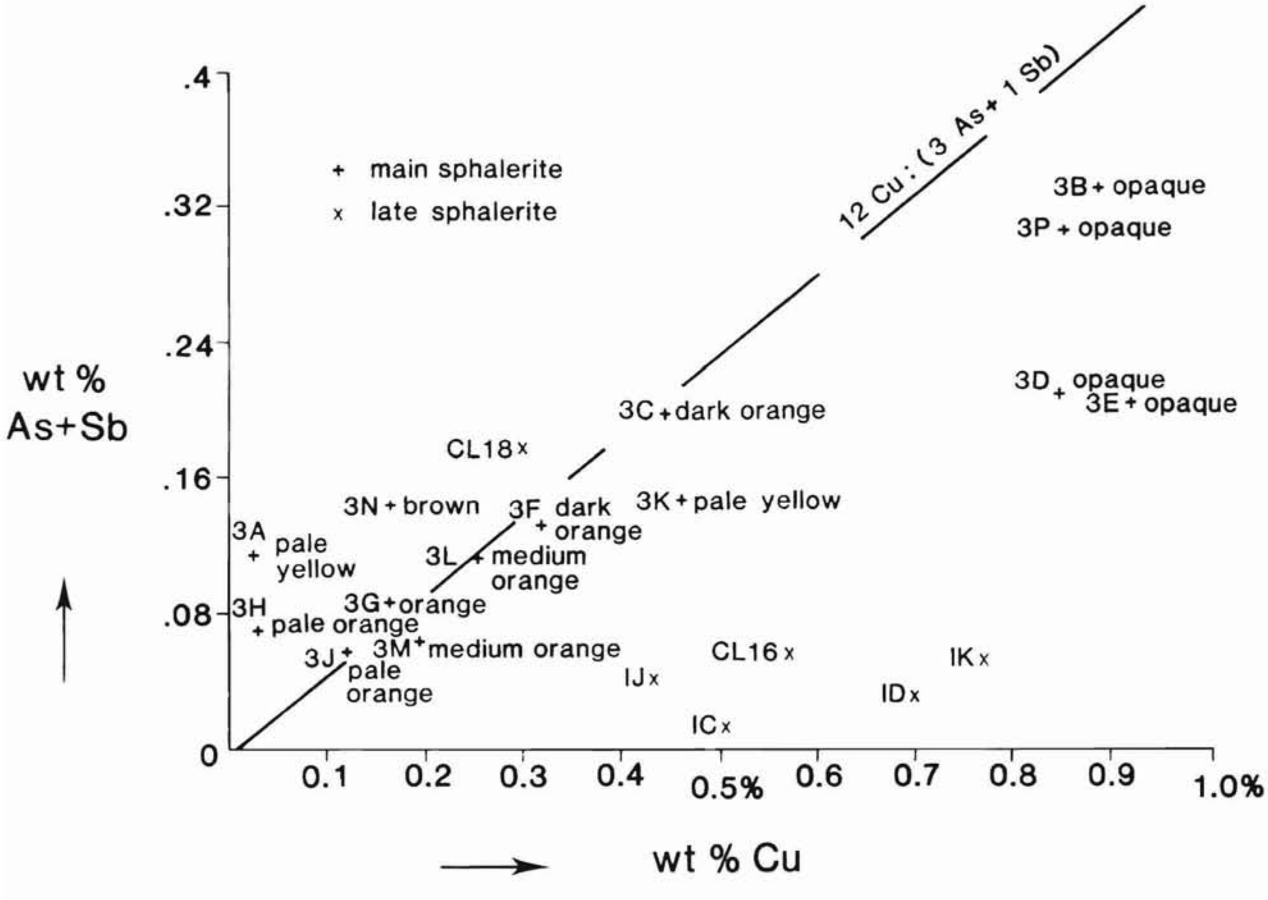

FIGURE 2. Plot of Cu wt % against (As + Sb) wt % for Clevedon sphalerite.

is little or no systematic variation in iron, cadmium, arsenic, antimony or silver but a marked increase in copper content from 0.77 wt % to 2.78 wt %.

Small, 10-60 μm long, bladed enargite crystals are present in minor amounts as the final primary phase to crystallize and it overgrows chalcopyrite, tennantite and sphalerite within voids in galena (Ixer, 1990). Analyses of enargite crystals (Table II) show them to be close to stoichiometric, with low iron (up to 0.41 wt % Fe), cadmium (up to 0.16 wt % Cd), and silver (up to 0.09 wt % Ag), and with trace amounts of zinc.

Up to 30 μm wide veinlets that crosscut baryte and carry twinned marcasite, euhedral pyrite and brown-yellow, low reflectance, 30 μm diameter botryoidal pyrite (the so-called melnikovite-pyrite[5]), are paragenetically very late. Locally, this assemblage is associ-

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[5] **Melnikovite or melnikovitic pyrite.** This is an informal name now commonly used to describe brown-coloured, poorly crystalline, botryoidal pyrite that occurs late in a paragenetic sequence, often with other secondary minerals.

TABLE IV. Analyses of late sphalerites associated with sulphosalts in vugs in galena. (Weight %)

	Zn	Cd	Cu	Fe	Ag	As	Sb	S	Total	Formula	Remarks
CL15	62.01	1.06	2.78	0.28	0.17	0.15	0.41	32.14	99.00	$Zn_{0.95}Cd_{0.01}Cu_{0.04}Fe_{0.01}S$	Intergrown with enargite CL12, CL13
CL16	61.24	3.82	0.58	0.09	0.10	0.06	0.00	31.83	99.72	$Zn_{0.94}Cd_{0.03}Cu_{0.01}S$	Grey, intergrown with tennantite CL20, CL21
CL18	60.20	5.62	0.30	0.08	0.00	0.09	0.09	31.86	98.24	$Zn_{0.93}Cd_{0.05}Cu_{0.01}S$	Grey, intergrown with tennantite CL20, CL21
CL17	58.89	4.96	2.58	0.11	0.06	0.04	0.15	31.75	98.54	$Zn_{0.91}Cd_{0.05}Cu_{0.04}S$	Blue altered sphalerite
CL19	59.12	5.77	1.31	0.05	0.06	0.00	0.17	31.85	98.33	$Zn_{0.91}Cd_{0.05}Cu_{0.02}S$	Blue altered sphalerite
1C	60.81	7.38	0.48	0.07	0.60	0.01	0.01	31.66	101.02	$Zn_{0.94}Cd_{0.07}Cu_{0.01}S$	Centre of sphalerite
1J	63.96	4.61	0.43	0.06	0.01	0.02	0.02	31.49	100.60	$Zn_{1.00}Cd_{0.04}Cu_{0.01}S$	Centre of sphalerite
1D	62.37	5.00	0.70	0.15	0.00	0.00	0.03	32.13	100.38	$Zn_{0.95}Cd_{0.04}Cu_{0.01}S$	Close to tennantites 1E & 1F
1K	62.92	4.65	0.77	0.02	0.00	0.02	0.03	31.42	99.83	$Zn_{0.98}Cd_{0.04}Cu_{0.01}S$	Close to tennantites 1E & 1F

ated with limonite, secondary galena and native silver and is present along galena cleavage planes.

DISCUSSION

The mineralization at Clevedon belongs to the widespread but minor lead-zinc-copper mineralization of the Bristol area (Alabaster, 1989), but also shares many features in common with that of the Central Mendip Orefield (Ixer, 1986; Ixer and Vaughan, 1993). In all cases, galena-sphalerite-baryte is accompanied by minor amounts of chalcopyrite, pyrite, marcasite and bornite.

Although strontium is commonly present in baryte, with hydrothermal vein baryte having higher concentrations than marine baryte (Bonatti *et al.*, 1972; Barbieri, 1989), the levels are normally only a few percent or less (Hanor, 1968), and therefore the high concentrations of strontium in the Clevedon baryte are significant. Indeed, the values are amongst the highest recorded (Starke, 1964; Bonatti *et al.*, 1972). The composition of the Clevedon baryte, $(Ba_{0.75}Sr_{0.25})SO_4$ is similar to that reported from material found at Clifton near Bristol, namely $(Ba_{0.70}Sr_{0.33})SO_4$ (Collie, 1879), but is slightly poorer in strontium. The occurrence of such highly strontium-enriched barytes should not be surprising as the Bristol area is one of the world's classical celestine orefields (de Brodtkorb, 1989), and all mineralizing fluids within the orefield might well be expected to reflect this geochemical anomaly.

Galena at Clevedon, in common with other examples from the Bristol-Mendip area, is optically free of small (<1 μm) sulphosalt inclusions. The probable presence of native silver as an alteration product of galena and the silver-poor nature of the copper-bearing sulphides and sulphosalts suggests the possibility that the silver content of the ores is locked in solid solution in galena as suggested by Dunham (1990) for other British, Mississippi Valley-type deposits, rather than in copper minerals as proposed by Ixer and Vaughan (1993).

Analyses of sphalerite show it to have low iron contents (<0.44 mol. % FeS) but to be high in cadmium (up to 8.46 wt % Cd). High cadmium values for zinc ores in the Central Mendip Orefield are shown by the presence of discrete crusts of cadmium sulphide at Green Ore (Kingsbury, 1941); by cadmium-rich smithsonite ('turkey-fat ore') near Weston-super-Mare, west of the main orefield (Alabaster, 1982); at Shipham where cadmium contamination of soils is severe (Davies *et al.*, 1981); and at Whatley, to the east of the orefield, where sphalerite with more than 2 wt % Cd has been recorded (Alabaster, 1982). High cadmium values are, therefore, a regional feature, although the Clevedon values are remarkably high, being the highest recorded in the U.K.

Table III shows that there is no simple relationship between cadmium content and colour or opacity of sphalerite but that there is one between copper, combined arsenic and antimony and the optical properties of the zinc sulphide. This is more clearly illustrated in Fig. 2, which shows that the colour deepens and opacity increases with increased amounts of copper, arsenic and antimony, although for higher concentrations of these trace elements the data suggest that opacity is related more to the copper content and is independent of changes in the arsenic and antimony values. The strong linear correlation between copper and combined arsenic and antimony suggests they may all be present in sphalerite as tetrahedrite or enargite group minerals and this conclusion is further strengthened by the good fit to the theoretical curve of 12Cu:(3As + 1Sb), an approximation of the ratio of elements present in the sulphosalts. The fit is most convincing for low concentrations. At higher concentrations of trace elements the opacity and colour appear not to be related to the possible presence of tennantite but rather to the copper content, either due to the presence of increased amounts of chalcopyrite disease or to incipient alteration to blue copper sulphides, a process that is further seen in analyses CL17 and CL18 of Table IV.

Inspection of sphalerite shows the presence of very fine-grained chalcopyrite disease, delineating grain boundaries and growth zones, accompanied by very rare tennantite inclusions (<1 μm). In addition, tennantite is seen to overgrow the millimetre-wide generation of sphalerite showing that copper-arsenic-antimony-bearing fluids were available to react with sphalerite to form 'tetrahedrite disease'. The presence of crystallographically orientated tetrahedrite group minerals in sphalerite ('tetrahedrite disease') is established.

The four analyses of late, post-tennantite sphalerite

(Table IV; 1C, 1D, 1J, 1K) all show low antimony and arsenic concentrations that are independent of copper values and plot away from the theoretical tennantite curve.

Tetrahedrite group minerals (general formula $(Cu,Ag)_{10}(Zn,Fe,Cd,Hg)_2(Sb,As,Bi)_4S_{13}$) have been recorded from Higher Pitts Farm in the Mendips (Kingsbury, 1941) but are rare. However, mineralogical descriptions of Mendip ores are few in number and tetrahedrite may be more widespread (Ixer, 1986); for example, the presence of beudantite at Sandford Hill (Livingstone and Cogger, 1966) may suggest the former presence of tennantite (Starkey, 1986). Tetrahedrite group minerals are uncommon in British Mississippi Valley-type deposits with only half-a-dozen recorded localities between the three Pennine orefields plus two recorded localities for enargite minerals (Ixer, 1986). However, at one of these localities, namely Higher Longrigg mine, near Kirkby Stephen, Cumbria, zincian tennantite has a composition, $(Cu_{10.00}Zn_{1.55}Fe_{0.36})(As_{3.06}Sb_{0.91})S_{13}$ (Braithwaite, 1988), very similar to those from Clevedon. As noted earlier, and in contrast with many lead-zinc-copper mineral deposits where tetrahedrite-group minerals are the main silver-carriers, tennantite from Clevedon is silver-poor with up to 0.12 wt % Ag, of the same order of magnitude as in the accompanying chalcopyrite and bornite. This silver value is below the 0.4 wt % Ag recorded for tennantite from the Askrigg Block (Small, 1982) and well below the 16.5 wt % Ag recorded for tetrahedrite from within the Alston Block (Vaughan and Ixer, 1980).

The low concentration of silver in the Clevedon tennantites is typical of arsenic-rich members of the tetrahedrite-group minerals. The absence of silver in tennantite is well documented (Charlat and Lévy, 1974; Pattrick and Hall, 1983; Johnson *et al.*, 1986) and is due to structural constraints. The presence of arsenic (as opposed to antimony) in the lattice reduces the space available for substitution of copper by relatively large silver atoms (Johnson and Burnham, 1985). This contrasts with silver substitution in antimony-rich tetrahedrites which often exceeds 20 wt %.

Natural tetrahedrite-group minerals normally contain 2 atoms of a divalent cation per unit formula $(Me^{+}_{10}Me^{2+}_{2}Me^{3+}_{4}S_{13})$; these are commonly zinc or iron, although mercury, cadmium and manganese are all known to be involved. In the Clevedon tennantites the divalent element is mostly zinc with some iron and only minor amounts of cadmium. Cadmium concentrations of 12 wt % have been recorded in antimony end-member tetrahedrites (Pattrick, 1978) and as the high cadmium concentration in sphalerite is evidence of high cadmium in the mineralizing fluids at Clevedon, a higher cadmium content might have been expected in the tennantite. The reason for low cadmium contents in these tennantites may be structural, with the lattice unable to accommodate the relatively large cadmium atoms substituting for zinc. However, Pattrick (1985) noticed that high-cadmium tetrahedrites only occurred when no sphalerite was present, and at Clevedon it appears that all the available cadmium has substituted into sphalerite while zinc has successfully competed for the divalent site in tennantite.

Although idaite was originally described as a discrete mineral with the formula Cu_3FeS_4 by Frenzel (1959), Rice *et al.* (1979) believe it to be a very fine-grained mixture, close to the resolving power of the optical microscope, of equal amounts of chalcopyrite and covelline, formed by alteration of bornite. Others have suggested that the supergene alteration of bornite follows the sequence: bornite → X-bornite (sulphur-rich bornite) → chalcopyrite plus digenite or covelline → a complex mosaic of idaite-chalcopyrite-bornite (Amcoff and Hedin, 1991). All of these mixtures/intergrowths have been described as 'idaite' and so the term 'idaite-like' material is used here.

At Clevedon both bornite and X-bornite (CL1, CL2) are present but in such minor amounts that they are extremely unlikely to be the precursors of the quite abundant 'idaite-like' material. Rather, supergene alteration and replacement of chalcopyrite, especially when associated with tennantite, has led to the formation of this secondary phase or phases. The material shows variations in its optical properties and in the density and size of the chalcopyrite spindles found within it. Its chemistry as determined by microprobe, and the resulting calculated formulae range from analyses 7A-7D (Table II), which give a result very close to Cu_3FeS_4, to analyses CL6-CL9 (Table I) that differ markedly from that formula and, indeed, do not fit a simple phase or simple mixtures of chalcopyrite, bornite and copper sulphides. The exact nature of the 'idaite-like' material therefore remains unresolved but, despite the stoichiometric analyses of 7A-7D, it is probably a mixture of phases.

The lack of comparable mineralogy and mineral chemistry from within the Bristol area, most notably from the Central Mendip Orefield, makes it difficult to assess the importance of the Clevedon mineralization or to place it into a regional context. However, sphalerite analyses suggest that the high cadmium values are not exclusively found in the Mendip Orefield. Similarly, baryte analyses show that the strontium mineralogy is not restricted to the precipitation of celestine or replacement of anhydrite or gypsum by it, but also is to be found in baryte-base metal vein deposits.

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NOTES

BOTALLACKITE FROM DOONEEN MINE, ALLIHIES, COUNTY CORK, REPUBLIC OF IRELAND

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Copper was mined from the Bearhaven (Berehaven) mines, Allihies, western Co. Cork, Republic of Ireland, from the early nineteenth century until the early 1930s. During this time, approximately one million tons of ore was raised, yielding about 25,600 tons of copper (Reilly, 1986). The main ore was chalcopyrite, with minor bornite and tetrahedrite/tennantite, in veins of massive milky quartz often tens of metres wide. Other minerals present are pyrite, molybdenite, micaceous hematite, albite, calcite, siderite and chlorite. The veins usually trend east-west, occasionally north-south, and cut Old Red Sandstone slates and sandstones which had undergone an earlier phase of WSW-ENE folding and faulting (Sheridan, 1964).

The district is not noted for the development of oxidised zones in the deposits. Some gossan was observed at Mountain mine (the richest of the mines, at Grid Ref. V 590 457) which contained brown copper oxide (Sheridan, 1964), and small specimens of malachite may be collected from the dumps of Coom mine (V 596 453) and Irhin or Urhin mine (V 608 469). Post-mining oxidation has resulted in the walls of the old workings, particularly those of Mountain mine, becoming coated with secondary minerals. Reilly (1986) describes these as 'malachite, azurite and ferromolybdate' (presumably ferrimolybdite). In fact they seem to be predominantly basic sulphates of copper, mostly langite, and fine specimens have been obtained from the Mountain mine stopes and levels for many years. Brochantite, devilline and connellite have been observed in these coatings (Ryback and Moreton, 1991) together with amorphous basic copper sulphates and limonite.

During a recent (1992) re-examination of these deposits, particular attention was paid to the coastal occurrence at Dooneen mine (V 576 458). Here, the east-west quartz-chalcopyrite lode forms a promontory jutting out into the sea. Heavily stained green with copper along its southern flank, it was the first copper deposit in the district to be noticed and exploited (Blenkinsop, 1904). Access is difficult, by means of a steep scramble down the northern side of the promontory. An adit, just above the high water mark, cuts through the promontory allowing access to the southern side. A branch follows the vein eastwards (i.e. inland) for a short distance before being blocked at the foot of an infilled shaft. The adit, the branch from it, and the south side of the promontory itself are all heavily encrusted with secondary copper minerals, as follows.

SECONDARY COPPER MINERALS

BOTALLACKITE, $Cu_2Cl(OH)_3$

The brilliant, emerald-green coatings, up to 1 mm thick and covering over 100 m^2 of the south side of the promontory, especially near its east (landward) end, consist largely of botallackite. It has been identified by X-ray diffraction (XRD), infrared spectroscopy (IR), and wet chemical tests. Both XRD and IR indicated the presence of a very small proportion of the polymorph atacamite mixed with the botallackite. The coatings are, in places, minutely mamillated and often exhibit a rippled appearance. No crystals have been found to date but the extensive development of botallackite over the cliff face makes this an exceptional occurrence of an otherwise rare mineral, and also an entirely natural occurrence rather than a post-mining growth.

CHALCANTHITE, $CuSO_4.5H_2O$

Bright, sky-blue, water-soluble, crystalline encrustations of chalcanthite (IR and wet chemical identification) coat the walls and ceiling of the adit cutting through the promontory. The chalcanthite is associated with green stains which wet chemistry indicates to be a basic copper chloride mineral, presumably of the atacamite group. Unfortunately, these green stains are so thin and superficial that it has not been possible to obtain enough pure material for IR or XRD identification.

COPPER SILICATE GEL

In the branch off the aforementioned adit, there is extensive development of an amorphous copper silicate which coats the walls and debris on the floor in layers up to 5 mm thick. When fresh it consists of a deep blue to blue-green, soft gel which, on drying, dehydrates to a cracked and flaky material. It is amorphous to X-rays but IR and chemical tests show it to be a copper-containing hydrous silicate. Minor sulphate and chloride are also present but may be due to contamination by langite and sea-water.

LANGITE, $Cu_4(SO_4)(OH)_6.2H_2O$

Deep-blue, well-formed crystals up to 2 mm in size occur abundantly, either scattered throughout the copper silicate gel (above) or as drusy encrustations on walls and debris associated with it. Identification was by XRD and IR.

DISCUSSION

This is the first reported occurrence of botallackite in Ireland. $Cu_2Cl(OH)_3$ has three known natural phases: botallackite (monoclinic), atacamite (orthorhombic) and paratacamite (trigonal). Of these, botallackite is often the one precipitated first but, when kept in contact with its parent solution, tends to recrystallise quickly to either of the more stable forms, atacamite or paratacamite, the latter being marginally the more stable form between 0 and 40°C (Pollard *et al.*, 1989). The presence of a small amount of atacamite in the material described here is, therefore, not surprising.

The botallackite is presumed to have formed by the action of sea-water on decomposing chalcopyrite in the cliff. Drying of the solution due to the exposed position of the occurrence may have helped to prevent extensive recrystallisation to the more stable phases. A more detailed sampling and testing at this locality may be worthwhile in case localised recrystallisation has occurred to give paratacamite, which has not yet been reported from Ireland. Atacamite, as a post-mining deposit, has been recorded as occurring with chalcanthite from Tankardstown mine, Co. Waterford (Moreton, 1991), this being reminiscent of the chalcanthite associated with basic copper chloride from the mine adit at Dooneen. Again, sea-water was implicated in its formation. The original botallackite localities in Cornwall (Botallack mine and Cligga Head) are also coastal ones (Pollard *et al.*, 1989), and minerals of the atacamite group should be looked for whenever copper deposits occur on the coast.

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CINNABAR FROM STANCOMBE QUARRY, NEAR BRISTOL, ENGLAND

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Cinnabar occurring in small amounts as a powdery secondary mineral in lead-zinc deposits was first recorded in Britain from Derbyshire and Yorkshire (Braithwaite *et al.*, 1963), and a number of other occurrences have since been described (e.g. Young *et al.*, 1989; Bridges, 1990). This note records cinnabar for the first time from the Bristol area.

Stancombe quarry, near Flax Bourton, Bristol, Avon (ST 505 684) is actively working limestones of the Clifton Down Group (Lower Carboniferous). Mineralization within the quarry consists of a few narrow, subvertical calcite-baryte veins (maximum width 30 cm), some of which contain minor galena, sphalerite, and/or pyrite. In addition, a large infilled mineralized cave containing the same primary minerals as those in the veins, together with an interesting suite of secondary minerals, including sulphur, greenockite, and an unidentified Sb-rich powder, has been described by Alabaster (1983). During a visit to the quarry in 1992 considerable amounts of predominantly massive baryte were found amongst the quarry spoil, some of the larger blocks (ca 40 cm) showing evidence of extensive silicification at and up to 10-15 cm away from the baryte contact, and also of limestone caught within and surrounded by the baryte. Within this silicified limestone there are roughly cubic to irregular voids 2-5 mm across, probably formed by removal of pre-existing galena since trails of cubic to sub-cubic fresh galena crystals are found embedded in some of the baryte blocks.

Close examination of the baryte revealed cinnabar as a scarlet powder richly lining cavities 1-2 mm in diameter (confirmed by XRD, NHM film No. 8799F). Cinnabar, including a few poorly formed crystals up to 1 mm in size, was also found lining a few of the voids within the silicified limestone. A small number of very rich specimens (for a British location) were collected. Larger cavities within the baryte matrix are lined with small (to 1 mm) dirty-white coloured cockscomb baryte crystals, some of which are covered with black to brown irregular patches up to 3 mm across, identified as sphalerite by XRD.

The origin of the cinnabar at Stancombe quarry is somewhat problematical. At the other British localities, cinnabar appears to have formed as a result of the oxidation of sphalerite and/or galena containing small amounts of mercury, HgS being rather resistant to oxidation. Thus in Derbyshire and the Northern Pennines, cinnabar is closely associated with supergene zinc minerals (Braithwaite *et al.*, 1963; Young *et al.*, 1989), and at Machen quarry, South Wales, with altered galena (Bridges, 1990). Despite a search using a stereomicroscope, no lead or zinc secondary minerals have been detected in the material collected from Stancombe quarry, and nearly all the galena has a fresh, unaltered appearance. It is possible that mercury may have been released when galena was removed during the silicification stage noted above.

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CONSERVING BRITAIN'S MINERALOGICAL HERITAGE

INTRODUCTION

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The following articles were amongst 27 papers presented at a meeting held at the University of Manchester between 31 March and 1 April 1992, with the title 'Conserving Britain's Mineralogical Heritage', and sponsored by the Geological Society of London, the Mineralogical Society of Great Britain and Ireland, and the Joint Nature Conservation Committee. Following the meeting, the organising committee decided to solicit selected written contributions with a view of producing a thematic set of papers covering the range of topics discussed.

The meeting aimed to address issues relating to the conservation of sites of mineralogical interest in the broadest sense, soliciting opinions and contributions not only from amateur and professional mineralogists, but also from other discipline interest groups. These include botanists, archaeologists, historians, and educationalists, as well as those concerned with planning policies for the redevelopment of old mine and quarry sites, and also bodies responsible for safety legislation. The involvement of the last is particularly pertinent in view of the fact that many sites of mineralogical interest are not only areas of considerable pollution, but may also provide a hazard in terms of their dangerous physical state. The intention was to provide a forum for open discussion, hopefully leading to a clearer identification of the diverse areas of interest and concern. It was felt that, in the first instance, this would provide a broader appreciation of the importance of such sites in terms of their research, leisure and education potential, as well as identify some of the problems involved in maintaining their availability in the light of current legislation and environmental and safety demands. Only when the potential uses and the constraints are identified and appreciated can meaningful policies be developed. Until that time a climate of partial ignorance will prevail which can only hamper dialogue and lead to mistrust, which will be a hindrance, in the long run, to the realisation of the full potential of the sites.

It was most unlikely that a consensus would emerge from such a meeting, but a number of crucial points were reiterated. Firstly, it was recognised that mine sites in particular have multi-group interests, which can be beneficial but may also lead to conflict. Archaeologists, for example, may despair at the excavation of mine dumps by mineral collectors. Nevertheless, there are advantages to multi-disciplinary values of sites, in terms of offering strength in lobbying against proposed developments, or at least demanding modification. However, in order for this to carry weight, the full interests must be recognised. To do this it is imperative that the potential of mineralogical sites are reviewed *in advance* of planning applications for development, before there is any threat to such sites. Clearly this demands a great deal of work, and an obvious question is who has responsibility or authority to do it. Unfortunately, there is no simple answer. Obviously the various conservation agencies have a responsibility in part, and the SSSI (Sites of Special Scientific Interest) and GCR (Geological Conservation Review) schemes have endeavoured to identify the most important mineralogical sites. However, as is widely recognised, this covers only a small number of known mineralogical sites, a fraction of those of potential value. The more recent RIGS (Regionally Important Geological Sites) scheme is a laudable initiative whereby sites of more local than national importance can be recognised and recorded. Expansion of this scheme, largely on a voluntary basis, seems at least a viable mechanism whereby information can be gathered. If RIGS co-ordinators were then to solicit opinions from local wildlife trusts, natural history societies, regional archaeological trusts, caving clubs and the like, as well as seeking assistance from appropriate academics either living or researching in the area of concern, at least some kind of database would be generated, which could form the basis for a response to threats to sites.

What is equally important, however, is knowing what to do with the assembled information. Those with access to or control over such data should target local authorities, obtaining copies of local structure plans and planning and derelict land policies, as well as reviewing planning applications periodically. In addition, a strategy for responses to development applications should be formulated. That is not to say, however, that each and every application should be opposed. More positive planning is taking place, where the interests of diverse groups are considered and if possible catered for, thereby enhancing rather than destroying a site's potential. Nevertheless, only if the right information is available in the right format and at the right time will there be any real hope of influencing policy. The process must start with the collection and collation of data, an area where there is still a vast amount to do. Groups such as the Russell Society, RIGS, the British Micromount Society, and so on have an important role to play on behalf of the mineralogical community.

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THE MINERAL COLLECTOR AS A CONSERVATIONIST – THE RIGHT TO COLLECT?*

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In most fields of natural history today, collecting and conservation may be seen as irreconcilable or contradictory activities. The casual collecting of biological material is now almost universally regarded as unacceptable. Indeed, many species are protected by law from collection, or in some instances simply disturbance. Even bona fide research involving certain species may require a special licence. For fragile populations of animals or plants such measures are obviously essential if their continued existence is to be assured. Conservation in its widest sense has thus come to be regarded as synonymous with a 'hands off – look but don't touch' attitude.

Geological science is perhaps unique amongst the natural history subjects in still regarding widespread collecting as acceptable. The situation even here is changing, however, and if he or she is not to see the eventual banning of collecting, today's mineral collector must accept an increasing burden of responsibility as a conservationist.

Minerals are often beautiful objects. It is their aesthetic appeal which for centuries has prompted their collection and invited interest and study beyond their mere usefulness as basic raw materials. Systematic mineralogy, like any other study of natural objects, has only been possible as a result of the activity of collectors. From the earliest days of scientific mineralogy the collectors have been mainly what today would be styled 'amateurs', together with a small but significant number of commercial collectors and mineral dealers. Collecting reached a peak in the nineteenth century: the Victorians were avid, in some instances obsessive, collectors of natural objects. This period saw the beginnings of many of today's most important collections and the expansion and systematic development of earlier and hitherto often poorly organised collections. Mineralogy continues to benefit from the activities of devoted collectors and dealers, having enjoyed an unprecedented growth in popularity over the past two or three decades.

Mineral collecting in Britain today is probably more popular than even in the heyday of the Victorian collectors. As in previous generations, the majority of today's collectors are content to acquire interesting but otherwise unremarkable material. However, there is a growing core of dedicated individuals, many with a sound grasp of technical knowledge, who may truly be described as 'amateur mineralogists'.

For at least two centuries there has been a trade in fine mineral specimens. A number of dealers are active in Britain today, supplying individual collectors and institutions with a wide range of material both from Britain and abroad. The valuable role of the responsible dealer in the development of systematic and topographical mineralogy has long been appreciated and continues today. The commercial value of mineral specimens, particularly those species most popular with collectors, and those from famous or sought-after localities, has had a regrettable influence on a number of collectors. The attraction of a quick financial gain from overcollecting, often illegally, at many sites has inevitably earned mineral collecting a bad name, especially with conservationists. The greed and destructive practices of the comparatively small number of such collectors rightly deserves contempt. However, this should not be allowed to conceal or overshadow the excellent and scientifically valuable efforts of responsible collectors, many or most of whom truly appreciate the need for conservation of sites, specimens and information.

Today's collectors differ from their 19th century predecessors in two important respects. Firstly, most of today's serious collectors own a good stereomicroscope and commonly have access to a range of analytical or determinative techniques. Coupled with a working knowledge of mineralogical and chemical principles these enable today's recreational mineralogist to make significant contributions to the science. Indeed, field mineralogy is one of the very few scientific pursuits that still offers a true role to the good amateur. It is worth reflecting that in recent years many, or perhaps most, of the important finds of unusual or rare minerals in Britain are the result of dedicated amateur work, often of high scientific quality. Secondly, the amount of raw material available at many sites is today much less than even a few years ago and is diminishing rapidly. Both of these factors are of vital importance in mineralogical conservation.

A large number of people derive a great deal of legitimate pleasure and satisfaction from the pursuit of recreational mineralogy. Whereas the collecting activities of many pose little real threat to most sites, some restraint on the amount of material collected is clearly

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desirable if localities are not to become totally exhausted.

It is the activities of the serious collectors, including dealers, who present on the one hand the potential for serious site conservation problems, and on the other the potential for greatly extending our knowledge of the country's mineralogical heritage. Seen against the background of ever-decreasing resources all collectors must surely realise that the freedom to collect should be balanced by certain responsibilities. Merely to collect, often rare material, as an end in itself or for purely commercial gain, can scarcely be justified today. A duty of *noblesse oblige* should be incumbent on all collectors.

In working mines and quarries or at other temporary exposures mineralogical material may be available for a limited period before it is destroyed or concealed. In these circumstances the collector performs a potentially important conservation function simply by rescuing material. This potential is, however, only truly realised if representative specimens are carefully curated, ideally with specimens presented, or at least made available, to a national or local museum with an established mineralogical collection policy. Provision of site records and field observations to a local or national site documentation scheme ensures the survival of vital locality information. Formal or informal liaison between mining or quarrying companies, museums, and interested individuals or societies is extremely valuable in this respect.

Mineralised outcrops or sites under no threat of destruction, other than by collectors, present more of a problem. Clearly, collecting which may reveal new finds or other information is desirable, though unrestrained removal of material cannot be sustained. All collecting requires the consent of the land or mineral owner. The owner may therefore be in a position to exercise a considerable degree of control over collecting. However, many sites are remote and difficult to oversee. Ownership may be difficult to establish and very many collectors simply do not bother to seek permission. Control solely by owners may therefore be unrealistic. Statutory protection by SSSI or RIGS status offers no real protection against the over-zealous collector who, in any case, may be unaware of a site's status. The responsible collector has a duty as an individual to refrain from excessive collecting. Local geological or mineralogical societies to whom many collectors belong can, and most do, encourage good field practice, and can in extreme instances exercise discipline in cases of irresponsible behaviour by members. Individuals and societies may bring the importance of a site to the attention of a statutory conservation authority and, for example through a local RIGS scheme, may take an active role in monitoring all aspects of the site's use and abuse. As with mine and quarry sites, collected material and information should be well curated and made available to museums and documentation schemes.

The collector has, therefore, a vital part to play in conserving both mineralised sites and specimens obtained from them. The conservation duty, however, goes further than this. With the sophisticated determinative techniques available to many collectors today, important mineralogical finds are being made increasingly often, paradoxically at a time when the amount of material available for collecting is diminishing rapidly. More than ever there is a need to place such discoveries on permanent record in a suitable reputable scientific journal. Club and society newsletters are generally unsatisfactory vehicles for such records: they are essentially ephemeral documents and the information is quickly lost or difficult to trace. For a number of years there has been a trend away from such topographic recording, especially in a number of long-established journals. This tendency is now reversing as the science again recognises the need for this essential basic information.

A number of collectors already well appreciate the need to publish and, having found that publication is not as daunting or as difficult as they feared, derive considerable satisfaction from adding their findings to the mineralogical literature for future generations.

In an increasingly conservation-conscious world the collecting of minerals in the field should be regarded as a privilege not a right. All privileges carry a weight of responsibility. Despite abuses of privilege by some individuals, collectors have on balance served mineralogy well. The price to be paid for a continuation of the privilege of collecting must surely be an acceptance by all collectors of their responsibility to ensure, so far as possible, that sites, specimens and information are all conserved for the future. If this is not accepted, the time may not be too far distant when collecting of minerals becomes as unacceptable as the collecting of birds' eggs or rare orchids.

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MINERAL COLLECTORS – FRIEND OR FOE?*

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INTRODUCTION

It is often said that driving a motorcar brings out the worst in people – the hidden aggression or compulsive competitive instinct. This innate desire to succeed and return victorious is seen in many leisure activities, and mineral collectors are no less subject to human weaknesses. Many collectors confess to enjoying 'the chase' but when lust and greed take over, rational people, trustworthy in all other respects, can behave quite strangely. Perhaps this truly is evidence of 'the power of stones'! Ironically, it is this very drive and commitment of successful collectors which results in the recovery of new and interesting material. Often the beneficiaries of such endeavours are the National Museums or research institutions such as universities.

ACCESS

The major issue facing mineral collectors today is that of gaining permission for access to sites. Increasingly, estate managers, landowners, and quarry and mining companies are becoming more and more reluctant to grant formal permission. In days gone by a polite request at the quarry office would usually result in permission being granted, a letter in advance to the quarry manager almost guaranteed access. Nowadays, in spite of individual quarry managers apparently being willing to allow bona fide visitors, the operating companies frequently feel compelled to impose a blanket ban on collecting 'for health and safety reasons'.

Happily, organisations such as the Russell Society have had some success in building relationships with particular mine and quarry companies, and this has resulted in visits to, for example, Geevor, Pendarves, South Crofty, and Boulby mines and many working quarries.

The situation regarding disused mines and quarries is much more difficult. Firstly, because mineral rights and the land on which the workings are situated may not be owned by the same person, it can be doubly difficult to obtain permission. In many instances it may be impossible to establish who owns a mine or quarry but, generally, asking at the nearest farm is recognised as the sound course of action. Often the response will be "It isn't my property – but I'm sure it'll be alright". The person apparently giving permission may not have the authority to do so, but this will not be apparent to a casual enquirer.

In more remote areas the need to seek permission is less apparent, but nonetheless desirable. Is it really necessary, for example, to seek formal permission to collect zeolites 2500 ft up Ben More, Mull? If the mountain terrain concerned lies within a National Park, or on National Trust property, again the answer should be yes, but in practice few visitors take the trouble. In closely policed areas such as Winnats Pass in Derbyshire or St Michael's Mount in Cornwall, any reprobate mineral collector would find himself the subject of swift action from wardens.

Where, then, should one draw the line? A casual stroll across a farmer's field to visit a spoil heap is unlikely to cause offence or lead to problems; similarly, removal of modest amounts of material from outcrops or mountainsides carries little attendant risk of rebuke. Unauthorised sorties into working quarries (even when not operating) are, however, clearly not acceptable behaviour and cannot be condoned. Disused quarries represent yet another dimension and, although technically permission should be sought, experience suggests that, in general, local people have already established a common right of access for walking dogs, etc., and problems are seldom encountered. The question of formal permission for access swings sharply into focus if one considers a group of people, rather than one or two individuals. Why is this so? Is it the greater likelihood of detection; the need for a body corporate to adhere to the law where individuals need not; or simply hypocrisy on the part of individuals who, if acting collectively, would readily acknowledge the need for permission?

To the individual collector it seems that bodies such as the National Trust and the Lake District Special Planning Board are acting to limit field activities as an end in itself rather than as part of a coordinated conservation strategy. A clear distinction may be drawn, for example, between a spoil heap which is gradually being grassed over, and the last block of mineralised ground in a quarry exposure or outcrop. There are many examples of places where one can no longer see or collect material which was until relatively recently quite abundant. Does this mean that the only 'safe' policy is an absolute ban on the removal of material? Is mineralogical material not safer stored under cover, carefully labelled and preserved for future generations? Consider the case of Wheal Gorland, sadly lost to a mineral reprocessing plant. Although there is now nothing remaining of the once extensive

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spoilheaps, sufficient material was salvaged by amateur collectors and mineral dealers that there is ample available to satisfy any collector or educational needs for decades to come.

If we extend this analogy to underground mine workings, the same rationale holds. Fifteen years ago it was possible to collect excellent green fluorite underground at Heights mine in Weardale. The mine workings lie adjacent to an active quarry, and blasting activity had resulted in dangerous flaking of the roof in the mine. Sadly, the entrance was blown in and access lost. In this case, it may be argued that because of the risk of injury to a member of the public access had to be denied. Does the same logic extend, for example, to cavers, rock-climbers and sub-aqua enthusiasts?

If it were not for individuals choosing to take some element of risk in their daily lives, the world would be a very much poorer place. Certainly our National Collections would be missing many fine specimens if it were not for the efforts of generations of active mineral collectors.

Why, then, does the term 'Mineral Collector' conjure up a bad image, prejudice and dismay in certain quarters? It is because of the actions of a relatively small number of people, in some cases actions of quite extreme proportions – use of explosives, breaking and entering, commercial mining of specimens without authority – that the vast majority of collectors unjustly suffer a poor reputation. I have resorted to introducing myself as an amateur geologist when seeking permission at quarries and farmhouses!

How can we move forward? Can not the responsible collecting fraternity re-establish their image by 'naming names' and ensuring that all acts of wrongdoing are well publicised? Unfortunately, there is probably not a single mineral collector who at some time has not transgressed the 'rules' where he considered this to be reasonable. It must be remembered that mineral collectors include company directors, solicitors, policemen, doctors, surgeons, scientists, teachers and many other professionals, normally considered to be 'respectable'!

The current situation with regard to retail trading on Sundays represents a very similar dilemma to that of access for the mineral collector. If we accept categorically that absence of formal permission means one does not visit a site, fieldwork will rapidly die, exposures will become overgrown and lost. Mineralogical material will be destroyed or buried. A more positive approach would be to adopt an aggressive campaign of educating landowners, planning boards, National Park Authorities, quarry companies and so on, of the worth to science and the community of responsible amateur collecting.

Local and national geological and mineralogical societies should pool information on sites, landowners, access agreements, etc., in order to provide the best chance to a potential visitor seeking proper authority. Paradoxically, the secretiveness and competitive element mentioned in the opening remarks is likely to prove a formidable barrier in establishing any such liaison. In this latter regard it is also worth noting that for fieldwork and mineral collecting to be truly of value to science, observations must be recorded and published in a reputable journal. Once any such account is published there is an immediate likelihood of the site being plundered and destroyed by others. If we collect and do not record, then we betray our responsibility to science, and hence forfeit what should be a natural right – that to collect and study minerals.

MINERAL COLLECTING IN SPACE AND TIME

Mineral collectors are a foe when they:

- destroy property in working premises;
- don't get permission when it is fairly obvious where to go;
- become abusive when tackled by a landowner;
- over-collect;
- make properties unsafe;
- create eyesores;
- destroy 'scenery' underground;
- create hazards for farmstock;
- destroy industrial archaeology;
- do not follow the Country Code;
- do not curate material properly.

Mineral collectors are friends when they:

- rescue material from temporary exposures;
- by careful study make new discoveries;
- publish their discoveries;
- deposit specimen material in museums;
- curate material properly for posterity;
- club together in good societies for purposes of research, education and conservation.

An important area where mineral collectors have a valuable role to play is that of temporary or threatened exposures. Often the collector 'on the ground' is more likely to be in the right place at the right time, and hence is able to recover and safeguard material which might otherwise be lost for good. In recent years much publicity has been given to so-called 'rescue collecting' by museums and research workers. It could well be argued that this has been the preserve of the mineral collector for decades.

We hear increasingly of the need for conservation – of flora and fauna, environments, geological and botanical sites, etc. It is important, therefore, to consider for whom such vital resources are being conserved, and what may be the consequences of any policies implemented in this regard. The Caldbeck Fells in Cumbria is a little visited and relatively remote part of the Lake District. The fells are pleasant walking country but without the grandeur of the major ranges of the Lake District. In many years of visiting the area I have seldom met more than a handful of people. Such visitors are invariably hill walkers, generally with a healthy interest in the scenery and its natural history, ornithologists, or those interested in the earth sciences.

Why then does the Lake District Special Planning Board adopt such a strict policy on mineral collecting and ban any underground access to the old mine workings? The answer, it seems, is on conservation and safety grounds. It is particularly lamentable that in this area, rich in mineralogical material and potential for new discoveries, such a short-sighted blanket policy has been imposed. Surely some sort of access agreement could be worked out to preserve the adit entrances and to facilitate bona fide underground work by collectors? By contrast, the Hopetoun Estates and Buccleugh Estates at Leadhills - Wanlockhead have for many years encouraged and supported mineral collectors, even to the extent of permitting the driving of a new level into the famous Susanna Vein workings.

If the ultimate effect of conservation policies is severely to restrict or prevent the carrying on of legitimate recreational collecting, then in a relatively short space of time interest in the subject will dwindle, exposures will become overgrown, mine workings will become inaccessible, and there will be no-one left to appreciate that which has been conserved. Science and the institutions will be deprived of material, and as a consequence the already low attendance figures for geological exhibits may well result in a total withdrawal of earth science materials from public display.

A much more preferable scenario would be that practised by the Royal Museum of Scotland as part of its work at Wanlockhead. Material excavated from the Straitsteps Vein dump using a mechanical shovel was subjected to initial screening by museum workers and then placed out to members of the British Micromount Society for detailed examination. Reports of minerals noted in the material were submitted to the Museum, together with relevant specimens. The remaining material was made available to members of the Society for incorporation into their collections.

CURATORIAL STANDARDS

It is of course important that any mineralogical material is properly curated. There is undoubtedly considerable scope for improvement in many amateur collections, but this alone does not constitute adequate reason for denigrating the mineral collecting fraternity. With further education and publicity or assistance from museum curators there is every reason to suppose that major progress can be made in this area. In many cases, material in amateur collections is better cared for than that in provincial museums.

What should happen to the mineralogical material presently residing in the custody of amateur collectors upon the death of its owner? If we are all to be true to our cause - Conserving Britain's Mineralogical Heritage - then we must identify truly safe depositories for the future. With the present trends for cost cutting and commercialisation in the museum world, the situation is changing and it is difficult to foresee what sort of service will survive 50 years hence. There are, however, some encouraging signs - the National Museum of Wales is maintaining a very positive role with regard to the collector, and the new Natural History Centre at Liverpool Museum offers facilities hitherto unknown in Britain.

CONCLUSION

There is undoubtedly a role for the mineral collector in the conservation of mineralogical material. Many problems remain to be resolved. The difficulties are considerable and will require the help, understanding and cooperation of landowners, estate managers, institutions and scientists. With a concerted effort we may yet be able to reverse the worrying trend and growing casualty list of sites no longer available to the mineral collector. It is to be hoped that the inclusion of earth science in the National Curriculum may result in growing numbers of young people taking up an interest in geology and mineralogy. It would be a tragedy if there is nowhere left for them to go.

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ABANDONED METAL MINES: A UNIQUE MINERALOGICAL AND MICROBIOLOGICAL RESOURCE*

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Many of our abandoned underground mine workings have developed extreme geochemical environments with a unique mineralogy and microbiology. The metal mines of North Wales provide some remarkable examples and constitute a valuable scientific resource that merits protection and investigation.

INTRODUCTION

In addition to embodying an important but relatively undervalued part of our industrial heritage, abandoned mine workings represent a unique geochemical resource. The underground workings usually provide the best exposures of the original ore mineralogy and structure and are thus a valuable source of unusual minerals; surface spoil can be a more convenient source but lacks context and suffers erosion. However, there is also an important geochemical consequence, which is expressed both mineralogically and biologically, and arises from a combination of special circumstances. Firstly, the exposure of ore minerals to the surface environment can often generate extreme geochemical conditions and consequently an unusual suite of alteration products and life forms. Secondly, this artificial underground environment is protected from surface erosion processes, and hence the unusual mineralogy and microbiology, which elsewhere might be ephemeral, can survive and thrive.

Interest in the microbial ecology of subsurface environments has grown appreciably in recent years. Areas of concern include the impact of microbial communities on groundwater quality, the possible effects that microbial activities may have on radioactive waste repositories, and the exploitation of subsurface microorganisms in oil and mineral recovery. Abandoned mine workings are important sites for studying this area of microbial ecology; mines which have been abandoned and derelict for some time, thereby facilitating the development of indigenous microbial communities, are particularly useful.

In this paper we intend to describe briefly the nature of such environments and to illustrate the secondary mineralogy and microbiology with some examples from abandoned mines in North Wales.

THE ENVIRONMENT

Mineral deposits are generated under a range of geochemical conditions characteristic of the particular ore, but generally markedly different from those of the surface today. Thus in hydrothermal deposits, the temperatures were elevated, the solute composition saline and enriched selectively in trace elements, and the conditions were reducing, although the pH is uncertain. Such an assemblage is inherently unstable when exposed to our current low temperature, hydrous and oxidising environment. As a consequence, a new suite of minerals is formed, characteristic of the new environment, and the energy released is exploited by specialised groups of life forms. However, some environmental factors, notably temperature, are much more stable within deep mines than they are in surface environments, and visible and ultraviolet radiation is excluded. Given the well-known potential of microorganisms to adapt to even the most seemingly hostile environmental niche, it is not surprising that mine environments are biologically active (Edwards, 1990).

The commonest ore deposits which have been mined comprise sulphides of copper, lead, zinc and a range of associated chalcophile elements. Such sulphide deposits weather readily to produce the distinctive coloured gossans that attracted the attention of early prospectors. However, in so doing, the oxidation of sulphides in siliceous rocks can generate some of the most acid natural conditions known. The orange-brown pools, pigmented by iron(III) (ferric) hydroxyl/sulphate ionic complexes and charateristic of so many old mine workings, are effectively sulphuric acid at remarkably high concentrations, with pH values below 2 having been recorded. These extreme conditions were noted, and put into a microbiological and environmental context, in the classic work of Baas Becking *et al.* (1960), as illustrated in Fig. 1 in which environments are plotted in terms of the two major parameters, pH and Eh. In calcareous host rocks, however, the macro-environment is buffered to higher pH values, and in localised flooded conditions, anoxic (oxygen-free) conditions may persist.

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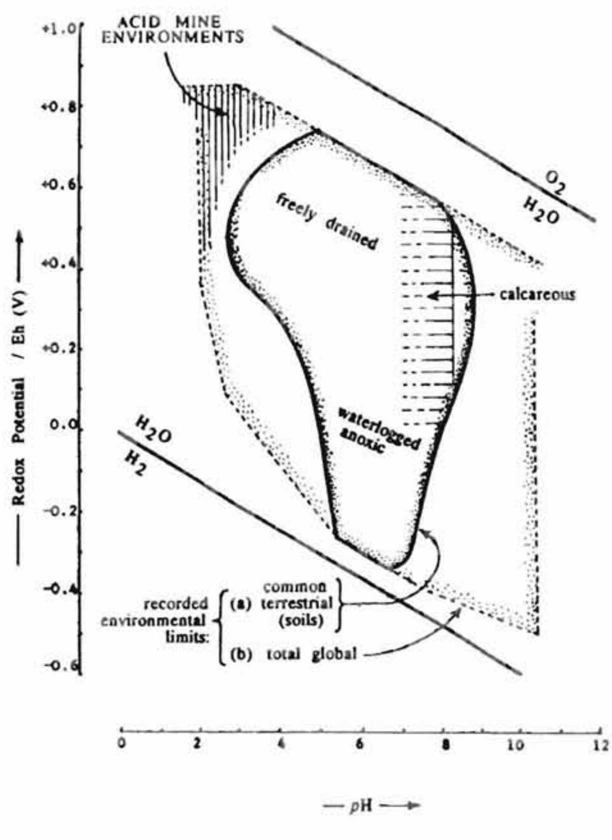

FIGURE 1. Environmental conditions in acid mines in terms of Eh and pH. (After Baas Becking *et al.*, 1960).

Under these varied conditions, and with elevated concentrations of elements that are normally trace constituents of the earth's crust, the range of unusual secondary minerals that can develop and survive in the protected underground workings is considerable. The microflora which colonise an abandoned mine will need to be able to tolerate the conditions as well as to exploit whatever energy sources are available. Organic materials in mines may derive from surface environments, though amounts of such materials are likely to be small, and would support a relatively small population of oligotrophic (or scavenging) microorganisms. Other potential sources are decaying roof-support timbers, bat faeces, and organic matter leached from weathering geological materials such as organic shales.

However, given the absence of light, any primary production within the mine itself would be a function of chemolithotrophic bacteria, which have the ability to utilise the energy available from the oxidation of inorganic chemicals, such as iron(II) (ferrous iron) and/or reduced sulphur compounds. Pyrite (FeS_2) is an abundant mineral in many derelict coal and metal mines, and both the iron and the sulphur, being present in their reduced forms, may be oxidised by chemolithotrophic bacteria. Inorganic chemical oxidation proceeds relatively slowly, particularly at low pH values. However, in the presence of chemolithotrophic bacteria, the reactions are speeded up by a factor of between 10^4 and 10^6, thereby dramatically accelerating the rate of sulphide dissolution.

MINERALOGICAL RESOURCES

Post-mining secondary minerals, being often poorly crystalline and a product rather than a cause of extraction, have not attracted the same attention in the past as the primary ore and supergene minerals. Nevertheless they present a range of interesting and often poorly defined minerals, varying with the ore mineralogy and underground environment. Protected from erosion by rain, they can, under favourable circumstances, develop as localised efflorescences and occasionally accumulate on a remarkable scale. The metal mines of North Wales, as elsewhere, provide some interesting examples in terms of either rarity or scale, a few of which are described below.

In the lead-zinc mines of Gwydyr Forest in Snowdonia, hydrozincite [$Zn_5(CO_3)_2(OH)_6$] has accumulated as a white mud up to half a metre thick in some of the lower levels of Aberllyn mine (Fig. 2). In a few places the deposit has a distinct pale sea-green tinge and contains namuwite [$(Zn,Cu)_4(SO_4)(OH)_6.4H_2O$], for which this is the type locality (Bevins *et al.*, 1982). In other abandoned passages, manganese concretions up to 2 cm in diameter have developed over the last century, comprising an unusual zinc analogue of asbolane [approx. $ZnMn_2O_4(OH)_2.H_2O$] (Roberts, 1986) and providing a useful insight into the growth of concretions. Other interesting trace occurrences include the discovery underground of the new mineral lanthanite-(Ce) [$(Ce,La,Nd)_2(CO_3)_3.8H_2O$] in the Britannia mine, Snowdon (Bevins *et al.*, 1985), and of erythrite [$Co_3(AsO_4)_2.8H_2O$] (Fig. 3) and clinoclase [$Cu_3(AsO_4)(OH)_3$] at the Great Orme mines, Llandudno, scorodite [$Fe(AsO_4).2H_2O$] at mines above Gerlan, Bethesda, and allophane (approx. $2Al_2O_3.3SiO_2.nH_2O$) in the iron mines at Betws Garmon (D.A. Jenkins, *unpublished work*). The type locality for the clay mineral dickite [$Al_2Si_2O_5(OH)_4$] is underground in an abandoned mine working on the Pant-y-Gaseg ridge near Amlwch on Anglesey.

The workings at Mynydd Parys on Anglesey are the type locality for anglesite ($PbSO_4$). They also display a range of secondary minerals including cuprian melanterite ['pisanite', $(Fe,Cu)(SO_4).7H_2O$] (Bor, 1950), halotrichite [$Fe^{2+}Al_2(SO_4)_4.22H_2O$], and extensive deposits in the underground passages of hydronium jarosite [$(H_3O)Fe^{3+}{}_3(SO_4)_2(OH)_6$] (Fig. 4) (D.A. Jenkins, *unpublished work*). However, although numerous iron(III) (ferric) hydroxysulphates are known, the XRD patterns of many of the samples from Mynydd Parys do not conform to those of known minerals; this is an area of mineralogy in need of detailed re-examination. An equally impressive underground site is that of Cae Coch, near Trefriw in the Conwy Valley, where a 1-metre thick band of pyrite has generated a similar range of secondary minerals,

FIGURE 2. Thick white deposits of hydrozincite on the floor of one of the lower levels in Aberllyn mine, now sealed, Gwydyr Forest, Gwynedd.

FIGURE 3. Erythrite efflorescence on copper ore from Treweek's shaft, Great Orme mines, Llandudno, Gwynedd. SEM photograph, width of field 0.02 mm.

dominated by mounds of fibroferrite $[Fe(SO_4)(OH).5H_2O]$ and accompanied by melanterite $(FeSO_4.7H_2O)$ and traces of copiapite $[Fe^{2+}Fe^{3+}_4(SO_4)_6(OH)_2.20H_2O]$ (Johnson *et al.*, 1979). This highly acidic environment provides the setting of a remarkable microbiology, as described below.

MICROBIOLOGICAL RESOURCES

The most significant pyrite-oxidising bacteria are autotrophic, i.e. they obtain their carbon from CO_2, like green plants; they also have minimal nutritional requirements which are generally satisfied in abandoned mines. Most are obligate acidophiles (they require acid conditions for growth), and their activities produce acidity and thus they tend to exclude many other microbes and higher life forms. The best studied in this group is *Thiobacillus ferrooxidans*, a bacterium first described over 40 years ago, though in recent years it has become apparent that other mineral-oxidising bacteria may populate environments such as derelict mines. One of these, *Leptospirillum ferrooxidans*, resembles *T. ferrooxidans* in its ability to grow autotrophically on iron(II) (ferrous iron), though it does not appear to obtain energy from the oxidation of reduced sulphur compounds. Recent evidence suggests that *L. ferrooxidans* is often the most abundant chemolithotroph in acid mining environments (Walton and Johnson, 1992).

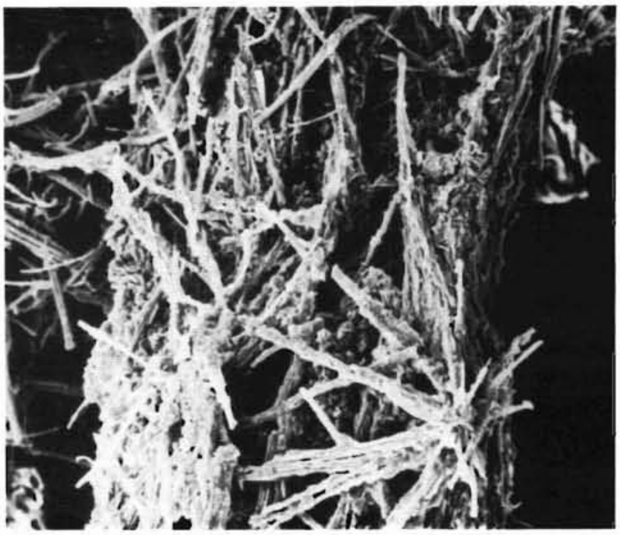

FIGURE 4. Hydronium jarosite deposit from underground workings, now sealed, at Mynydd Parys, Anglesey. SEM photograph, width of field 0.15 mm.

Whilst primary production in abandoned mines which contain significant quantities of sulphide minerals is a function of chemolithotrophic bacteria, other microorganisms may benefit, either directly or indirectly, from the carbon assimilated by these bacteria. The ecology of extremely acidic environments is, in contrast to earlier assumptions, highly complex (Johnson, 1991), though indigenous populations appear to be exclusively microbial. Acidophilic, heterotrophic bacteria (those that cannot use CO_2 as their carbon source) form close associations with autotrophic primary producers, utilising organic compounds leaked from the latter as well as products of cell lysis. Other microbes observed in, and isolated from, acidic waters in abandoned mines are water moulds, yeasts, protozoa and rotifers (Johnson, 1991). Together, these may exist as an intricate food web (Fig. 5). Such a system, involving autotrophic and heterotrophic bacteria and acidophilic protozoa isolated from Cae Coch mine, has been re-created *in vitro* (McGinness and Johnson, 1993).

The most obvious and dramatic manifestation of microbial life in derelict mines comes in the form of macroscopic, gelatinous growths, known as 'acid streamers' (Fig. 6). These may be found as pale cream growths (sometimes with a faint pink tinge) in acidic streams within derelict mines; occasionally they have

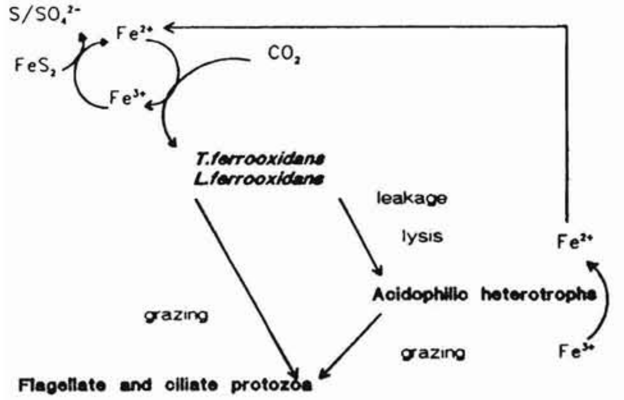

FIGURE 5. Food web based on the microbial oxidation of pyrite.

been reported to occur as stalactite-like forms (up to about a metre long) on moist vertical and near-vertical faces. The most extensive acid streamer growths reported to date were found within the abandoned Cae Coch mine. Here the main drainage stream running through the mine is ramified with acid streamer growths which can be up to 0.5 m deep, accounting for an estimated >100 m^3 biovolume; in addition, most moist surfaces in Cae Coch are colonised by streamer growths in various stages of development (Johnson *et al.*, 1979). A survey of five other mines (lead-zinc, and copper) in the nearby area has found much smaller, discrete streamer growths within them.

FIGURE 6. Deposits of 'acid streamers', on the right, flowing down into the shaft at the bottom of Cae Coch mine, Llanrwst, Gwynedd. The pale foreground consists of deposits of fibroferrite.

The exact reason why acid streamer growths are so prolific in Cae Coch mine is unclear. One reason may be that the heavy metal content of the drainage stream is relatively low, except for iron; acidophilic bacteria vary greatly in their metal tolerance characteristics. Secondly, organic materials leaching from the bituminous shales which are associated with the pyrite deposit may provide carbon and energy sources for acidophilic heterotrophic bacteria. Thirdly, the microbial community has been unaffected by major disturbances for over 50 years since the mine was abandoned. The acid streamers at Cae Coch have been shown to be predominantly bacterial; acidophilic autotrophs (such as *Thiobacillus ferrooxidans* and *Leptospirillum ferrooxidans*) and heterotrophs, as well as some neutrophilic bacteria (those with pH optima around 7) have been isolated from them (Johnson, 1991). One of the acidophilic isolates which demonstrates streamer-like growth *in vitro*, and which is considered to be a major microbial component of the acid streamer community, has been found to be light-sensitive (Johnson *et al.*, 1992); interestingly, the streamer growths do not occur in the drainage stream once it has left Cae Coch mine. This highlights another special feature of the underground environment.

CONCLUSIONS

In this paper we have shown how, owing to special circumstances, a unique mineralogy and microbiology develops in the artificial environment presented by underground mine workings. Apart from their intrinsic interest as minerals or bacteria with unusual chemistry and behaviour, these materials may have specific industrial value.

The microbiology of abandoned mines is seen to be highly complex. Because of their diverse characteristics, they may serve as sites from which novel microorganisms have been, and continue to be isolated. These microorganisms, such as many of those isolated from Cae Coch, have potential in areas of biotechnology. At present, however, the number of isolated and characterised microbial species from the extreme environments presented by derelict and abandoned mines is limited and probably accounts for only a small percentage of those present. The process of using bacteria to oxidise sulphidic ores and solubilise metal constituents (such as copper from chalcopyrite) is known as 'microbial leaching' or 'biomining'. This has developed into an important area of biotechnology and in 1986, for example, it was estimated that the process accounted for 18% of copper production in the U.S.A. (Torma, 1986). Microbial leaching is also used in the recovery of gold and uranium, and the technology may also be used to remove pyritic sulphur from coal (Ehrlich and Brierley, 1990). On the negative side, bacterial oxidation of sulphides at abandoned mine sites and in mine spoil is responsible for the genesis of 'acid mine drainage', a major form of river pollution in many industrialised countries.

Underground workings give access to an understanding of all these important processes. However, once abandoned, such workings can become dangerous through collapse of levels or work chambers and of shaft collars in particular. Derelict mine sites tend to be considered only as eyesores and in need of comprehensive reclamation. Many do, indeed, have to be rendered safe and reclaimed but this approach can be destructive and unjustified. Indiscriminate capping of shafts and sealing of adits without consideration of the unique biogeochemical systems that may be present destroys access to a valuable resource. A prime example of such a loss is at Mynydd Parys, where all entrances to these historic mines, comprising over a hundred shafts and several adits, have been sealed permanently, with the consequent loss of access to a remarkable mineralogy and microbiology, as well as to the historic, and possibly prehistoric (Timberlake, 1988) record. A similar situation has arisen at Aberllyn mines and is threatened at Cae Coch. This situation may be contrasted with that at the Great Orme mines where, through imaginative cooperation between the local Council and mining enthusiasts the mines have been rendered safe yet accessible for continuing exploration and research (Jenkins and Lewis, 1991).

This resource has diminished at an alarming rate in recent years as more mines have been 'reclaimed'. Underground workings are the products of past labour-intensive mining activities and, once lost, their special environment cannot be replaced. It is to be hoped that a more enlightened policy will now be employed such that their remaining mineralogical and microbiological potential can be protected, understood and utilised. The intention of this paper has been to draw attention to this important asset.

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THE BOTANICAL INTEREST OF MINE SPOIL HEAPS – THE LICHEN STORY*

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Spoil heaps are important refugia for certain lichens formerly restricted to naturally metalliferous rocks, many of which have now been mined away. Conservation of such mine vegetation is important not only for preserving rare species and communities, but also because such sites provide a valuable opportunity to study ecosystems stressed by high levels of toxic metals.

INTRODUCTION

Lichens are a combination of a fungus and an alga living together in a mutual relationship. The plant body or 'thallus' may be crust-, leaf-, shrub- or beard-like in form. Lichens occur in a wide range of habitats, many of which are not widely exploited by other plants, e.g. rock surfaces, tree bark and toxic soil. They usually show marked preferences for particular types of substrate, though in common with all living organisms they are affected by a wide range of environmental factors (Barkman, 1958; Brodo, 1973; James *et al.*, 1977). The extent to which rock chemistry, as opposed to the physical nature of the substratum, influences the species composition of lichen communities is not well documented. Since both chemical and physical factors are controlled to a large extent by the mineralogy of the rock, it is necessary to take petrography as well as the chemical composition of the rock into account. Unfortunately, a petrographic examination has rarely been carried out during botanical surveys, making interpretation of such data difficult.

The major objective of this paper is to describe briefly the specialised lichen flora occurring on metal-rich rocks and associated soils on mine spoil heaps in Britain and to assess the importance of conserving mine spoil as a refugium for these lichen communities.

LICHEN COMMUNITIES ON MINE SPOIL

There has been no comprehensive review of lichens occurring on mine spoil heaps in Britain. James *et al.* (1977) refer to a distinctive community, the *Acarosporion sinopicae*, as being restricted to rocks rich in heavy metals, occurring primarily on spoil tips from old mine workings for copper, lead, silver and associated metals. Poelt and Ullrich (1964) introduced the term 'chalkophile' to describe those lichens which occur almost exclusively on metal ore and metalliferous substrata. This somewhat nebulous term serves to accentuate our general lack of knowledge as to the precise relationship of lichens to specific elements in the substratum, this being often complicated by the heterogeneous composition of the substrata. However, it is now clear that iron and copper sulphides as well as lead and zinc minerals may give rise to characteristic lichen assemblages; distinctive communities occur on non-mineralized, carbonate-rich rocks and siliceous rocks, as indeed also on ultrabasic rocks, though these will not be considered further here (see James *et al.*, 1977).

LICHENS OF IRON- AND COPPER-SULPHIDE-RICH ROCKS

IRON

It has long been recognised that certain iron-bearing rocks tend to support a range of predominantly rusty coloured species (Acharius, 1798; Fries, 1831). These lichens belong to the *Acarosporion sinopicae* community, reported by many researchers from central Europe (Wirth, 1972) and in Scandinavia (Creveld, 1981). This distinctive community, dominated by crust-like lichens, is characteristic of rocks rich in iron(II) (ferrous) sulphides which through oxidative weathering create a low pH environment (Wirth, 1972; Purvis and James, 1985). Two constituent associations have been described, characterised by their different ecologies. The *Lecanoretum epanorae* V. Wirth ex P. James *et al.* is typical of steep or vertical, sheltered or exposed, dry and overhanging rock surfaces, whereas the *Acarosporetum sinopicae* V. Wirth ex P. James *et al.* is characteristic of exposed, sunny, horizontal surfaces (Wirth, 1972; Purvis and James, 1985). These communities are best developed in Britain at the Coniston copper mines, Cumbria (Purvis and James, 1985) where five lichen species new to Britain were discovered, but is also well represented at Parys Mountain, Anglesey (Purvis, 1987a) where it is well developed on stable goethite-capped rocks, particularly at the summits and towards the bases of the spoil heaps. Lichen communities on soils bearing significant sulphide contents are typically rather poorly colonised by lichens, though *Micaria lignaria* and other species typical of low pH environments occur.

COPPER

Chalcopyrite, $CuFeS_2$, the most common copper mineral, often occurs together with iron sulphides.

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However, where iron sulphides are subordinate or absent and calcite is additionally present, a different lichen flora develops (Purvis, 1985; Purvis and James, 1985). Alternatively, the same flora may also occur on rocks lacking iron sulphides, but where other secondary copper minerals such as azurite, $Cu_3(CO_3)_2(OH)_2$, and malachite, $Cu_2CO_3(OH)_2$, are present, as at Coniston. At Black Scar workings, Coniston, *Lecidea inops* was found (a first British record) on vein quartz bearing azurite and malachite (Purvis and James, 1985). It was subsequently found on copper minerals on Dale Head, Lake District (Ivan Day, *personal communication*) and is otherwise known on cupriferous substrata in Norway, Sweden and Czechoslovakia. *Stereocaulon symphycheilum* was also present on the same substrate here at its only known British site, but this species is not restricted to mineralized substrates abroad. A recently described species, *Psilolechia leprosa* (Coppins and Purvis, 1987) favours dry, steep or overhanging surfaces of copper-rich rocks, which may be calcareous, such as boulders or, more usually, the walls of old mine buildings or flues. First found in Britain at mines in Cornwall, e.g. at Caradon Hill copper mine near Liskeard and mines near Redruth (Gilbert and James, 1987), it has subsequently been widely found on church walls on mortar beneath, for example, copper lightning conductors throughout the British Isles (Purvis, 1987b).

As in the case of iron in iron-rich rocks, which often produces lichens with rusty coloured thalli, copper can exert a similar influence, turning the thalli of certain species yellow-green as a consequence of the formation of copper-lichen acid complexes including those of norstictic acid (Purvis *et al.*, 1987) and psoromic acid (Purvis *et al.*, 1990), or alternatively making them accumulate blue inclusions of the copper oxalate, moolooite (Purvis, 1984; Chisholm *et al.*, 1987). Whilst lichens with copper oxalate inclusions are frequent, the green copper-rich morphs are much rarer in Britain than those reported from central Scandinavia (Purvis, 1984). In Britain only *Acarospora smaragdula* and *Buellia aethalea* have been observed to change colour as a consequence of copper accumulation, e.g. at Caradon Hill copper mine (Purvis *et al.*, 1985; Gilbert and James, 1987; Giavarini, 1990).

LICHENS OF LEAD- AND ZINC-RICH ROCKS AND ASSOCIATED SOILS

No lichen community has yet been specifically described for lead- and zinc-rich substrates, though rocks on mine spoil heaps containing this mineralization are often observed to be colonized by a range of Stereocaulon species (e.g. James *et al.*, 1977). Lichen communities dominated by species belonging to the genera *Baeomyces, Cladonia, Peltigera* and *Vezdaea* often occur on soils enriched in these elements, as at the Derbyshire lead mines (Gilbert, 1980a), heavy metal-rich shingle beside the River South Tyne (Gilbert, 1980b), mine spoil at Nenthead and other mines near Alston, Cumbria (Coppins and Gilbert, 1981), on heavy metal shingle and at several mines in Wales (Purvis, 1988; Fryday, 1989), and at Leadhills and Wanlockhead (O'Dare and Coppins, 1992). The open vegetation, light grazing and wide pH range of such workings encourage a luxuriant development of terricolous lichens. A detailed survey of Welsh mines was carried out by Fryday (1989) who concluded that they support a distinctive, terricolous flora of great importance with many nationally and internationally important species present, including a number that are apparently undescribed. He considered that the best terricolous lichens were developed on flat areas of relatively high pH, often around old buildings where leaching of lime from mortar has increased the alkalinity of the soil. The presence of *Peltigera lactucifolia* suggested areas worthy of further exploration, whereas more acidic areas with a lichen flora dominated by *Placynthiella icmalea* were generally less interesting.

Several rare species have also been recorded, including *Gyalidea lecideopsis* at one of its two known British sites (Gilbert, 1980b); *G. roseola* from a single collection on shaded limestone at the entrance to an old lead mine at Strontian, Argyllshire, the site subsequently having been destroyed (Gilbert, 1984); *G. subscutellaris* in mid-Wales (Purvis, 1984); the rare *Peltigera venosa* recorded at Black Burn mine near Alston (Coppins and Gilbert, 1981) and at an old spoil heap near Cannigill, Cumbria (D.E. McCutcheon, *private herbarium*), which otherwise is known only from mountains in Scotland and Snowdonia; and *Placynthiella hyporhoda* in mid-Wales (Fryday, 1989). Other rare species present in such habitats but otherwise recorded from mountainous areas include *Arthrorhaphis fuscireagens* (Woods, 1988) and *Micarea cinerea* and *Stereocaulon condensatum* (Fryday, 1989).

DISCUSSION

Until recently, mine sites have received relatively little attention from lichenologists involved in taxonomy and/or ecology as compared with many other lichen habitats. Lichen physiologists, on the other hand, have for long realised the research potential of such sites and have studied certain species (mostly the larger, foliose species) to look at mechanisms of metal uptake with a view to suggesting tolerance mechanisms, etc. This general lack of attention by ecologists has probably been due to, at least partly, a misconception that such sites are species poor. It is, for example, a matter of general observation in churchyards (a much studied lichen habitat) that lichens are usually absent on parts of tombstones subject to run-off from lead lettering. Likewise, copper grilles covering stained glass windows produce bright green deposits of secondary copper compounds on adjacent stonework; these areas at first sight appear to be devoid of lichen growth. On mine sites, cover by lichens (and other plants) is frequently low and some species may be stunted, leading to problems of identification. A further difficulty is the seasonal nature of some of the more interesting terricolous species which are best developed during the winter and spring. Furthermore, the important influence of mineralogy on the composition of lichen communities has only recently been recognised in Britain. Clearly, different spoil heaps can support very different lichen communities, mainly in response to subtle difference in mineralization.

Recently there has been considerable interest in lichen communities associated with metal-rich substrates in the UK, for two major reasons. Firstly, detailed field work has added a significant number of new species to the British list, including some new to science; this has stimulated further survey work. Secondly, many metalliferous rocks contain toxic elements and the study of tolerance mechanisms of lichens (and other organisms) associated with these substrates is of fundamental biological importance. For example, in the case of copper, many copper compounds are used both as a fungicide and an algicide, yet some lichens not only tolerate copper-rich environments but seem to have a requirement.

Heavily mineralized, naturally occurring rocks exposed at the surface are uncommon in Britain, most having been mined away. Therefore, mine spoil heaps and associated mineralized habitats, including mine buildings, must be considered refugia since they may contain a lichen flora and communities which are rare or fragmentary in an undisturbed habitat. As many spoil heaps are currently under threat from restoration or rewashing, there is an urgent need to assess and document the importance of these sites in Britain as a first step towards the conservation of the best examples. A further threat is that of capping mine spoil with benign material. Grading out and seeding with heavy metal tolerant strains of higher plants is preferable for lichen conservation interests. It has been observed that the removal of mine spoil and its transport to other sites can result in new areas being colonised by characteristic species. Woods (1988) has reported how mine spoil has been spread about the countryside by the Forestry Commission, private companies and farmers as a weedkiller. For example, The Cambrian Railway Company made widespread use of spoil from the Van lead mines at Llanidloes in Montgomeryshire, so that, 25 years after the railway closed, tracks over 30 miles away in south Radnorshire were still relatively weed-free and supported communities of lichens reminiscent of those on lead mine spoil tips, e.g. *Vezdaea leprosa, V. retigera*, and *Steinia geophana*.

The dispersal of lichen propagules and their establishment in new environments is a little studied phenomenon. Some species must be efficient colonisers, for example *Psilolechia leprosa* which is in a large number of churches, and *Vezdaea leprosa* which regularly occurs in the drip zone beneath galvanized wire fencing. However, it seems likely that these and several other species are also able to colonise other, non-mineralized disturbed habitats where competition from other plants is reduced. Interestingly, Gilbert (1990) reports on the occurrence of several metallophyte lichens in disturbed urban habitats, e.g. *Steinia geophana, Vezdaea leprosa, V. retigera*, and *Sarcosagium campestre*. These occur, for example, around old bonfire sites and on bricks. A second group of metallophyte lichens can be identified as occurring in mountainous areas, mostly in Scotland. *Peltigera venosa* occurs on mine sites in England, but in natural habitats in Scotland and Wales. It is possible that such populations in lowland habitats are glacial relicts, which formerly occurred on naturally mineralized substrates but which secondarily spread, to a very limited extent, to adjacent mining areas. A similar explanation has been used to explain the distribution of certain metallophyte higher plants, e.g. *Minuartia verna* and *Armeria maritima* on copper turf at Dolfrwynog, north Wales (Ernst, 1990).

In conclusion, the conservation of mine spoil heaps is clearly important from a lichenological point of view, though there are many factors which are still poorly understood. Amongst these, for example, are the age of exposure of rock surfaces, i.e. how long it takes for particular communities to develop; the stability of heaps; and the importance of rock mineralogy. With respect to the last, more work clearly needs to be done on the availability of toxic metals to plants. In the short term it is a priority to define criteria for grading metallophyte mine sites and for carrying out further field work in areas likely to be of particular interest. The Nature Conservancy Council have developed a system for evaluating sites for their nature conservation and wildlife value (Nature Conservancy Council, 1988). It involves the systematic application of ten criteria and could be adapted to cover heavy metal sites by, for example, giving a high 'rarity' weighting to their characteristic flora. In view of the many thousands of mine sites, it will be important to consult geologists and other specialists to help identify those which should be surveyed as a matter of high priority before they are erased from the landscape.

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CWMYSTWYTH, WALES: 3500 YEARS OF MINING HISTORY – SOME PROBLEMS OF CONSERVATION AND RECORDING*

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Excavations at Copa Hill, Cwmystwyth, central Wales, have provided evidence for a mining history back to the Bronze Age. These studies have led to the designation of an Ancient Monument. However, mineralogical interests in the area generally, and at Copa Hill specifically, highlight the potential for conflicts of interest at such sites.

INTRODUCTION

Situated on the west edge of the Cambrian Mountain divide and about 23 km ESE of Aberystwyth, within the Central Wales Mining District, is one of the most spectacular mining landscapes in Britain. With many of the adits, shafts and opencast workings located high up on the rocky slopes of a glaciated U-shaped valley, it is easy to understand why this area attracted prospectors from such an early date. In fact, recent research has indicated that it must now rank amongst the oldest known metal mines in Britain, first exploited for copper during the Early Bronze Age – more than three and a half thousand years ago (Timberlake, 1992). Field and documentary evidence suggests a more or less continuous history of lead (and subsequently zinc) mining from the Late Medieval Period until the closure of the mines in the 1930s. A more detailed account of this was presented by Hughes (1981).

This paper sets out to examine the archaeological importance of Cwmystwyth, and by inference of other similar sites, and comments on the sorts of problems encountered and the types of approach required, both for the investigation and the conservation of the mining landscape.

HISTORICAL RECORD OF MINING AT CWMYSTWYTH

The earliest authenticated account of mining at Cwmystwyth relates to the issuing of a lease by the Abbot of Strata Florida Abbey dating from 1535 (Hughes, 1981). Nevertheless, when Leland passed through this valley in 1539, it appears that Cwmystwyth was already known as an old mine.

Cwmystwyth was later at work during the Elizabethan period and again throughout the 17th century. After the Civil War there was a revival in mining under the direction of William Waller and the Company of Mine Adventurers, and following this Thomas Bonsall, a Derbyshire man, was engaged to manage the mines. By the 1780s he was reaping a clear profit of £2000 per annum. It was Bonsall who first began to exploit the vast reserves of zinc ore left by the old miners.

The 19th century saw an expansion and technological improvement in mining and by 1848 John Taylor & Sons, the eminent Cornish mining engineers, had a controlling share in the operation. However, with the discovery of the massive Broken Hill lead deposits in New South Wales in 1883 and the resulting slump in the lead price, the fortunes of Cwmystwyth, and indeed of many other British mines, began to decline.

The onset of the 20th century at Cwmystwyth saw a further revival in activity and a great deal of exploratory work and new development was undertaken. Despite these last-ditch attempts, all activity ceased at the mine in 1939, effectively bringing to an end a long era of mining, and a memorable episode in the social and industrial history of the valley.

SURFACE REMAINS - THE UNWRITTEN RECORD

To anyone visiting the site it soon becomes apparent that there are many unrecorded features in the landscape. Such a situation is not peculiar to Cwmystwyth, but the scale and preservation of such features here is perhaps exceptional.

The south-west slopes of Copa Hill are dissected by a vast array of water-cut trenches or 'hushes' (Fig. 1), radiating out from a reservoir on the moorland above. These are cut by a still older series of trenches originating from an ancient leat which runs along the brow of Copa Hill. The older trenches were excavated downslope following the outcrop of the Comet (Copper) lode. Hushing is an activity that has been practiced at least since Roman times, but here at Cwmystwyth the hushes are most likely to be post-Medieval. They were cut by directing a surge of water from a breached dam or watercourse, to reveal mineral veins hidden beneath an overburden of drift covering the lower slopes of the hill. This is possibly the finest

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FIGURE 1. Mining landscape of Copa Hill, Cwmystwyth, showing some of the finest hushes outside the northern Pennines. The site of the Prehistoric opencast is labelled 'A'.

surviving example of hushing in Britain outside the lead mining areas of the northern Pennines.

In other areas of the mine, such as the Kingside lode workings on Copa Hill, there are 'ancient' tips and open rakes hundreds of yards in extent, which contain upwards of 200,000 tons of hand-crushed waste (Hughes, 1981). Amongst these are to be found small roofless dry-stone shelters in which the hand-dressing of ore may have taken place. Some contain mortar stones *in situ* and small primitive stone-lined buddles. These are all of uncertain date, but many are probably pre-19th century, and some are almost certainly pre-gunpowder (ca 1700) in origin.

To the west of Copa Hill, on the rock called Craig Fawr, is a large opencast working situated at the point where the two main lodes, the Kingside and the Comet, meet. Here the shoots of ore were extremely rich, and these were also worked from an early date.

It is the ambiguity and complexity of all these workings which makes archaeological investigation so essential a process in gaining an understanding of the site. As part of the work of the Early Mines Research Group, such investigations have been carried out on Copa Hill over the last five years (Timberlake and Mighall, 1992).

ARCHAEOLOGICAL SURVEY

Whilst the focus of this research has been the examination of the prehistoric workings, it was also important to try and identify the sequence of mining events over the whole of the site. It was necessary in fact to conduct a total landscape survey of the hill. This survey revealed other contemporary elements of land use, often juxtaposed with, yet quite unrelated to mining remains. These included the foundations of small hafods (summer dwellings), peat diggings on the moorland above, as well as peat sledding tracks and drying platforms adjacent to the earliest mineworkings. Elsewhere, it uncovered the existence of a previously unsuspected Bronze Age cairn, and the barest remains of a Medieval or early post-Medieval lead smelting site. The survey showed that the sequence of mining and mining-related features was very much more complex than previously suspected.

ARCHAEOLOGICAL EXCAVATION

Ten years ago few archaeologists (or geologists) would have contemplated the possibility of identifying both the sites and the remains of prehistoric metal mining in Britain. However, within the last few years four Bronze Age copper mines have been identified and dated, and at least 20 other sites have been suggested, all based on fairly good circumstantial evidence (Timberlake, 1992). The great majority of these are in Wales. Such sites, characteristically, have been identified on the basis of the presence of primitive stone mining hammers. One of the best preserved sites is that on the top of Copa Hill. Here, weathering out from more than 100 metres of overgrown spoil tip, are found hundreds of bruised and fractured pebble hammers, associated with shattered' fire-set' waste rock and charcoal. The tips were first sampled scientifically in 1986, and radiocarbon dating of the charcoal suggested a date of *ca* 1500 BC (Timberlake, 1990).

The depth (>7 m) and preservation of the early opencast here is surprising. Pounding marks made by stone tools have survived well within a short cave-like mine gallery (Fig. 2), and waterlogged wood and peat occur within a complex stratigraphy of later infill deposits. Such environmental evidence as is known suggests that this working was already abandoned and partly infilled by the Middle to Late Bronze Age.

All the same, there are many lessons to be learnt from the investigation regarding the interpretation of this and, by inference, other early metal mining sites in Britain. The site was chosen because it appeared to be so little disturbed, yet careful excavation has revealed evidence for much later activity and reworking. In fact, within an area no larger than eight square metres, evidence has been found for three or four phases of mining activity, spanning more than 3000 years.

It is because so many unresolved questions remain about the early history of the mine that a much broader-based scientific investigation of the landscape

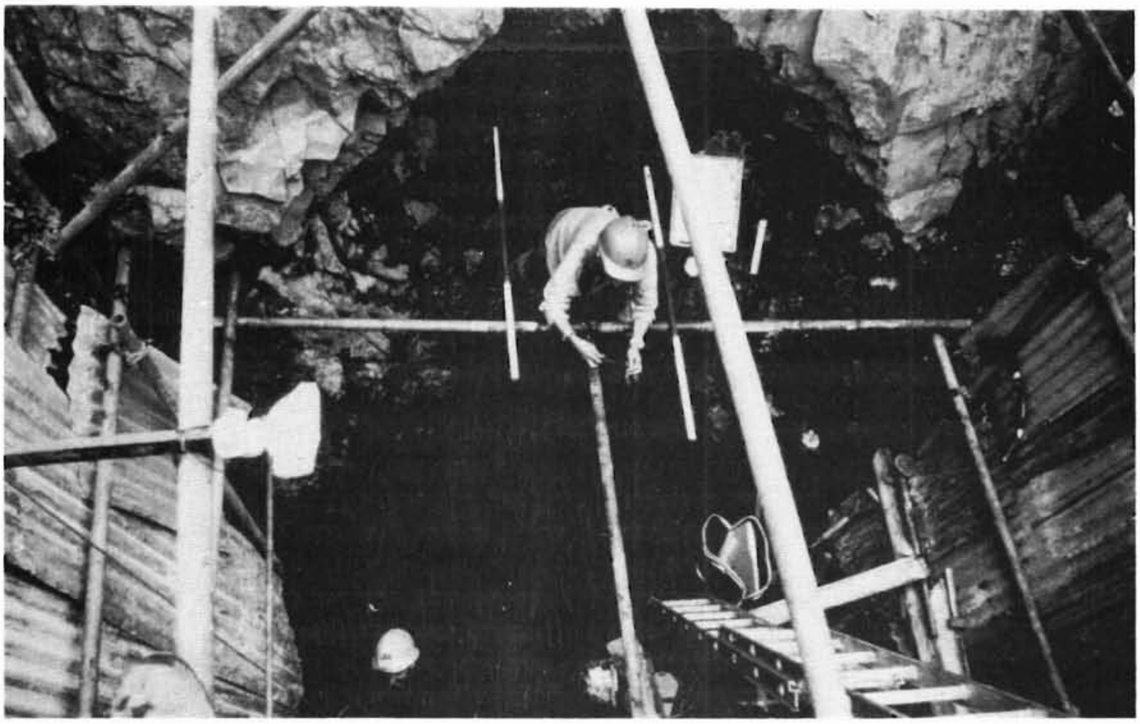

FIGURE 2. Excavation and recording within the ancient opencast, Cwmystwyth, 1991. In the background is a short mine gallery worked by stone tools and fire-setting.

has become necessary. Pebbles of lead ore, and also of slag from smelting, have been found within lenses in the riverine gravel deposits exposed on the banks of the River Ystwyth, whilst on the top of Copa Hill the blanket bogs have been cored to sample the pollen record. The cores have been examined for evidence of periods of deafforestation, burning, cultivation, and other indications of human activity (Timberlake and Mighall, 1992). Radiocarbon dates from these have suggested that peat initiation began contemporaneously with, or else shortly after, the abandonment of Bronze Age mining on the site. Further study of these sediments may also reveal past levels of pollution, and hence an indication of smelting nearby.

UNDERGROUND SURVEY OF MODERN WORKINGS

Many of the underground workings at Cwmystwyth are still accessible, and this has made the mine popular with sporting cavers, as well as with more serious documenters of the underground industrial landscape. Since 1985 members of Aberystwyth Caving Club and Ceredigion Mining Group have systematically surveyed all the accessible workings within the Pugh, Kingside (Lefel Fawr), and Copa Hill mines. The outline survey, produced to BCRA Grade 4, is now all but complete, with over 15.5 km of passages surveyed.

Underground workings (Fig. 3) have been opened up and access gained to sections of the mine which have been closed off for almost 150 years. This has afforded the surveyors the unique experience of recording mineworkings 'frozen in time', little changed from the moment they were abandoned. In such instances it has been essential to record even the most minor details, such as hob-nailed clog footprints preserved in the mud of the floor, before the passages are fully entered and changed forever. Comparisons with other known workings have shown that it is quite possible to differentiate and date several different styles of mining carried out over the last 400 years.

SOME PROBLEMS AND CONFLICTS OF CONSERVATION

INDUSTRIAL ARCHAEOLOGY

Whilst in other mining areas of Great Britain there are, and have been, many examples of successful projects to conserve mine buildings and to interpret sites, the record for mid-Wales is poor. Possibly more has been destroyed or lost in this mining region during the last 25 years than during the previous 100 years or so. Cwmystwyth is no exception.

The ore-dressing shed at the mine (Fig. 4), built by Henry Gamman at the turn of the century, and possibly the only surviving example of such a building in Britain, was a prominent landmark which stood above the roadside in the middle of the valley. Free from vandalism until its final years, it was nevertheless recently demolished. This seems to have been the only tangible product of a large sum of Welsh Development Agency money thich had earlier been earmarked for 'environmental work, landscaping and improvement at the mine'. Whilst the problems of liability associated with the ownership of or responsibility for abandoned mines are well recognised, a more positive and imaginative solution would have been more appropriate. Surely planning should aim to preserve important

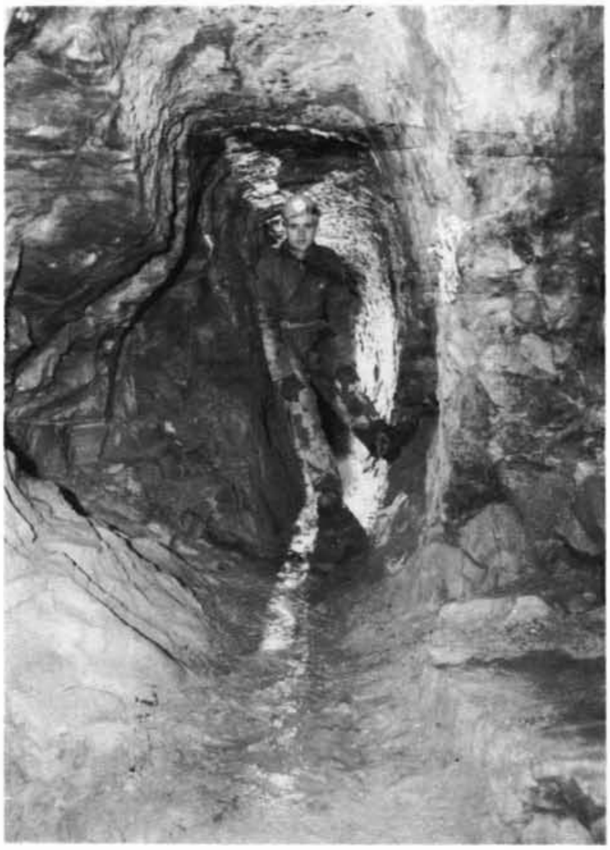

FIGURE 3. Pick-cut 'Roman' level crosscut above Lefel Fawr. Cwmystwyth, 1986. Photograph courtesy of Mr R.P. Jones, Welsh Industrial and Maritime Museum.

features, and enhance rather than diminish the heritage value of sites like Cwmystwyth? In many cases such a heritage use is perhaps the only promising future they are ever likely to have.

ARCHAEOLOGY

In 1985 the south-western slopes of Copa Hill, along with their hushing remains and ancient workings, were designated an Ancient Monument. Whilst this area is not currently under threat, it is worthwhile to consider the matter of its conservation.

The excavated area within the prehistoric opencast. by agreement with CADW, will have to be backfilled and returned to its pre-excavation state. In the long term, this will help to protect the site, by preventing the drying out of waterlogged remains and by protecting the Bronze Age gallery from human or natural damage such as weathering. A further issue relates to the large number of artefacts, such as pebble hammers and mortar stones, lying loose upon the surface at the site. These are all part of the monument, and thus it is an offence to remove or disturb them without permission, although this fact may not be at all obvious to the casual visitor. This element of human erosion is a potential threat to the site, and illustrates the opposing merits of making such sites better known.

MINERAL COLLECTORS

A similar situation arises regarding the activities of mineral collectors. The exposed tips at Cwmystwyth have regularly received the attention of both the amateur and the professional mineral collector. In fact,

FIGURE 4. The ore-dressing mill at Cwmystwyth in 1985, prior to demolition.

some of the most sought after locations for mineral species are to be found on Copa Hill within the statutory protected area. Whilst collecting on a minor scale is unlikely to cause much harm, there are a few examples where serious damage has taken place as a result of more intensive or possibly commercial collecting for pyromorphite and cerussite from amongst some of the earliest workings at the top of the Kingside Lode (Fig. 5). Ancient tips are just as much part of a monument as buildings are and, in fact, these tips may contain buried structures of as yet unknown age and significance. Clearly there is a real conflict of interests.

CONCLUSIONS

This paper has examined the kind of research currently being carried out by mining archaeologists at some of Britain's most ancient metal mining sites. However, it also raises a number of important issues relating to the conservation, management and future use of abandoned mines and mining landscapes.

If such sites are to be fully recognised as both monuments and also unique geological and ecological environments in their own right, then it must be accepted that spoil tips, shafts and ruins are as much a part of these as any upstanding structures that survive. In fact, it would be best to preserve whole landscapes, rather than just individual 'features' within what might otherwise become completely reclaimed environments.

With the benefit of foresight, planners should perhaps be alerted to the realization that future generations may wish to see some of this past preserved, and that the uniqueness and attraction of an area to tourists might best be served by keeping some things as they are, rather than by 'normalising' the landscape through reducing such interesting sites to the fate of landfill, golf courses, theme parks and the like.

What is clear is the inherent importance of much of what is left, and also the variety of scientific research which is already being undertaken. However, an important question is who is qualified to judge what is or isn't worthy of protection, and on what basis? Furthermore, if no adequate mechanism or forum for cross-disciplinary consultation exists, how it is possible to know what is being threatened, and when? In the race to 'green away' the past, we are losing the opportunity to assess the real value of what is disappearing beneath the tracks of the bulldozer.

FIGURE 5. Ancient mineworkings on the Kingside lode, showing signs of excavation for mineral specimens, despite lying within a statutory protected area.

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RESOLVING CONFLICTS: RECLAMATION AND MANAGEMENT OPTIONS*

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The reclamation of metalliferous mines is carried out principally to remove environmental pollution or to make sites safe. Such reclamation can fulfill these needs and protect features of value on site.

INTRODUCTION

Metal mining in the United Kingdom now accounts for a tiny proportion of the world metals output and is virtually confined to fluorspar and tin mining. However, Britain was a major metal producer in the eighteenth and nineteenth centuries. At that time little thought was paid to the environmental consequences of such activities, and water and land became polluted. It has been estimated that over 4000 km^2 of land in Britain has been affected by metalliferous mining activities (Johnson *et al.*, 1977). Many individual mines were small but densely concentrated in areas where metal-rich rocks are found. For example, the District of Ceredigion in Wales contains over 200 known mines at an average density of one in every 10 km^2. Other mines were large and some individual mines have resulted in many hectares of land being grossly polluted. The dependence of these mines on water as a source of power and for ore processing meant that all are close to water courses and water pollution is a principal problem caused by these mines today. Because many of the abandoned mines are old and have been relatively undisturbed, they are of industrial archaeological, mineralogical and wildlife importance.

In recent years there have been attempts to remove the dereliction left by these mining operations. This is particularly so in Wales where initiatives by the Welsh Development Agency have led to a number of reclamation schemes for metalliferous mines having been completed.

This paper discusses reclamation techniques with respect to balancing the need to prevent environmental damage and to conserve features of value.

AIMS OF RECLAMATION

There are five principal reasons why the reclamation of metalliferous mine sites is carried out:

(i) Prevention of pollution.
(ii) Making the site safe.
(iii) Removal of eyesores.
(iv) Putting the land to beneficial use.
(v) Conservation of valuable attributes.

Where long-abandoned mines are concerned, reason (iii) may not apply, and (v) will apply if the site is of wildlife, mineralogical or archaeological value. Where operating or recently closed mines are concerned, the aims of reclamation may include any of the above, but reclamation has additionally to satisfy the regulatory authorities and planning consent conditions.

PREVENTION OF POLLUTION

Of the reclamation aims listed above, the prevention of pollution is the one to which most attention has been devoted. This is because, compared with the commonly used standards for water and soil, metalliferous mine wastes and the waters draining from them are grossly polluted. As with other contaminated land, techniques for dealing with metalliferous mine wastes are concerned with addressing the following model:

$$\begin{array}{c}\text{Source of}\\ \text{pollution}\end{array} \xrightarrow[\substack{\text{medium of}\\ \text{transport}}]{} \text{Target}$$

For metalliferous mines the source of pollution is invariably metalliferous mine waste or mine adit drainage, and the transport medium is air or water. There is a range of targets depending on the end use and location of the site. These targets may include grazing animals, people occupying or using the site, and aquatic life. The model only functions if all three components, source, transport medium and target, are present. The aim of reclamation is to render the model inoperable and thus the techniques centre on removal of any of the components. It is usually impractical to remove the source of pollution, the mine water, or the target, so techniques focus on preventing the contaminant reaching the target in such concentrations as to cause damage. The techniques available are thus conveniently discussed under headings of the transport media, air and water.

AIR AS TRANSPORT MEDIUM

There is considerable evidence of the pollution of adjacent land through wind-blown dust and of the elevated levels of metals in household dusts and in the gardens of domestic properties (Davies and Roberts,

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1978; Moffat, 1989). In some areas of former mining in the U.K., livestock suffer from disorders or die because of lead poisoning (Wardrope and Graham, 1982). The key to the prevention of airborne pollution is the establishment of an effective vegetation cover and management to sustain it. Techniques for achieving this have been discussed elsewhere (Palmer, 1991) and will not be further addressed here.

WATER AS TRANSPORT MEDIUM

Water is a transport medium of metals in a number of potentially polluting situations:

(i) Movement of metals into plants and thus the wider environment.
(ii) Movement laterally or vertically into unpolluted soils.
(iii) Movement into water courses and thence to other aquatic and terrestrial habitats.
(iv) Movement into groundwater.

Metals are transported in water in three principal ways:

(a) In solution.
(b) Suspended as particles of spoil.
(c) Absorbed on to non-spoil particles such as organic matter.

The degree to which these three are important depends to an extent on the mineralogy, pH and erodibility of the spoil. In addition, other site-specific conditions such as rainfall and degree of natural colonisation are important.

RECLAMATION TECHNIQUES

Reclamation schemes to deal with such environmental pollution may involve the following techniques:

(i) Excavation and removal of spoil.
(ii) Capping or covering of spoil heaps with uncontaminated materials.
(iii) Remodelling of spoil heaps.
(iv) Removal and demolition of structures.

Unless the features of value at a site are considered prior to the design of a reclamation scheme, these features are likely to be lost during reclamation works. All reclamation schemes should therefore be preceded by a feasibility study which considers both negative and positive aspects of a site (Table I), and involves consultation with conservation and pollution regulation bodies.

Considerable flexibility may be available within a reclamation scheme to conserve features of importance as well as to deal with pollution matters. Crucial considerations are the end use of the site, the extent to which the site is a pollution hazard in its existing state, and the control that is likely to exist over the future management of the site. It is quite feasible,

TABLE I. Example of the contents of a feasiblity study for a metalliferous mine reclamation scheme.

1	**INTRODUCTION**
2	**SITE DESCRIPTION**
2.1	Setting
2.2	Soil and spoil contamination status
2.2.1	Introduction
2.2.2	Areas
2.3	Vegetation and wildlife
2.3.1	Introduction
2.3.2	Vegetation
2.3.3	Other features of wildlife interest
2.4	Waters
2.4.1	Introduction
2.4.2	Regional water courses
2.4.3	Contamination by water issuing from shafts and adits in the study area
2.4.4	Local water courses
2.5	Mine workings
2.5.1	Shafts and adits
2.5.2	Extent of underground works
2.5.3	Water levels and discharge
2.5.4	Structures
2.6	Industrial archaeology
2.6.1	Introduction
2.6.2	Description of the remains
3	**MINING POTENTIAL**
4	**MINERALOGICAL VALUE**
4.1	Introduction
4.2	Geology
4.3	Mineralogy
4.4	Areas of mineralogical significance
4.5	Conclusions
5	**SURFACE AND MINERALS OWNERSHIP**
5.1	Surface ownership
5.2	Minerals ownership
5.3	Future ownership
6	**REPROCESSING POTENTIAL**
6.1	Introduction
6.2	Experimental results
6.2.1	Sample characterisation
6.2.2	Investigation of gravity separation
6.2.3	Froth flotation testwork
6.3	Conclusions
7	**LAND USE OPTIONS**
8	**RECLAMATION OPTIONS**
8.1	Introduction
8.2	Constraints and opportunities
8.2.1	Industrial archaeology
8.2.2	Wildlife and conservation
8.2.3	Mineralogical value of spoil heaps
8.2.4	Pollution of water courses
8.2.5	Drainage and water treatment
8.2.6	Disposal and containment of contaminated material
8.2.7	Reprocessing
8.2.8	Structures and shafts
8.2.9	Landscape considerations
8.2.10	Outline design
8.2.11	Programme
9	**COSTS**
10	**REFERENCES**
11	**APPENDICES**

therefore, and not uncommon, for a reclamation scheme to include:

(i) Remodelling and capping of some spoil heaps.
(ii) Excavation and removal of some spoil.
(iii) Preservation of some spoil heaps intact.
(iv) Conservation of buildings and other structures.
(v) Making mine openings safe while conserving their wildlife and archaeological importance.
(vi) Conservation of areas of mineralogical importance.
(vii) Conservation of areas of wildlife importance.
(viii) Allowing of appropriate public access and use.

The list above is in fact extracted from the recommendations made in a feasibility study for the reclamation of a mine in mid-Wales. In that study, lode outcrops were recommended for protection because of their geological value. In another feasibility study, the internationally rare secondary mineral ramsbeckite was found, indicating that such studies can add to our knowledge of the occurrence of such features. Features of value do sometimes have to be destroyed or disturbed and, on sites where features of value are being affected, it is common practice to have an industrial archaeologist or wildlife specialist present during site works to advise on working methods and conservation. Employment of a resident mineralogist is less common, but is likely to become more common in future as the mineralogical value of metalliferous sites becomes more widely recognised. One feasibility study has, however, recommended the employment of a mineralogist to oversee the removal of a spoil tip, the salvage of material of mineralogical value from the tip, and its placement in an area where it can be used for educational purposes.

MANAGEMENT OF SITES

In all reclamation schemes the future use of the site must be considered at the outset. It is also important that funding and permission for the management of the site for the proposed end use are assured before design takes place. So, a minimal reclamation scheme to make structures safe and to preserve features of value would involve little earthmoving and perhaps little disturbance over large areas. Such a scheme would, however, need management to ensure continued protection of the features, prevention of erosion of sensitive vegetation, and site use only as designed. For example, if metalliferous spoil is exposed at the surface the area must not be allowed to become a children's play area, and management must ensure this is so. Conversely, if a children's play area is needed, appropriate barriers such as a tarmac surface must be installed to ensure children do not come into contact with metals in the spoil. Management would then need to ensure the integrity of the barrier. A more comprehensive reclamation scheme would require management of a different kind, for example the maintenance of grass swards or trees. Protection of capping layers through restictions of certain activities on the site would also then be needed.

CONCLUSIONS

The reclamation of metalliferous mine sites can destroy features of value unless the site is properly researched before reclamation design starts. The carrying out of a feasibility study with an appropriate scope should ensure that features of value are properly considered. Once this has been done, flexibility of approach in reclamation design and appropriate site supervision should ensure the conservation of features of interest. In many cases reclamation schemes have been the saviours rather than the destroyers of features of value. Management must aim to continue the desired use of the site without detriment to features of value.

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GREENING THE ENVIRONMENT AND ACCESS TO MINERALOGICAL SITES: CONFLICTS AND OPPORTUNITIES*

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Pressure for a greener environment is leading to vigorous attempts to reclaim derelict land. Planning conditions for restoration of mineral workings and tips are becoming more rigorous. Advice on forward planning of land-use and control of development reflects these trends. Treatment of mined and contaminated land and of shafts is often included in derelict land reclamation initiatives. At the same time, society is producing large quantities of wastes which are disposed of in landfill sites which are often former quarries. These factors can remove access to features of mineralogical interest. Whilst environmental improvements need to be secured, it is important to retain sites for research and education. This requires awareness of the importance of this aspect of conservation amongst the local authorities responsible for preparing Development Plans, industry which carries out development, and the public, and also imaginative solutions. However, wide awareness can lead to over-collecting of specimens from individual sites.

INTRODUCTION

The last 40 years have seen a marked reduction in underground mining of minerals in Great Britain together with a substantial increase in surface workings, notably for aggregates and coal. Extraction of metalliferous and vein minerals is a tiny fraction of that in the past as reserves have been worked out or more competitive sources have been found elsewhere.

Therefore, whilst mineral extraction for industry and construction has flourished, access to those associations of minerals which are of greatest interest to researchers and collectors has become increasingly difficult. Attention has become concentrated increasingly on a limited range of sources. Increased emphasis has been placed on investigating workings and tips left by earlier generations of miners, for instance in South West England, North Wales, the Pennines and the Lake District. The importance of museum collections made when fine specimens could be more readily obtained has also been enhanced.

WORKING QUARRIES AND MINES

Good material can still be secured from some working quarries and mines, for instance in the north Pennines ore field, the Peak District and the china clay pits of Cornwall. However, increasingly stringent Health and Safety requirements have, understandably, led to more restrictions on access and, in some cases, to charges for staff time taken up in supervising visitors. Limitations on access continue when working has ceased.

In addition, it is Government policy to ensure that land taken for mineral operations is reclaimed at the earliest opportunity and is capable of an acceptable use after working has come to an end (DOE/WO, 1989). This is achieved through planning conditions to secure restoration of workings and tips. Tips are landscaped. Quarries are often infilled and there is a strong demand for use of such sites for waste disposal where the ground conditions are suitable.

A substantial proportion of active sites of mineralogical interest are old workings which have limited restoration conditions. It has been recognised that there is a need to bring these into line with current practices. The Minerals Act 1981 contained provisions for review of planning conditions by the Minerals Planning Authorities (DOE/WO, 1988). The Planning and Compensation Act 1991 addressed the matter of Interim Development Order Permissions – those which existed at the time of the implementation of the original Town and Country Planning Act and were regularised by it. Those permissions are now subject to an application to the Minerals Planning Authority for determination of conditions (DOE/WO, 1992a). Provisions have been introduced also to update planning conditions on permission given during the 1950s and 1960s in order to bring these into line with modern standards (DOE/WO, 1991).

These measures will help to ensure that mineral extraction is undertaken with the least adverse environmental effects and that workings are adequately reinstated when operations cease.

DERELICT LAND

Government attaches high priority to the reclamation of derelict land, a legacy of past industrial and extractive activity, and to encouraging its return to beneficial uses as soon as possible (DOE, 1991). Derelict land grant is made available for approved reclamation

*Paper presented at the conference on 'Conserving Britain's Mineralogical Heritage', University of Manchester, 31 March - 1 April, 1992.

schemes. The initial emphasis of this reclamation initiative was placed on restoration of sites to uses such as housing and factories. More recently, greater weight has been placed on schemes which will improve the environment or deal with serious contamination (DOE, 1991; Cmnd 1200, 1990). The policy for disbursement of derelict land grant will be reviewed when this is transferred to a new Urban Regeneration Agency in the near future.

In rural settings, the emphasis is placed on reclamation in areas of particularly high scenic quality or nature conservation value. Much land left derelict by past metalliferous mining occurs in such circumstances. A number of key metal mining locations are included in Assisted Areas where a higher rate of grant is payable towards reclamation works because of the extent of derelict land.

Substantial areas of mined ground have been reclaimed using derelict land grant and this has included, for example, infilling of voids, treatment of mine openings, and landscaping of tips. Derelict land grant can be made available for appropriate schemes to treat groups of disused mine shafts in order to secure public safety. Research was undertaken for the Department, by Freeman Fox Ltd, on the treatment of disused mine openings (Freeman Fox Ltd, 1988a) and planning guidance based on the results of this work is due to be issued in 1993.

Reclamation of contaminated land has included sites formerly used for the extraction and processing of some minerals. Research is being undertaken currently for the Department, by ECUS with Richards, Moorhead and Laing, on techniques for reclamation and management of metalliferous mining sites. The results, which are due to be published in late 1993, will be used in preparation of planning guidance.

All of these initiatives should help to secure environmental improvements. In doing so, however, all may contribute to a reduction in the number of available sites for mineralogical research and collecting.

NATURE CONSERVATION

There are initiatives, however, which are intended to protect sites for future scientific study. Key amongst these is the designation of Sites of Special Scientific Interest identified by the Nature Conservancy Council, and now the responsibility of its successor bodies. This network of mainly nationally and internationally important sites is a valuable resource for future study. A recent government circular (DOE/WO, 1992b) has emphasised that SSSIs are a key part of the nature conservation framework. It has strengthened earlier advice by introducing a requirement that local planning authorities should consult English Nature or the Countryside Commission for Wales before dealing with planning applications which are likely to affect land within an SSSI. Planning policy guidance on nature conservation, aimed at local authorities and developers, is currently in preparation.

The framework of SSSIs is necessarily limited, however, to the most important, representative sites. These contain only a small proportion of sites of interest to mineralogists. Continuing access to the remainder depends very much on future trends in development and land reclamation, as well as the goodwill of land owners.

The Geological Conservation Review carried out by the Nature Conservancy Council has played a major part in systematically identifying sites which are considered worthy of protection. More recently the establishment and expansion of a scheme for identifying Regionally Important Geological Sites has given a means for drawing attention to sites which, whilst not SSSIs, are considered worthy of protection. The Earth Science Conservation Strategy developed by the Nature Conservancy Council, and now being followed by its successor bodies, has laid out a clear approach to conservation of sites and liaison with interested parties (Nature Conservancy Council, 1990).

Conservation concerns more aspects of such sites, however, than those relating to geology or mineralogy. Mined ground, which may look barren, can be a repository of rare plants. Animals such as bats may occupy mines and use mine openings for access. Bats and some other organisms are protected from disturbance under the Wildlife and Countryside Act 1981. In some cases, the disturbers may be people interested in the geology or mineralogy of sites.

Mined ground may also be part of our archaeological and historical heritage. Some workings go back to Neolithic and Bronze Age times. Others contain important relics of the industrial revolution. Under the Ancient Monuments and Archaeological Areas Act 1979, English Heritage is concerned with the scheduling of ancient monuments and in providing advice and financial assistance for repairs and management. Some mining sites are scheduled ancient monuments, but these are only a small proportion of those which exist. Consultations with English Heritage about proposed development which might affect archaeological areas, however, extend to a much wider range of sites. Planning Policy Guidance on archaeological sites has been issued by the Department (DOE, 1990). The conservation and preservation of such sites for this purpose can involve steps which could adversely affect other interests.

Even among conservation bodies, therefore, there may be conflicts of interest. The key to resolving any problems which may arise is consultation, but this needs to be based on awareness of, and sound information on, the diverse interests involved.

AWARENESS

It is important to remember that the barren mine tips, often in scenic upland areas, are regarded as an eyesore by many people. Awareness of the value of these for research and teaching can be developed, for instance, through popular publications, schools, and adult education.

Museums also play a major part. Large mineral specimens often are attractive objects which draw attention. However, there is a gap between the appreciation of these and, for example, of equally beautiful but much less conspicuous 'micro' crystals, or of unspectacular specimens which show interesting paragenetic features. There is a growing interest in museums which display our industrial heritage, a substantial number of which have opened over the last decade or two. These include sites, some of which were restored using derelict land grant, which preserve surface features and machinery and, in some cases, have underground access for visitors. The excitement for many visitors of going underground, whether for educational or tourist purposes, should not be underestimated.

There is, therefore, a substantial and receptive public for information on mined ground and this interest can be harnessed to explain the value of many apparently scarred and barren sites. In some cases, continued access for researchers and collectors to some tips can be incorporated into schemes but this requires awareness on the part of those proposing, managing or controlling these, and of the authorities which provide grant aid.

The mineralogical community has a key role to play in identifying sites and drawing them to the attention of conservation bodies and decision makers. There is a risk in this since wide awareness of locations which contain, for instance, rare minerals can expose them to over-collecting. However this needs to be weighed against the possible permanent loss of access if the value of a particular site is not appreciated.

There is another side to awareness. The various interest groups concerned with different aspects of mined ground – mineralogical, geological, ecological, archaeological and historical – need to be aware of the implications of their own aspirations for sites in relation to the interests of others. This can be achieved only by sharing information on key interests and accepting that compromises may be necessary between different objectives.

For example, old mines are dangerous places and it is sensible to ensure that mine entries are secured and made safe. Land owners may have responsibilities and liabilities in respect of injury or death of people who enter their land (Freeman Fox Ltd, 1988a). Permanent closure of mine openings is generally cheaper than installing, for instance, a shaft cap with access manhole. Continued access depends, therefore, on the ability or willingness to pay the higher costs involved.

This may require persuasion or assistance. There are, however, other reasons than mineralogical ones for retaining access to mines. This allows inspection and monitoring of the condition of underground workings and of the treatment works on the mine entry. There are other groups of people who also use underground space, for instance mining researchers and recreational 'cavers'. Mines may have tourist or educational potential. There may be a need to protect organisms which inhabit mine workings, notably bats, although the presence of these may inhibit visits for other purposes.

COLLECTIONS AND INFORMATION

Mineral specimens held by museums are an increasingly valuable record of locations which can no longer be studied in the field. Over the years, the Geological Curators Group of the Geological Society has drawn attention to many instances of poorly stored and uncurated material particularly in those small museums which do not have geological expertise amongst the staff. The mineralogical community can play a part in increasing awareness of the value of such collections and in identification of material ensuring a continued research resource and material for educating visitors.

There is a great deal of information on mined ground but much of this is widely dispersed and some may be difficult to trace. Whilst mine plans exist for many workings, these have only been kept systematically since the late nineteenth century. Evidence of the nature and extent of many older workings can only be compiled from meticulous archive searches. A significant amount of information is in the hands of private individuals.

Mining historians, such as those belonging to the member organisations of the National Association of Mining History Societies, have carried out much important work and these, together with caving clubs, have undertaken many underground surveys of mines. The results of these labours, however, are mainly published in specialist journals and books which have a relatively small readership.

There is a need to provide information in a more readily accessible form. The Department of the Environment has commissioned research to develop cost-effective methods for doing this. A review of mining instability in Great Britain has outlined the nature and extent of mining (Arup Geotechnics, 1992). The resulting maps and database can be used by planners, developers and others as a first step towards defining areas within which mined ground might be material to decision making. Many of these decisions will relate to possible hazards to development. However, the information can also be used to define areas within which there may be mining conservation interests.

In addition, demonstration projects have been undertaken to show how digital databases can be developed. A study of the Chacewater-St Day area of Cornwall was carried out (Acer Geotechnics, 1992) and a general report on mining databases for recording positions of mine openings, the extent of underground roadways and voids, and other important features, was prepared (Freeman Fox Ltd, 1988b). These have been used in preparing draft policy guidance on recording of information on mined ground which is due to be issued during 1993. The Department of the Environment has also commissioned a series of applied geological mapping studies of selected areas, mainly in collaboration with the British Geological Survey, which contain information on the extent of surface and underground mineral extraction and on the locations of mine openings. Information on these can be obtained from the present author.

In addition, the Department of the Environment has commissioned a review of natural contamination in Great Britain which is being undertaken by the British Geological Survey with the Soil Survey and Land Research Centre and PEIDA. This is examining the general distribution of naturally occurring materials which may give rise to health and safety problems, such as methane, carbon dioxide, radon and other gases, and potentially toxic elements. All occur at certain mines.

These sources may bring a wider awareness of mined and mineral-bearing land. In particular, databases of mining information might help to make relevant information more accessible by storing data both on sites and on additional sources of information.

CONCLUSION

There is strong public pressure for a greener and safer environment. A number of initiatives are in place to prevent additional dereliction of land and to reclaim the legacy of earlier dereliction. Some of these might reduce the number of mineralogical sites available for study and collecting. However, the need to conserve sites for research and education is recognised, and measures to protect selected sites are in place.

The success of such measures requires a wide awareness of the various interests in mined ground, adequate information on the nature and importance of sites, and the need to consult appropriate organisations. Initiatives are under way to improve access to mining information to assist in the implementation of advice to planners, developers and others issued by, or being prepared by, the Department of the Environment.

However, there is an important role for the various groups who are interested in mineral-bearing sites, in resolving potential conflicts of interest, in drawing attention to important sites, and in demonstrating to the public, including planners and developers, that these can be research and educational resources and not merely blots on the landscape.

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MINERALOGICAL CONSERVATION IN GREAT BRITAIN – THE GOVERNMENTAL CONSERVATION AGENCY APPROACH*

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Mineralogical sites are of diverse character and accordingly their conservation is complex. Issues facing mineralogical conservation in the 1990s are explored.

INTRODUCTION

This paper reviews mineralogical conservation as seen from the viewpoint of the governmental conservation agencies. In particular it looks at: the diverse physical character of mineralogical sites from a site management standpoint; the role of the governmental conservation agencies; the Geological Conservation Review (GCR) as a Great Britain-wide system of selecting sites for conservation as Sites of Special Scientific Interest (SSSIs); and it highlights some of the issues facing mineralogical conservation in the 1990s.

THE PHYSICAL CHARACTER OF MINERALOGICAL SITES AND THEIR CONSERVATION REQUIREMENTS

Although mineralogical sites are often characterised on scientific grounds and in terms of orefield associations, the practical art of conserving a site can be usefully viewed by consideration of its physical characteristics. In this light it is possible to recognise two basic types of site (Nature Conservancy Council, 1991), namely:

'Exposure' sites, i.e. those that provide exposure of a deposit which is extensive underground, but whose surface or near-surface expression is limited. A mineralogical example might be a disseminated ore deposit which can be viewed in outcrop at a number of different localities. Underground mines are another example, often offering many miles of workings which enable the form of a deposit to be studied selectively in three dimensions.

'Integrity' sites, i.e. those where the mineralogical feature is finite and limited and, consequently, irreplaceable if destroyed. Spoil heaps are an obvious example but many small *in situ* deposits also fall into this category.

The exposure and integrity concepts are ends of a spectrum and a particular mineralogical site, especially a complex one, may contain elements of both. Nonetheless the concepts are useful as the conservation needs of each group can be markedly different. In essence, the integrity sites require a strict preservationist approach, whereas exposure sites can accomodate more robust interference by man. Continued quarrying, for instance, of an exposure site may be acceptable provided there is a strong likelihood of comparable material being exposed as extraction proceeds.

Although many geological sites are man-made, quarries being the obvious example, this situation is particularly true of mineralogical sites. Spoil heaps are notable in that the material is no longer *in situ* and they are especially vulnerable. Their small size as landscape features makes them susceptible to very rapid destruction. This threat is reinforced by the commonly-held view of them as eyesores, rather than as landscape elements of heritage importance, reflecting vestiges of former industrial activity.

Mines are a category of mineralogical sites that also have distinct conservation requirements. Being essentially 'open systems', closely analogous to caves, they are vulnerable to pollution carried in by groundwater, although many land managers are more concerned with their potential as geochemical sources of pollution which can be transferred outwards by air or water. Clearly these contrasting approaches can produce quite different management regimes with quite different consequences. A further complication concerns access to mines by mineralogists and others. Abandoned mines are generally prone to instability and are hazardous places to venture into. This gives rise to understandable concerns over legal liability and Health and Safety concerns on the part of site owners and managers.

*Based on papers presented at the conference on 'Conserving Britain's Mineralogical Heritage', University of Manchester, 31 March - 1 April, 1992.

THE ROLE OF THE GOVERNMENTAL CONSERVATION AGENCIES

Since the reorganisation of the Nature Conservancy Council in 1991, responsibility for statutory nature conservation has devolved to three country agencies, English Nature, Scottish Natural Heritage and the Countryside Council for Wales. Each agency is responsible for promoting geological conservation within England, Scotland and Wales, respectively. The country-based approach was designed by the Government to ensure that the delivery of nature conservation was brought closer to the people. It also offers each agency the opportunity to develop specific solutions to the conservation problems peculiar to it. For instance, the needs of mineralogical sites in remote, upland parts of Wales or Scotland are clearly quite different from those of quarries in heavily-populated parts of lowland England. This freedom to try different approaches and solutions contributes to building a diversity of conservation options which are tried and tested, and can only be healthy for conservation in the long run.

When the country agencies need to address common issues, of Great Britain or international scope, they come together as the Joint Nature Conservation Committee (JNCC) and can run joint projects to meet specific aims. One such project is the Geological Conservation Review (GCR), whereby the countries assess and select geological sites for nomination as Sites of Special Scientific Interest (SSSIs). The task of agreeing common standards and protocols for this shared system, which embraces the GCR mineralogy sites (see below), is co-ordinated by JNCC.

It is important to note that the country agencies, as well as being statutorily charged to enforce conservation legislation such as the SSSI system, have discretion to pursue policies and promote activities in geological conservation. The Special Meeting on Mineralogical Conservation, under whose banner this set of papers appears, was the outcome of one such initiative undertaken jointly with others.

Another recent initiative is the RIGS programme. Regionally Important Geological/Geomorphological Sites (RIGS) are identified locally by country-based voluntary sector groups. The sites, of regional and local importance, can be chosen for a variety of criteria including scientific importance, historical value, and amenity or educational significance. Their existence and conservation value is drawn to the attention of local authorities, with whom the RIGS work in partnership to safeguard the sites from adverse development. Although non-statutory in status, RIGS are a powerful mechanism for conservation when backed by local support and it is notable that the response of local authorities to the schemes are generally very positive. Since 1990 over 30 such groups have been created across Britain and although most are based in England, Scottish and Welsh RIGS groups are also active. It is encouraging to see that mineralogical sites are prominent among those proposed for RIGS status. The country agencies provide financial and other support to the RIGS movement and are keen to work closely with it.

THE GEOLOGICAL CONSERVATION REVIEW

The Geological Conservation Review (GCR) is the name used by the conservation agencies for the collaborative framework whereby earth science sites are selected as SSSIs. The mineralogical part of the GCR coverage consists of about 160 sites selected mainly during the 1980s. To meet the GCR standard a site must be, either in its own right or by virtue of its contribution to a network of closely related sites, of national importance with regard to the following criteria:

a) Representativeness, which means that the site is required to demonstrate adequately the diversity of the geological history of Britain. For example, it can be convincingly argued that Leadhills and Wanlockhead must feature in any series of sites that seeks to exemplify the lead deposits of Britain.

b) Exceptional features, which means that the site possesses spectacular, rare or remarkable features, which by definition are not represenative but which make the site a highlight of British geology. For instance, the spectacular replacement flats in the Great Limestone at Smallcleugh mine, although a feature of the North Pennine Orefield, are sufficiently remarkable in their own right to merit conservation.

c) International importance, which means that the site is commonly acknowledged to be of importance to the international geological community. The Meldon aplite, unusually rich in lithium and beryllium and characterised by a remarkable diversity of rare mineral species, is an example.

The mineralogical site selection phase of the GCR, largely undertaken by contracting-in the necessary mineralogical expertise, initially focussed on a geographic approach. The sites were selected in networks on a country basis for Scotland and Wales or, in the case of England, to reflect ore-fields (e.g. North Pennines, Mendips, etc.). In practice, each was typically further subdivided to reflect particular themes (e.g. Dolgellau Gold Belt, etc.).

In the late 1980s this scheme was further refined by the categorisation of the sites into two GB-wide networks, namely: mineralogy network sites, largely representing occurrences of rare or unusual mineral species; and metallogenic network sites, embracing those that are important in studying the origin of ore deposits and their mineral assemblages. Some localities, of dual interest, feature in both networks.

ISSUES FOR THE 1990s

The GCR programme of work during the 1980s has helped to put mineralogical site conservation firmly on the conservation agenda. Over the same period there has been a marked increase in interest and activity on the part of academic and museum-based mineralogists.

It has also become apparent, however, that the GCR approach, focussed on statutory protection of sites, cannot, in isolation, provide all the answers to the challenge of conserving what is a vast and poorly-known resource. From the conservation agency point of view a number of issues can be identified as requiring attention during this decade:

a) The mineralogical resource, outcrops, spoil heaps and underground mines, are part of a mosaic of features that collectively constitute the expressiion of industrial extraction, both past and present, on the landscape. As such they have both scientific and heritage value.

b) The sites are a locus of interest from many quarters, including mineralogists, archaeologists, botanists, and mining historians. These specialist interest groups have much to gain by integrating their efforts in promoting the public awareness of the value of mineralogical and mining sites, and by arguing for an integrated approach to their management.

c) It is recognised that SSSI protection, although valuable and appropriate for sites of undoubted national or international importance, cannot offer protection to the multitude of sites spread across the countryside. There is a keen need to document this broader resource and to encourage the development of new and alternative mechanisms, such as RIGS, as a way of safeguarding it at local level.

By way of contributing to this process the conservation agencies are supporting new initiatives. English Nature's new holistic approach to the countryside is based on the recognition of 'Natural Areas' which are underpinned by geological features. Natural areas provide a geographic framework that can take account of all aspects of land use, and allow a local sense of place to guide conservation initiatives. This offers an open door to mineralogists to join with other interested parties in building a locally-harmonised approach to conservation. Scottish Natural Heritage are focussing efforts to reassess the conservation of spoil heaps which have been scheduled as SSSIs. The surface layers of many of these dumps are now depleted of interesting material. A fresh stimulus for both researchers and collectors will be provided by controlled investigation, trenching and turning over of the dump material, in the process providing an opportunity to reconfirm their national importance and to highlight the management requirements of each site. The Countryside Council for Wales, in cooperation with the Natural History Museum, are responding to the increased threat to old mine sites, in particular the threat posed by an increased number of landscape reclamation schemes, principally by local authorities and other agencies, designed to 'green' the sites rapidly. Such schemes can lead to a fast and dramatic loss of the mineralogical resource. Resource surveys are being carried out in the North Wales, Dolgellau Gold Belt, and Central Wales orefields.

CONCLUSIONS

More broadly, the country agencies believe that, if we are to address effectively the issues facing mineralogical conservation today, mineralogists must work closely together with other heritage and nature conservation groups. The agencies can be selectively effective with projects of the type outlined above. To create a truly vibrant movement for mineralogical conservation in Britain, however, the mineralogical fraternity needs to find a united voice, one which will sustain mineralogy into the next century.

REFERENCE

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BOOK REVIEWS

Clark, A.M., *Hey's Mineral Index. Mineral Species, Varieties and Synonyms.*
Chapman and Hall, London, 1993, xii + 852 pp. Price £50.00. ISBN 0-412-39950-4.

M.H. Hey's *Index of Mineral Species & Varieties Arranged Chemically* was published in 1950. A second, revised edition followed in 1955, and was reprinted with corrections in 1962. To this were added two Appendix volumes, in 1963 and 1974. The publication of the Chemical Index was a landmark. For the first time, if one knew the chemical constituents of an unknown, one could look up what minerals might fit or be similar; one could get a list of, for example, all the then known sulphates of copper, or silicates of iron, with or without additional cations or anions; and the extensive cross-referencing enabled one to find, e.g., bravoite both under sulphides of iron and under sulphides of nickel. A second valuable feature was the listing of a vast number of varietal names, synonyms, obsolete names, mis-spellings, etc., a great help to anyone working with old collections or old literature.

In this long-awaited new edition, weighing 2.2 kg, the contents have been rearranged, much augmented and, of course, updated. All the information on minerals is now contained in an alphabetical section of over 760 pages, while a smaller section (68 pages) comprises the chemical classification of mineral species – a more practical arrangement than that of the original *Chemical Index*. In the simplified chemical section, Hey's numbered divisions and subdivisions by anions and cations have been retained, and under each subdivision are listed the corresponding mineral species and their formulae, e.g.: 11. Carbonates; 11.1. Carbonates of the alkali metals and ammonium (18 species); 11.2. Carbonates of Cu (5 species); etc. Each species is given a number but, because so many additions and other changes had to be incorporated, these numbers differ from those in previous editions; thus trona was 11.1.3 but is now 11.1.6. (Those who have arranged their collections according to 'Hey numbers' will have to relabel everything!) Dr Clark's reason for limiting the listing to species, that computer databases are now available for searching by chemical composition, is valid, but unfortunately you can't buy such a database for the cost of a book.

The alphabetical section lists all known published names applied to mineral substances. For species, headed in bold type, Dr Clark gives the formula; group affiliation if any; literature reference for the first use of the name; crystal system; unit cell parameters and the X-ray Powder Diffraction File card number if available; type locality; and derivation of the name. But the format of the entries is not restrictive and, where necessary, further and sometimes quite lengthy comments and references are added. The remaining entries – the majority – are for names of varieties, uncertain and discredited species, true synonyms, spelling and transliteration variants, etc.; their meaning and status are explained, with references where appropriate. The inclusion of full references is particularly welcome, for a good library and plenty of time was sometimes needed to track down references cited in the old *Chemical Index* by author and year only. Greek words from which mineral names are derived are printed in Greek, and original Russian names in Russian. Proper use is made of diacritical marks (åkermanite, löllingite), though curiously they are omitted from words of Czech origin (bořickite, Příbram, F. Čech), and occasional inconsistencies can be spotted (is there or not an ë in kësterite and ferrokësterite, or an é in boléite?).

As regards new minerals, the work appears to be quite up to date, but the updating of old entries has been more patchy. For example, one might expect new data in the literature on andrewsite (1990), fernandinite (1989), eskebornite (1988), furongite (1985) and others to have been incorporated. Likewise, paratacamite is listed as monoclinic, clearly on the authority of Oswald and Guenter (1971); the later structure refinement and confirmation of a rhombohedral unit cell (Fleet, 1975) is not mentioned.

For a work of this complexity, errors appear to be few. For example, the formula for pseudomalachite has a superfluous H_2O; for banalsite and bannisterite, the type locality is placed in Clwyd not Gwynedd; under cancrinite, davyne is said to be characterised by the presence of considerable carbonate instead of chloride; and the whole paragraph on acanthite (incorrectly described as the high-temperature polymorph of Ag_2F) is misleading. The proofreading, on the other hand, has been so perfunctory as to leave the pages peppered with silly misprints. Some are obvious and not important; some amusing, as when, after a Greek word, the Greek characters continue to be used for the rest of the English sentence (see campylite, chrysotile, ichthyophthalmite, ixolyte); but some can be a trap for the unwary reader (e.g. the borate gowerite is given the formula $CaBa_6O_{10}.5H_2O$; under sarcopside, gratonite is printed instead of graftonite). It is to be hoped that a corrected new edition, or at least a list of errata, will become available soon. A new edition would also give an opportunity to introduce more cross-referencing to help the user of this book (e.g. under tourmaline there is no mention of elbaite, dravite or schorl, though varieties like rubellite are listed); and to remove some inconsistencies (e.g. the plagioclase feldspars albite, anorthite and bytownite are treated as full species, but andesine, labradorite and oligoclase as varieties).

If I have tended to emphasise some defects in this new edition it is because users of such a book need to be aware of them, and because it was so surprising to find them in what is in all other respects close to the ideal reference book we have been waiting for. While

Fleischer and Mandarino's *Glossary of Mineral Species* will continue to be useful as a handy and more portable quick reference guide, the 'new Hey' should be on the shelves of all serious collectors, or at least in the nearest public library, in spite of the problems mentioned above. So start saving, or start dropping hints about birthday and Christmas presents! The fifty pounds buys an enormous amount of information – and fun, too, for there is much here for the compulsive browser. You can learn that Merda di Diavolo is the name of a hydrocarbon; that eveite was so named because it is isostructural with adamite; and that Panebianco in 1916 tried to rename willemite (named in 1830 after William I of the Netherlands) as belgite, since he objected to naming minerals after kings. More usefully, you can find out that in the older German literature, Stilbite is likely to mean heulandite (our stilbite being Desmin), and become aware of the many instances of mineral names with two or more meanings.

The layout is excellent and the book is very easy to use. No entry is carried over from one column or page to the next, and no word or formula is split with a hyphen between lines. The resulting spare space at the ends of many of the lines and columns, and the generous bottom margin, would make it possible, by reverting to a more economical and more usual style of typesetting, to incorporate new species and other extra material in future editions without increasing the size (and weight!) of the book.

G. Ryback

Nickel, E.H. and Nichols, M.C. *Mineral Reference Manual*. Van Nostrand Reinhold, New York, 1991, vi + 250 pp. Price £9.95. ISBN 0-442-00344-7.

This alphabetical listing of minerals provides data for more than 3700 species, the names being based on the latest recommendations of the IMA Commission on New Minerals and Mineral Names. Each entry includes the name, formula, currently accepted status (A approved by the Commission, D discredited by the Commission, G 'grandfather' status, i.e. minerals introduced before the formation of the IMA but generally accepted, P polytypes not specifically given approved status, and Q questionable status), crystal system, hardness, measured and calculated density, type locality, classification (based on a combination of letters and numerals) and selected literature references (including those for structure determinations when available). There is also a brief synonymy, mainly for recent changes, explaining, for example, that sphene is now titanite and that eggonite is kolbeckite.

The style and price invite comparison with the *Glossary of Mineral Species* now into its sixth edition. The *Mineral Reference Manual* usefully includes diacritical marks on mineral names, e.g. åkermanite or hübnerite, and gives rather more information on colour, whereas the *Glossary* lists separately all the minerals in a particular group, e.g. the spinel group or the zeolite group. Both have minor errors which will be corrected no doubt in due course. I certainly find it convenient never to have either work beyond armslength and use each on a more-or-less equal basis.

R.A. Howie

Howie, F.M. (ed.), *The Care and Conservation of Geological Materials* Butterworth-Heinemann, 1992, 138 pp. Price £35.00.

To many people, academics and non-academics alike, geological samples are robust objects needing little to no maintenance and no special storage conditions. This is reflected in the general lack of published information on the care and maintenance of geological collections, and also in the scarcity of geological conservators. At present there are only 10 to 12 specialist geological curators employed in Britain's museums. However, as most geological curators know all too well, geological materials are indeed subject to deterioration when removed from their natural context, and do require special conditions of storage. This had led to an increasing awareness of the needs for the conservation of geological materials of all kinds, rocks, fossils, minerals, thin and polished sections, and cores, as well as any accompanying documentary matter. Clearly therefore this book is a welcome addition to the scant literature concerned with the conservation of geological materials.

The book covers a range of topics, including: the stability of minerals; conserving light-sensitive minerals and gems; temperature and humidity sensitive mineralogical and petrological specimens; native elements, oxides, sulphides and sulphosalts and other minerals; pyrite; meteorites; the lunar sample collection; hazards for the mineral collector, conservator and curator; and in appendix form the effects of construction materials on rock and mineral collections, and also the collecting and processing of minerals and rocks. The editor clearly states in his preface that the aim of the book was 'to emphasise more the principles of care through the identification and explanation of basic mineral instabilities rather than describe specialised treatment methods for preservation', and anyone considering buying this book should be fully aware of this. It is not a practical manual detailing procedures to be adopted. To me, this was a disappointment. While I fully accept the editor's statement that 'materials, processes and techniques used in the conservation of specimens and artifacts alter and evolve on a continuous basis', I feel that those few persons around who do have some knowledge and experience of geological conservation should be prepared to share that 'state of the art' with the many curators and collectors who have no such expertise. This would serve as a first measure to halt the rapidly decaying state of many collections.

Another quibble concerns topics covered, and their general imbalance. Considerable attention is paid to the particular case of minerals, and quite rightly so, but other areas are only poorly covered. For example, the collection of rocks and their conservation is all but absent. While aesthetically less appealing, rocks are still scientifically very important, and present their own specific problems, for example the collection and conservation of shales, of wet or unlithified specimens, particularly polished ore sections. While it could be argued that these are rather specialised materials, none could surely be classed as being anywhere near as specialised as the collection and conservation of lunar material, which is allocated 12 pages.

Overall, therefore, I was somewhat disappointed with the book but, as I said at the outset, there is very little literature concerned with the care and maintenance of geological materials. I would therefore urge those responsible for such collections to have access to this book.

R.E. Bevins

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Pattrick, R.A.D. and Polya, D.A. (eds), *Mineralization in the British Isles*. Chapman and Hall, London, 1993, xii + 499 pp. Price £49.95. ISBN 0-412-31200-X.

The British Isles host some of the world's classic ore provinces of which the Cornubian tin-tungsten province and the Pennine lead-zinc-fluorite-baryte province are but two examples. In this book, after an introductory chapter by the editors on the mineralization and geological evolution of the British Isles, there are chapters dealing with eight provinces, each being described by research workers active in their areas. Where possible, descriptions and models of geology, mineralization and ore genesis are placed in context by comparisons with other metallogenic provinces around the world.

The stratiform mineralization in the Dalradian of Scotland is described by A.J. Hall, who demonstrates the existence of an early barium-rich mineralization typified by that at Aberfeldy, and a later, more variable Cu, Zn, Pb and Ni sulphide mineralization seen in the Tyndrum area. Mineralization associated with Caledonian intrusive activity is summarized by C.M. Rice, including the Coed-y-Brenin (North Wales) Cu deposit, the Unst (Shetland) Cr and platinum-group elements ophiolite sequence, the granite-related W-Sn-Mo mineralization of Carrock Fell (Cumbria) and Leinster (S.E. Ireland), and the volcanic/subvolcanic-hosted Au-Ag-base metal deposits of Lagalochan (Argyllshire) and Rhynie (Aberdeenshire). The Dolgellau gold belt of North Wales is covered by T.J. Shepherd and S.H. Bottrell, who ascribe the localization of the veins to interaction between ore fluids and the graphitic shales, leading to enrichment in methane and nitrogen and the precipitation of gold. The Zn-Pb deposits of the Irish Midlands are described by C.J. Andrew who demonstrates that mineralization was initiated isochronously across the orefield during the Lower Carboniferous.

The mineralization associated with the Cornubian batholith is reviewed in detail by D.H.M. Alderton. Although known mainly for its production of Sn and Cu, this region produces other metals, such as Fe, Pb, As, Mn and Zn, as well as kaolinite, baryte and fluorite. In this area, the hydrothermal activity continued long after the main-stage igneous processes and a variety of fluids were incorporated into the circulation system, resulting in a range of mineral deposits commonly in N-S or cross-course faults. The Pb-Zn-F-Ba deposits of the Pennines, North Wales and the Mendips are described by R.A. Ixer and D.J. Vaughan, who make comparisons with the Mississippi Valley-type deposits. A distinctive feature of the Pennine ores is the importance of fluorite. A mixing model is favoured for the genesis of these ores in which brines with Pb, Zn, Ba and F (partially derived from granites) reacted with H_2S-rich fluids and organo-sulphur compounds in the host Carboniferous limestones.

The Cumbrian hematite deposits (now virtually abandoned) are described by T.J. Shepherd and D.C. Goldring, and an overview of the sedimentary iron ore resources of Britain is given by T. Young, these ores having played a unique role in the 'industrial revolution' in this country, despite being rather low in iron and relatively high in phosphorus.

The great strengths of this book lie in the many clear maps and diagrams and in the very extensive reference lists given at the end of each chapter. It will be a valuable source of information for all students and research workers keen to keep up-to-date with recent developments.

R.A. Howie

Floyd, P.A., Exley, C.S. and Styles, M.T. *Igneous Rocks of South-West England*. Chapman and Hall, London, 1993, xii + 256 pp., 49 photos, 27 maps. Price £65.00. ISBN 0-412-48850-7.

This volume is one of the Geological Conservation Review series initiated by the Nature Conservancy Council, which will eventually document all the geologically important sites (SSSIs) in Great Britain. Each volume highlights the special interest of each site, decribes its geology, reviews research on the site, and summarizes its importance in simple terms for the non-specialist.

After two introductory chapters introducing the geology of the region, reviewing the igneous activity and summarising the more important isotopic ages, the four main chapters describe localities illustrating the four principal igneous rock associations in the region: the Lizard ophiolite complex (10 sites); the pre-orogenic (spilitic) lavas, tuffs and intrusions (19 sites); the Cornubian granite batholith (19 sites); and the post-orogenic Exeter volcanic rocks (5 sites).

The geology of the Lizard and Start complexes is outlined before detailed descriptions of the classic sites at Lizard Point, Kennack Sands, Kynance Cove, Coverack, Porthallow Cove-Porthkerris Cove and Mullion Island are given. The chapter on the pre-orogenic igneous rocks include descriptions of the pillow lavas at Penwith, the basic hornfels at Botallack Head formed by metamorphism and metasomatism of dolerite sills and basaltic pillow lavas, Dinas Head with its progressive development of adinole at the contact between a dolerite and enclosing sediments, the Tintagel volcanic formation, and the conical knoll of Brent Tor composed of Lower Carboniferous basaltic pillow lavas which formed a near-emergent seamount with a reworked volcanoclastic apron.

The Cornubian granite batholith and its modifications are fully documented with descriptions of the Haytor Rocks, Luxulyan, St Mewan Beacon (quartz-topaz-tourmaline rock), Roche Rock (quartz-tourmaline rock) and the magnificent coastal exposures at Rinsey Cove (showing a section through the roof of the Tregonning granite), Megiliggar Rocks (showing contacts between lithium-mica granite and hornfels, sheets of leucogranite, aplite and pegmatite, and apatite and other phosphates), and Praa Sands (fresh exposures of a large granite-porphyry dyke with evidence of multiple intrusion, chilled margins, etc.). The unique late-stage aplite-pegmatite dyke at Meldon, well-known for lepidolite, tourmaline, topaz and axinite, is described and the chapter ends with a description of the spectacular greisens and condensed W-Sn-Cu-Fe mineralization at Cligga Head. The chapter on the Exeter volcanic series decribes sites displaying flow-banded rhyolites and the minette-type lamprophyres.

The volume concludes with an up-to-date list of some 500 references, a useful glossary of petrological and other terms, and a comprehensive index. The volume is beautifully produced with many line diagrams and photographs; the sketch-maps are particularly clear. The book is not, however, intended as a field guide and readers are warned that description of a site does not imply that it is open or that a right-of-way exists; the descriptions are included to justify the conservation of these sites which have enriched geological literature over the years.

R.A. Howie

Fettes, D.J., Mendum, J.R., Smith, D.I. and Watson, J.V. *Geology of the Outer Hebrides. Memoir for 1:100000 (solid edition) geological sheets, Lewis and Harris, Uist and Barra, Scotland.* British Geological Survey, London, 1992, x + 197 pp., 38 figs, 17 plates, 5 maps. Price £39.00. ISBN 0-11-884478-4.

The Outer Hebrides form a 210 km long archipelago on the NW seaboard of Scotland. They have never been systematically mapped by the Geological Survey, and until recent years we have had to rely on a series of classic papers by Jehu and Craig (1923, 1925, 1926, 1927, 1934) and by Davidson (1943), all published in the Transactions of the Royal Society of Edinburgh. Recognizing that there was no prospect of the Geological Survey undertaking a comprehensive mapping programme in the islands within the foreseeable future, the Survey have now collaborated with research workers in the Universities to complete the coverage.

The Outer Hebrides form the largest area of Archaean crust exposed in Britain, the Lewisian gneiss getting its name from the preponderance of gneiss in the Isle of Lewis. The islands of the Outer Hebrides are composed mainly of quartzofeldspathic gneiss, metasediments, banded basic and ultrabasic intrusions and granites, all of Archaean or Lower Proterozoic age. Following Scourian deformation at 2800-2600 m.y., the gneisses were intruded by further granitic bodies and a widespread suite of tholeiitic dykes dated at approximately 2400-2200 m.y. In the southern part of South Harris there is a suite of gabbro, anorthosite, norite and diorite intrusions which are also dated at 2200 m.y. and which form spectacular geology and scenery (the maps accompanying the memoir include a 1:50000 coloured geological map of South Harris). The South Harris igneous complex was intruded into metasediments which display granulite and upper amphibolite facies metamorphic assemblages, including marbles, calc-silicate rocks as well as garnet-kyanite gneisses.

The Outer Hebrides Thrust zone runs down the eastern edge of the archipelago and produced extensive bands of mylonite and pseudotachylite, the black glassy rock formed when frictional heating is caused by faulting along discrete planes in dry rock. Later granites, acid veins and pegmatites intrude the gneiss complex, notably in the Uig Hills of Lewis and in South Harris. Suites of Permo-Carboniferous dolerites and lamprophyres occur mainly in Barra and South Uist, while Tertiary basaltic dykes are common in Harris and central Lewis.

Although the famous Scottish mineralogist Heddle graphically described the undulating rocky peneplain of the northern part of South Harris as the most barren part of the British Isles, the Outer Hebrides take the full force of many Atlantic storms and display a great variety of scenery, ranging from the rugged cliffs and mountains of Harris to the gentle sandy machair of South Uist. This memoir is in no sense a guide book, but most localities mentioned have an accompanying National Grid Reference.

R.A. Howie

Criddle, A.J. and Stanley, C.J., *The Quantitative Data File for Ore Minerals*, 3rd edition. Chapman and Hall, London, 704 pp., 653 figs. Price £75.00. ISBN 0-412-46750-X.

Recently I have been fortunate enough to review this book and the new student edition of Deer, Howie and Zussman. Both have many similarities, they are well written and presented, they are obvious leaders in their field and both show, in their latest editions, an increasing mineralogical *glasnost* – the use of a more relaxed and informative style but without relinquishing authority (perhaps this is an acceptance by authors that each new generation of mineralogist/petrologist is not as well taught as earlier ones so that less can be taken as read).

The earlier (second) edition of the data file was published by the British Museum (Natural History) in a neat pocket-book format that essentially comprised 420 cards covering 327 mineral species. The new edition, published by Chapman and Hall, is much larger, well beyond any pocket, and now has 635 cards for 510 species arranged in alphabetical order from acanthite to zvyagintsevite (but sadly we must continue to whistle for xingzhongite), including new data on many of the platinum group minerals, tellurides, and a number of 'gangue' minerals like cerussite and anglesite (taken from recent Chinese studies). Valuable as these lists of data are, they have been enormously enhanced by the inclusion of reflectance spectral graphs, in air and where possible in oil from 400 to 700 nm, for each mineral. These graphs are much easier to use for determining colour and bireflectance than are the tables of the second edition (these tables are, however, retained in the third edition). Of the many improvements in the third edition this has to be the best and the time taken to produce them was very well spent.

The expanded introduction is excellent value. The seven pages discussing reflectance, with its superabundance of reflectance curves, will be incorporated into my final year and M.Sc. teaching. But the introduction is also full of mineralogical gossip and scandal: some, like the downgrading of VHN as a useful parameter in the identification of opaque minerals is of mild interest; but other news is sad – especially the loss of old and dear friends – bravoite despite its colourful zoning is now to be known as nickeloan pyrite, and chloanthite becomes nickel-skutterudite. However, most sensational is the removal of blaubleibender covelline – the reflectance curves in oil on page XVI very clearly show that blaubleinder covelline is spionkopite and that covelline (should be called covellite) and yarrowite are difficult to distinguish optically. Like Africa, the copper sulphides always have something new.

The data file is a specialist reference book that will have limited sales and indeed this type of systematic mineralogy is unfashionable despite being *essential*. The Natural History Museum is to be congratulated in continuing to support Criddle and Stanley in their work which has allowed them to produce a quintessential museum publication, namely a definitive one of practical use. Let us hope that the funding can continue so that in ten years' time there will be a fourth edition, full perhaps of more platinum group minerals including their oxides, to augment this excellent third edition.

R.A. Ixer

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