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The Russell Society

THE JOURNAL OF THE RUSSELL SOCIETY

Aims and Scope The Journal publishes articles and reviews by both amateur and professional mineralogists dealing with all aspects of mineralogy. Contributions concerning topographical mineralogy are particularly welcome. In addition to full articles, short notes (up to 1000 words) may be submitted. Book reviews and correspondence will also be accepted with a view to publication. Notes for contributors can be found at the back of the Journal.

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FRONT COVER: Barite, Cleator Moor, Cumbria. National Museum of Wales specimen NMW 83.41G. M8874. R.J. King Collection. The specimen is 19cm tall.

JOURNAL OF THE RUSSELL SOCIETY

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ARTHUR EDWARD IAN MONTAGU RUSSELL

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Arthur Russell was born on 30 November, 1878, and was to become the 6th baronet of Swallowfield Park, Reading. He succeeded to the title on the death of his elder brother, George Arthur Russell in 1944.

Sir Arthur was educated at Eton and studied chemistry at Kings College, London. He subsequently took up an appointment with the London and South Western Railway. This continued the family connection with railways, and in later years the name plate from the engine 'Swallowfield Park' was kept close to his mineral collection. He was later to work on British mineral resources, for instance he investigated the chromite deposits of the Shetlands.

It was from his mother Lady Constance Charlotte Elizabeth Russell that Arthur first acquired his interest of mineral specimens. Indeed, Lady Constance had started out having elementary lessons in mineralogy from Miss Henson, sister of Samuel Henson the London dealer and had spent her pocket money buying specimens. It was her small collection that started the nucleus of Arthur's which was to become the most outstanding and comprehensive private collection of British minerals that had ever been made.

Arthur made his first visit underground in a working mine, at Wheal Providence, St. Ives, Cornwall, being about 8 years old at the time. Three years later he went underground at Botallack, thereafter he was to visit every mine in Great Britain and Ireland, and to go into every metalliferous mine in the British Isles that had been worked during his life time, with the exception of the Foxdale and Laxey mines on the Isle of Man. Much attention was devoted to both working and abandoned mines in the former of which whole days and nights were spent underground securing specimens that otherwise would never have seen the light of day. In this field Russell was outstanding, he had a keen eye for good specimens, especially for the rarer and more unusual species which tended to be overlooked. He paid great detail to mineralogical conditions and had an instinctive feeling for where minerals might be found. Russell had a great sense of humour and was a good 'mixer', getting on well with almost everyone and making many friends among mine and quarry managers, miners, and quarrymen. He was, in consequence, usually notified of any interesting discoveries in mines or quarries, and so was able to get hold of many fine specimens which might have otherwise been destroyed.

Over the years Russell acquired a considerable number of collections, some dating back to 1800 or earlier, many containing specimens no longer available *in-situ*. Among the more important were; Philip Rashleigh (1728–1811), John Hawkins (1761–1841), Edmund Pearse (1788–1856), Sir Warington W. Smyth (1817–1890), Baroness Burdett-Coutts (1814–1906), John Ruskin (1819–1900), Samuel Henson (1848–1930), J.H. Collins (1841–1916), and W. Semmons (1841–1915).

The Russell Collection contains many outstanding specimens, but special mention must be made of the excellent suites of chalcopyrite, chalcocite, fluorite, barite, pyromorphite and mimetite. One of Russell's unfulfilled ambitions was to write a book on the mineralogy of the British Isles, and his copious notes on the subject are now in the Mineralogy Department, The Natural History Museum, London. As Russell said 'It is my earnest hope and desire that this collection upon which I have bestowed so much loving care and so much of my life shall remain intact and be well cared for wherever it finds a resting place'.

On his death in February 1964, aged 86, the whole of his superb collection amounting to some 12,000 specimens was passed to The Natural History Museum, together with storage cabinets, maps, notes and many books by Russell's generous bequest, on condition that it will not be dispersed but kept as a British regional collection. The collection will remain his greatest memorial.

Further reading. Sir Arthur Russell. Obituary by Arthur Kingsbury. 1966. *Mineralogical Magazine*, **35**, 673–677.

RUSSELLITE FROM BUCKBARROW BECK, CUMBRIA, ENGLAND

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Russellite is known from only four localities throughout the world. At the fourth and most recently discovered of these, in the English Lake District, the mineral is abundant and occurs in some of the finest specimens yet found. It is accompanied by cuprotungstite, bismutoferrite and other supergene minerals in a quartz-scheelite-ferberite-chalcopyrite vein in granodiorite.

INTRODUCTION

Since its original description as a new mineral, from Castle-an-Dinas wolfram mine, Cornwall by Hey and Bannister (1938), russellite, Bi_2WO_6, has been recorded from only a very few localities worldwide. Kagule-Magambo (1969) reported it from the Buyaga wolframite deposit in Uganda, and Hodge (1970) described it from a quartz-wolframite-muscovite vein near Poona, Western Australia. More recently Young *et al.* (1986) have reported russellite as a constituent of the supergene assemblage in a quartz-scheelite-ferberite-chalcopyrite vein at Buckbarrow Beck in the Lake District. Although these authors discussed the chemistry and X-ray characterisation of the Cumbrian russellite, making comparison with the Cornish and Australian material, they provided comparatively little descriptive detail. As this is only the fourth known occurrence of russellite, and as the specimens obtained appear to be some of the best examples of the mineral yet found, its occurrence is described here and examples of the russellite are figured.

Until the discovery of the Buckbarrow Beck vein, recorded occurrences of tungsten minerals in the Lake District comprised the wolframite- and scheelite-bearing veins related to the Skiddaw Granite at Carrock Fell Mine [NY 323 329] (Shepherd *et al.*, 1976; Ball *et al.*, 1985) where small amounts of supergene tungstite and stolzite have also been found (Davidson and Thomson, 1948; Kingsbury and Hartley, 1957), traces of scheelite in drusy cavities in the Shap Granite [NY 558 084] (Firman, 1953, 1978), a report of scheelite at Scar Crag cobalt mine [NY 206 216] (Kingsbury and Hartley, 1957) and stolzite at Force Crag Mine [NY 200 216] (Greg and Lettsom, 1858). The last two occurrences have not however been substantiated by more recent workers (Russell, 1944; Ixer *et al.*, 1979; Freeman, 1982).

BUCKBARROW BECK VEINS

Buckbarrow Beck is a small stream which drains the
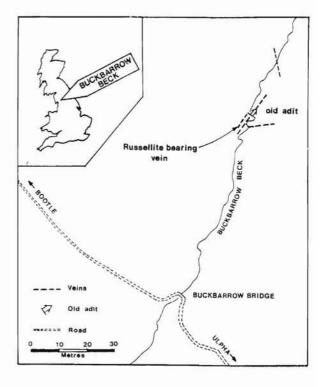
FIGURE 1. Location map and sketch map of veins in Buckbarrow Beck.

southern part of the Eskdale Granodiorite, a large but poorly exposed intrusion of mid-Silurian age. Recent detailed geological mapping revealed a number of quartz veins in the upper reaches of the streams (Figure 1). Small, but apparently unsuccessful trials were made many years ago on a chalcopyrite-rich portion of one of these [SD 1371 9102]. The dump from the trial adit shows abundant quartz veinstone in which chalcopyrite is common together with thin crusts of malachite and chrysocolla. About 100 m south-west of the adit the
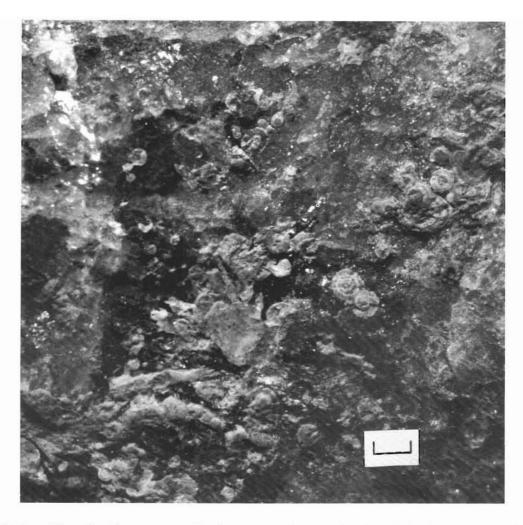
FIGURE 2. Russellite spherules on quartz showing concentric colour banding in broken spherules. Scale bar is 1 mm.

vein is exposed in the west bank of the stream [SD 1368 9096] as a barren belt of kaolinised granodiorite with iron and manganese oxide stains.

A few metres to the north-west, a sub-parallel vein, up to 100 mm wide, is exposed for a strike length of only a few metres, within vertical walls of chloritised granodiorite [SD 1366 9097]. This massive quartz vein is distinctive in carrying, in addition to chalcopyrite, appreciable quantities of tungsten minerals including russellite. Scheelite is plentiful as pale brown friable aggregates up to 8 mm across. It is accompanied locally by minor ferberite in crystals up to 4 mm in length, many of which are partially replaced scheelite. Chalcopyrite occurs as irregular massive patches up to 10 mm across, locally associated with minor pyrite. Chlorite is common as radiating aggregates of small (to 2 mm) dark green, platy crystals, mainly at the margins of the vein. Electron microprobe analyses indicate this to be an iron-rich variety transitional between ripidolite and daphnite of Hey's (1954) classification.

Supergene minerals identified from the deeply weathered vein outcrop are malachite, chrysocolla, brochantite, covellite, goethite, cuprotungstite, bismutoferrite and russellite. The latter two minerals occur in some abundance. Malachite, chrysocolla and brochantite occur mainly as thin (< 1 mm thick) crusts and pockets within the veinstone. Minor covellite is found locally with chalcopyrite. Goethite is common as irregular masses and coatings of earthy 'limonite'. Cuprotungstite occurs rarely, as vivid grass-green crusts < 0.05 mm thick on scheelite. Bismutoferrite is abundant as vivid yellow, soft, earthy patches up to 6 mm across, within pockets of dark brown earthy "limonite". The occurrence of russellite is described below.

Examination of small ore-bearing fragments of veinstone by X-ray fluorescence revealed minor amounts of arsenic, molybdenum, cobalt and zinc, all probably present as minor constituents of the supergene assemblage. Traces of indium, thought to be present in the chalcopyrite, were also found. No discrete minerals of these elements were found. Despite

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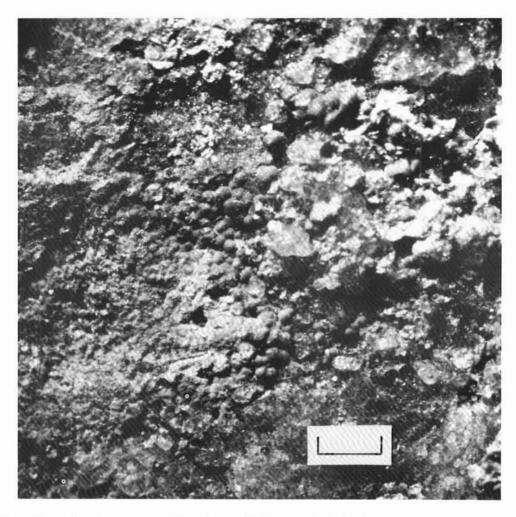
FIGURE 3. Russellite spherules aggregated into botryoidal crusts. Scale bar is 1 mm.

the abundance of bismutoferrite and russellite, no primary bismuth minerals were found in the outcrop. It is likely therefore that a more diverse assemblage of hypogene minerals may originally have occurred and may be present at depth beneath the weathered zone.

No trace of tungsten or bismuth minerals has been found in the material on the trial adit dump. A few minute specks of scheelite have been observed in an almost E-W trending belt of quartz stringers on the east bank of the beck [SD 1369 9096] and also in a NW-SE trending quartz vein about 200 m further upstream in Buckbarrow Beck [SD 1379 9122]. No supergene minerals have been observed in these.

RUSSELLITE

Russellite is locally abundant within the vein. It commonly forms thin (< 1 mm), pale buff to greenish-yellow, discontinuous crusts, up to 10 mm across on the joint and fracture surfaces of massive quartz. In places, these consist of small coalescent, circular, spherulitic masses up to 1 mm across in which faint traces of a radiating crystalline texture can locally be distinguished. Concentric banding in different shades of colour is common (Figure 2). Open joints up to 2 mm wide have yielded a number of specimens which consist of complete hemispherical masses or spherules up to 0.3 m across. The outer surface of these spherules is commonly slightly darker in colour than the mineral beneath. In places, these are united to form botryoidal crusts up to 3 mm across (Figure 3). Where this spherulitic form is not obvious the russellite is easily overlooked. However, in very many of the specimens obtained, traces of this structure can be found and are a valuable preliminary field aid in identifying the mineral.

Type russellite, from Castle-an-Dinas, Cornwall, was found as compact and apparently structureless, cream-coloured to pale green pellets which commonly included grains of native bismuth, wolframite, 'limonite', quartz, topaz, lithium-mica and tourmaline (Russell, 1938). All of the specimens obtained from the locality are understood to have been collected from jig concentrates. Despite a careful search of the stope from which the russellite-bearing ore was mined, the mineral was not found *in situ*.

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TABLE I

Analyses of russellite from Buckbarrow Beck.

Sample number	1	1	3	3	5
Al_2O_3	0.13	0.15	0.16	0.14	0.14
SiO_2	0.24	0.30	0.27	0.29	0.32
WO_3	19.90	20.21	19.92	20.01	21.65
V_2O_3	1.16	1.07	1.16	1.02	1.11
Fe_2O_3	1.12	1.15	1.24	1.37	0.96
CuO	1.91	1.76	1.61	1.95	1.00
As_2O_3	1.10	0.93	0.88	1.02	0.63
Bi_2O_3	61.31	62.13	61.97	63.95	62.53
UO_2	3.58	3.19	3.13	3.40	2.79
SO_3	2.71	2.50	2.91	3.25	2.54
Total +	93.16	93.93	93.25	96.40	93.67

Formulae calculated to nine oxygen equivalents

Al	0.03	0.03	0.04	0.03	0.03
Si	0.05	0.06	0.05	0.06	0.06
W	1.00	1.01	1.00	0.98	1.08
V	0.18	0.17	0.18	0.15	0.17
Fe	0.16	0.17	0.18	0.19	0.14
Cu	0.28	0.26	0.24	0.28	0.15
As	0.13	0.11	0.10	0.12	0.07
Bi	3.05	3.08	3.09	3.11	3.10
U	0.15	0.14	0.14	0.14	0.12
S*	0.39	0.36	0.42	0.46	0.37
	5.03	5.01	5.02	5.05	4.91

Wavelength-dispersive analyses by Cambridge Instruments Microscan V microprobe operating at 20.0 KeV beam potential, using pure metal and mineral standards.

+ Analyses as weight percentages.

* Formulae are calculated by allotting nine oxygen equivalents to the elements Al to U, S being then brought into proportion. S is not included in the formulae cation-totals.

Hey and Bannister (1938) showed russellite to be a tetragonal mixed oxide with the approximate formula Bi_2WO_6. Hodge (1970) published a formula of $Bi_{4.62}W_{2.04}O_{13.06}$ for the Poona russellite.

The Buckbarrow Beck russellite gives an X-ray powder pattern very similar to that of the type material from Castle-an-Dinas. It exhibits line broadening consistent with the very fine crystalline size although, according to Hey and Bannister (op. cit.), this may also be attributed to variation in composition. A partial microprobe analysis of the Buckbarrow Beck mineral is given in Table I. The choice of elements was based on a spectrometer scan of X-ray emission from the mineral. In order to avoid X-ray line interference, the As_L and

Pb_M lines were analysed, and the latter element was not detected. The low percentage totals obtained are in part a consequence of the soft, microporous nature of the grains and in part to the additional presence of P, Cl, H_2O and possibly CO_2. Water was detected by infrared absorption spectroscopy by D.J. Bland. Calculation of formulae is based on the presence of SO_3 as a structurally distinct ion. Formulae were calculated for 6 to 10 oxygen atoms. The results for 9 oxygens gave formulae of simple stoichiometry as shown in Table I. This approximates to the formula: $Bi_3(V,Fe,Cu,As,U)_1W_1O_9(SO_3O$ etc$)_x$ where x was not determined. Clearly there are differences in the relative proportions of W, Bi and O from both the type Castle-an-Dinas mineral and that from Poona. This appears to confirm the variability in composition suggested by Hey and Bannister (op. cit.).

CONSERVATION MEASURES

In recent years some irresponsible collectors have caused irreparable damage to a number of important mineralogical sites in the Lake District. It was feared that the Buckbarrow Beck vein was likely to attract similarly destructive collecting, leading rapidly to its total obliteration. In view of the abundant presence here of several rare species, including russellite, some means of ensuring the preservation of sufficient material for future study seemed warranted. Accordingly, the Nature Conservancy Council (NCC) negotiated with the owners of the land and the minerals permission to carry out a rescue collection from the vein (Nature Conservancy Council, 1987). Staff from NCC and the British Geological Survey (BGS) excavated the top metre of the outcrop. The material collected is held by the BGS and is available to research workers. Representative examples of all the species identified have been deposited with Britain's national museums. The vein remains exposed in situ and should continue to be so, provided it is not subject to over-collecting.

It is unfortunate to reflect that the risk to many important mineralogical sites is now so great that protection of scarce material for future research can often be assured only by the sort of action taken at Buckbarrow Beck.

ACKNOWLEDGEMENTS

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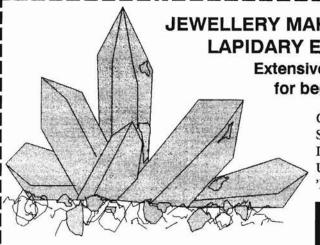
LEAD-MOLYBDENUM MINERALIZATION IN AN ANCIENT CAVE IN NORTH LEICESTERSHIRE

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A section of a phreatic cave system in diapirically-contorted limestones of Dinantian age was formerly exposed in Breedon Quarry in Leicestershire. A red clay, rich in euhedral crystals of oxidised galena with well-developed crystals of cerussite and wulfenite, filled the floor of the cave. This suggests subsequent vadose modification of the cave system.

INTRODUCTION

A phreatic cave passage system, possibly of Triassic age, occurring in limestones of Dinantian age was formerly exposed at Breedon-on-the-Hill in north Leicestershire. The limestones were seen to contain an interesting mineral association, as described in this paper.

Although sporadic occurrences of sulfide mineralisation occur throughout the English Midlands where Permo-Triassic red beds lie unconformably upon older strata (King and Ford, 1969), the relationships between the mineralization and the rocks above and below the unconformity have never been clear; neither has the genesis of the sulfide mineralisation been explained.

GEOLOGICAL SETTING

The cave system at Breedon-on-the-Hill is developed in strongly dolomitised and diapirically contorted Dinantian age limestones (Spink, 1965; Monteleone, 1973; Simms, 1990). These limestones, which constitute almost the complete Dinantian succession in the area, are overlain with marked unconformity by the Mercia Mudstones of Upper Triassic age. The latter are composed of basal breccias of variable thickness, which are locally and intensely hematitised, succeeded by red sandstones and mudstones.

Flints and chalky debris overlying the Triassic beds may be eroded remnants of tills of north-easterly derivation, as in other parts of north Leicestershire (Rice, 1968).

FIGURE 1. Exposed portion of the phreatic cave system on the northern face of Breedon Quarry, Breedon-on-the-Hill, Leicestershire. The pick handle is 800 mm long.

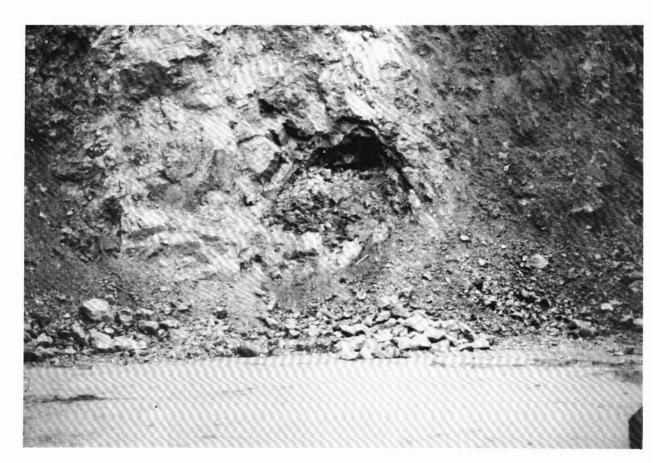**FIGURE 2.** Euhedral crystal of galena entirely coated by crystallised cerussite. The upper face shown is 57 mm across (specimen K83-13).

FIGURE 3. An aggregate of etched galena crystals from the cave wall showing two periods of cerussite growth with isolated single crystals of wulfenite. The mass measures 112 mm across the base.

THE CAVE SYSTEM AT BREEDON-ON-THE-HILL

The cave system, formerly exposed in 1983 and now quarried away, was exposed on the second bench of the north-eastern face of the quarry at Breedon-on-the-Hill (Fig. 1). The cave formed part of a phreatic tube, representing possible Triassic cavernisation along a prominent east-trending joint (Simms, 1990). By removing fallen debris and excavating at the back of the cave it was possible to estimate the approximate plunge of the tube as 58° to the east.

The cave, 4.8 m wide at its base, was an open void for the top third of its height. The lowermost two thirds, however, comprised breccias and clay. Some 1.2 m of breccias of Triassic debris and dolomitised blocks of Dinantian limestone were cemented largely by white microcrystalline barite and wad. Below these breccias the remaining cave fill consisted of 1.6 m of dark red, structureless clay. Dispersed throughout the clay occurred euhedral crystals of partially oxidised galena. Groups of crystals of similarly oxidised galena were also found loosely attached to the cave walls.

The cave was surrounded by a halo of strongly dolomitised and hematitised limestone which merged laterally into the regionally dolomitised limestones of the area. Both breccia and clay fill possibly represent vadose modification of the original phreatic conduit.

MINERALOGY

DOLOMITE

Dolomite appears first in the paragenesis of the mineral suite at Breedon, with the walls of the cave being covered by small, well-developed, pale-brown rhombohedra, usually no more than 1.3 mm across. The

crystals were transparent, except where small areas were covered by films of limonite.

GALENA

Euhedral galena crystals were recovered from the red clay-fill from the base of the cave. Three samples, each of 5 kg, were de-flocculated over a period of 3 weeks at room temperature in a 20% solution of sodium hexametaphosphate. The resulting solutions were washed through a bank of 3 sieves ranging from 1 to 4 mm in size. The average weight of galena from the samples in each sieve was as follows:

4 mm sieve	2.29 kg
2 mm sieve	0.85 kg
1 mm sieve	0.53 kg

In view of the fact that the finer fractions were contaminated by cerussite, it was decided not to attempt a gravimetric separation of galena using heavy liquids. The largest proportion of galena crystals was retained by the 4 mm sieve and consisted of euhedral crystals showing varying degrees of oxidation (Fig. 2). From the whole fraction it was noted that crystal size varied from a fraction of a millimetre up to 60 mm across individual crystal faces. All were simple cubes with no modification.

Galena crystals from the walls of the cave, which were collected separately, were composed of aggregates of simple cubes (Fig. 3), the largest of which weighed 625 grammes. A thin layer of friable microcrystalline

FIGURE 4. A barite-filled void in the breccia-fill of the cave.

FIGURE 5. A mass of spheroidal barite from the breccia-fill of the cave (specimen K83-17).

barite occurred between the galena and the dolomite lining the cave walls.

Immediately below the cave, thin veins of galena up to 4 mm wide and a maximum length of nearly 90 mm filled fractures in the dolomitic limestone. Small crystalline masses of galena, up to about 20 mm across and associated with crystallised dolomite, occurred in small vughs in the dolomite adjacent to the veins. However, neither veinlets nor masses of galena persisted below the intense dolomitic halo below the cave. Neither veins nor masses showed oxidation, dominant in the cave galena.

BARITE

While there was no bedded deposit of barite on the upper surfaces of the breccia-infill of the cave, much of the breccia itself was cemented by thin microcrystalline films of white barite. Where there were voids in the fill, loosely aggregated spheroids of white barite developed (Fig. 4). Each spheroid (average diameter 6 mm) was composed of thin tabular crystals radiating from a common centre. The surfaces of the spheroids showed the termination of each tabular crystal (Fig. 5). Deposited on the upper surfaces of outwardly projecting masses of dolomite occurred nodular masses of white spheroidal barite on the so-called 'Stoss-side' (Bandy, 1942), possibly indicating a downward direction for the mineralising fluids.

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CERUSSITE

Early oxidation processes produced a patina of earthy grey cerussite which completely coated the cave galena. This was followed later by microcrystalline cerussite, which in some cases completely covered the earlier cerussite (Fig. 2). This later stage cerussite was pale grey in colour with a waxy lustre. The crystals, averaging 0.4 mm in length, consisted of either single crystals tabular on $\{010\}$, or simple twins on $\{110\}$ (see Fig. 6).

WAD

Thin films of black, soot-like material partially coated the cave walls and were dispersed through the breccias. Wet chemistry proved the presence of Mo indicating that the films are molybdic-wad or jordisite-containing material (amorphous MoS_2).

WULFENITE

Single, highly lustrous, pale orange crystals of wulfenite, up to 1.3 mm across and clearly visible to the naked eye, were found, contrasting sharply with the underlying crystalline films of slate-grey cerussite on which they were dispersed. The crystals were sometimes thick and tabular on $\{001\}$ but most were commonly cuboidal due to parallel growth on $\{001\}$ (Fig. 6). Microscopic overgrowths of later wulfenite formed fringes on the $\{101\}$ and $\{10\bar{1}\}$ faces of some crystals.

DISCUSSION

It seems likely that the catchment area for the presumably heavy flow of water, which produced the extensive phreatic cave systems in the Dinantian limestones of north Leicestershire in late Triassic time, lay to the west of the Breedon area. The most likely source of the mineralizing solutions which produced the carbonate-sulfate-sulfide paragenesis may therefore have been the Coal Measures (Simms, 1990). The exposed areas of the Leicestershire-South Derbyshire Coalfield have yielded abundant base metal mineralization (King, 1983). However, without many more data on the mineralogical composition of the Triassic mudstones above the unconformity and on the galena-rich clay in the cave and of their respective ages, few conclusions can be drawn concerning the paragenesis.

On the other hand, the presence of wulfenite is readily accounted for as being supergene in origin. There is evidence for three phases of oxidation, the first producing etching of cave galena crystals and the formation of thin films of earthy cerussite on their faces; the second stage formed crystallised films on first-stage earthy cerussite and the third produced isolated single crystals of wulfenite. While there is apparent evidence for three distinct phases of oxidation, the processes may well have been continuous.

Until quarrying disrupted it, meteoric water still passed through the conduit (A.E. Allcock, *personal communication*). It seems probable, therefore, that the oxidation is a recent event and vadose modification of the cave provided an ideal situation for supergene activity to take place.

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FIGURE 6. A single crystal of wulfenite measuring 1 mm across, on crystallised cerussite (specimen K83-13).

THE ZINC ANALOGUE OF KTENASITE FROM SMALLCLEUGH AND BROWNLEY HILL MINES, NENTHEAD, CUMBRIA

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Within the Northern Pennine Orefield, at Nenthead [Nat. grid ref. NY 788 430], in the Parish of Alston, Cumbria, are the Smallcleugh and Brownley Hill Mines, which previously worked lead-zinc ores. The specimens on which this investigation has been based are derived mainly from the Middlecleugh First Sun Vein, Smallcleugh Mine. They may be generally described as 'collapsed-rubbly' material with secondary deposition in fissures and cavities. A sample from Brownley Hill Mine is very similar in origin.

A small suite of specimens collected underground at the Smallcleugh and Brownley Hill Mines contain blue-green and blue grains which have been identified as the rare species ktenasite, $(Cu,Zn)_5(SO_4)_2(OH)_6.6H_2O$, using X-ray powder photography. Energy dispersive X-ray fluorescence and electron microprobe analyses, however, reveal that the ktenasite is zinc-dominant. Raade *et al.* (1977) demonstrated that ktenasite from

Modum, Norway, possessed the empirical composition $(Cu_{6.80},Zn_{2.91})_{9.71}(SO_4)_4(OH)_{12}.12H_2O$ [SO_4, OH and H_2O are idealised throughout], containing 37.9% CuO and 16.6% ZnO. The Modum mineral occurs as blue-green, platey crystals up to 1 mm and is associated with gypsum and bianchite, $(Zn,Fe)(SO_4).6H_2O$, on a breccia of rock and mineral fragments; primary sulfides are sphalerite, pyrite and chalcopyrite. Mellini and Merlino (1978) determined the structure of a ktenasite from Miniera Trentin, Italy, which is richer in zinc than that from Modum and gave the unit cell contents as $(Cu_{5.2},Zn_{4.8})_{10}(SO_4)_4(OH)_{12}.12H_2O$ (28.5% CuO and 27.0% ZnO). Olsen and Lewis (1979) demonstrated that a ktenasite from Creede, Colorado, was zinc-dominant and contained 48.0% ZnO and 12.4% CuO, which yields an empirical formula of $(Zn_{8.22},Cu_{2.16})_{10.38}(SO_4)_4(OH)_{12}.12H_2O$. The above formulae show that zinc can replace copper in the
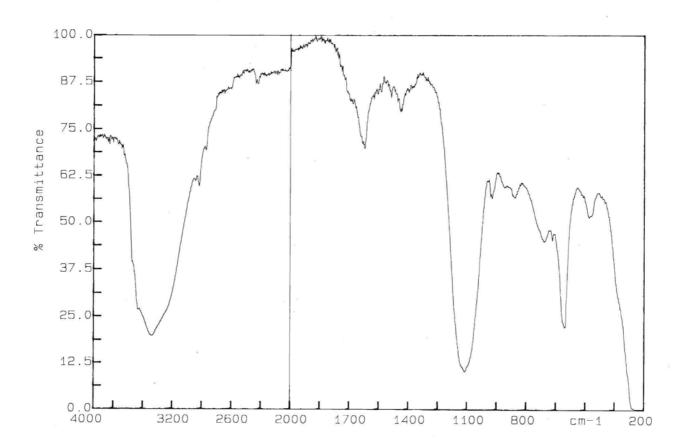

FIGURE 1. Infrared scan of bright-blue ktenasite from Nenthead.

Analysis	1	2	3	4	5	6	7	8
ZnO	73.19	62.01	61.67	59.09	60.67	60.65	31.52	24.77
CuO	2.79	2.61	4.49	2.74	4.10	3.41	27.19	26.25
SO$_3$	19.67	17.74	17.20	16.77	17.54	17.20	23.59	22.11
Total	95.65	82.36	83.36	78.60	82.31	81.26	82.30	73.13

Analysis	9	10	11	12	13	14	15	16
ZnO	27.11	30.21	30.78	29.72	28.89	29.19	35.07	34.99
CuO	28.36	21.90	22.27	21.59	22.31	20.00	21.06	29.07
SO$_3$	22.79	22.91	23.46	23.50	22.29	23.76	21.82	26.65
Total	78.26	75.02	76.51	74.81	73.49	72.95	77.95	90.71

Analysis	17	18	19	20	21	22	23	
ZnO	29.17	30.82	45.57	28.22	26.45	25.56	28.54	
CuO	23.05	20.24	16.38	21.47	21.80	22.84	21.30	
SO$_3$	22.74	21.85	17.10	23.04	22.43	22.66	22.85	
Total	74.96	72.91	79.05	72.73	70.68	71.06	72.69	

	Average analyses			
	1–6	7–12	13–19	20–23
ZnO	62.88	29.02	33.38	27.19
CuO	3.36	24.59	21.73	21.85
SO$_3$	17.68	23.06	22.31	22.74
Total	83.92	76.67	77.42	71.78

Analyses 1–6: small polycrystalline area 1.5 mm across, 10–12 μm rasters across a single, bright blue grain; Smallcleugh Mine. Analyses 7–12: bright blue grains on edge of oval-shaped area of blue-green phase; 7–9 on single grain, 10–12 on separate grains; Smallcleugh Mine. Analyses 13–19: separate, bright blue grains, each rastered; Brownley Hill Mine. Analyses 20–23: Grains from the blue-green phase area; Smallcleugh Mine.

species, although the full extent of the replacement has not yet been defined for natural material.

The Nenthead samples contain two colour variants of ktenasite: (1) blue-green and (2) bright blue (the latter is exceedingly rare). Gypsum covers most samples and tiny crystals pervade the ktenasite areas and are included in both types. Smithsonite is finely disseminated throughout some gypsum-bearing regions of the specimens. Additional minerals identified using X-ray powder diffraction methods include dolomite, ankerite, chalcopyrite, malachite, serpierite, $Ca(Cu,Zn)_4$ $(SO_4)_2(OH)_6.3H_2O$, beaverite, $Pb(Cu,Fe,Al)_3(SO_4)_2$ $(OH)_6$, namuwite, $(Zn,Cu)_4(SO_4)(OH)_6.4H_2O$ and schulenbergite, $(Cu,Zn)_7(SO_4,CO_3)_2(OH)_{10}.3H_2O$. Both the blue-green and bright blue varieties of ktenasite form irregular grains, though generally platey and approximately 0.2–0.3 mm across. The grains are soft and do not fluoresce under long or short wave ultraviolet light. Devoid of cleavage, they are optically biaxial with a negative sign, the blue-green variety having $\alpha = 1.588$, $\beta = 1.604$ and $\gamma = 1.619$ (all ± 0.003 NaD). X-ray powder diffraction data for both types

show virtually no differences from those published by Raade et al. (1977) or Olsen and Lewis (1979). Cell parameters for the blue-green type, as refined from the powder data, are $a = 5.652$Å, $b = 6.101$Å, $c = 23.645$Å, $\beta = 95.6°$, which yields a unit cell volume of 811Å^3. Again there is very little difference in these cell data from those determined for the Modum ktenasite.

An infrared spectrum (Fig. 1) of the blue-green type reveals marked similarities with that of Modum ktenasite. Major differences in copper-zinc ratios are apparent, however, between Modum and Nenthead ktenasites. Although grains of the latter are small, soft and difficult to hand-pick free from impurities (mainly gypsum), electron microprobe and X-ray fluorescence analysis reveals zinc is dominant over copper with variable ratios from sample to sample. Due to the high water content, the mineral is difficult to analyse when using electron microprobe methods; consequently, analyses in Table I are presented as raw data (analyses 1–23), which have been recalculated in Table II utilising the same Zn:Cu ratios and stoichiometric SO$_3$ and H$_2$O (analyses 1S–23S). Wide variations in the Zn:Cu ratios

Analysis	1S	2S	3S	4S	5S	6S	7S	8S
ZnO	53.74	53.53	51.99	53.34	52.25	52.85	29.83	26.96
CuO	2.05	2.26	3.78	2.47	3.53	2.97	25.73	28.57
SO_3	21.97	21.98	21.98	21.97	21.98	21.96	22.09	22.11
H_2O	22.24	22.23	22.25	22.22	22.24	22.22	22.35	22.36

Analysis	9S	10S	11S	12S	13S	14S	15S	16S
ZnO	27.15	32.22	32.25	32.19	31.36	32.98	34.74	30.35
CuO	28.40	23.36	23.33	23.29	24.21	22.60	20.86	25.21
SO_3	22.09	22.08	22.08	22.08	22.08	22.08	22.07	22.09
H_2O	22.36	22.34	22.34	22.34	22.35	22.34	22.33	22.35

Analysis	17S	18S	19S	20S	21S	22S	23S	
ZnO	31.04	33.56	40.95	31.56	30.46	29.33	31.82	
CuO	24.52	22.04	14.72	24.01	25.10	26.21	23.75	
SO_3	22.09	22.07	22.04	22.09	22.09	22.10	22.09	
H_2O	22.35	22.33	22.29	22.34	22.35	22.36	22.34	

	Average analyses			
	1–6S	7–12S	13–19S	20–23S
ZnO	52.96	30.10	33.57	30.79
CuO	2.84	25.46	22.02	24.77
SO_3	21.97	22.09	22.08	22.09
H_2O	22.23	22.35	22.33	22.35
Zn/Cu	18.2	1.15	1.50	1.21

clearly exist from almost 50:50 Zn:Cu through to compositions very close to the pure zinc end-member. On a 1 mg sample the blue-green variety, using a carbon, hydrogen, nitrogen analyser, yielded 20.5% H_2O.

The ktenasite structure was shown to contain two copper sites (CuI and CuII) (Mellini and Merlino, 1978) into which zinc enters, and a pure zinc site also, *viz* $Zn_2(CuI, Zn)_4(CuII,Zn)_4(SO_4)_4(OH)_{12}.12H_2O$. Empirical formulae derived from average analyses 1S-6S and 13S-19S, on the basis of 40 oxygen atoms are as follows, A: $(Zn_{9.48}Cu_{0.52})_{10}(SO_4)_4(OH)_{12}.12H_2O$ and B: $(Zn_{6.0}Cu_{4.0})_{10}(SO_4)_4(OH)_{12}.12H_2O$. By use of the crystal chemical formula, A can be rewritten (for the metal part) as $Zn_2(Zn_4)_4(Zn_{3.48},Cu_{0.52})_4$ and for B, if a 1:1 Zn:Cu site occupancy is assumed, we then have $Zn_2(Zn_2,Cu_2)_4(Zn_2,Cu_2)_4$. However, zinc tends to preferentially enter the CuI site so the occupancy may be greater than 50%. Although formula A clearly demonstrates that Zn can dominate in all sites, the zinc

analogue of ktenasite has not been named and must await further investigation.

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STANNITE REVISITED

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The current status of stannite and related Cu-Fe-Zn-Sn sulfides is reviewed, with particular reference to the occurrence of these minerals in southwest England. Attention is focussed on the problems in characterising and distinguishing the individual minerals in the group. The following have been identified from localities within the region: stannite (often Zn-rich), kesterite, ferrokesterite, mawsonite, stannoidite, kuramite. Other additional unidentified phases also occur. Chemical analyses of these mineral phases are presented.

INTRODUCTION

Most mineral collectors are aware that the mining district of southwest England contains some good sites for collecting the tin-bearing sulfide, stannite. However it is perhaps not so widely appreciated that the mineral stannite is in fact only one member of a complex group of Cu-Fe-Zn-Sn sulfides, and that many of the 'stannites' from Devon and Cornwall do not actually consist of this mineral. The purpose of this article is to review the current status of this group of minerals, and to highlight the occurrences of individual species in the region.

CURRENT STATUS OF 'STANNITE'

The tin-bearing sulfide that we know as stannite was first discovered by Raspe in 1785, in Wheal Rock (later part of West Kitty), St Agnes (Embrey and Symes, 1987), and subsequently analysed by Klaproth (see Table I). Stannite has always presented a problem to the mineralogist and in the early days there was even some doubt as to its status as a distinct mineral species, it being regarded by some as a mixture of cassiterite and chalcopyrite (Collins, 1892). In the early mineralogical literature it had various names, including *tin pyrites,*

TABLE I

Old analyses of stannites from southwest England (taken from Collins, 1892).

	1	2	3	4	5
Cu	36.0	30.0	29.18	23.55	29.39
Fe	2.0	12.0	6.73	4.79	12.44
Zn			7.26	10.11	1.77
Sn	34.0	26.5	26.85	31.62	25.55
S	25.0	30.5	29.46	29.93	29.64
Total	97.0	99.0	99.48	100.00	98.79

Localities and analyst: 1: St Agnes (Klaproth); 2: St Agnes (Klaproth); 3: St. Michael's Mount (Mallet); 4: St Michael's Mount (Johnston); 5: Huel Rock (Kudernatsch).

stannine, and *bell-metal ore* (in allusion to its colour). The term stannite was in fact initially used to describe a mechanical mixture of quartz and cassiterite found as pseudomorphs after quartz at Wheal Primrose, St Agnes (Greg and Lettsom, 1858; Rudler, 1905). However, the name stannite became accepted and the mineral was subsequently found at numerous tin-bearing localities worldwide. Several chemical analyses were obtained of stannite and these tended to confirm a general formula of Cu_2FeSnS_4, but with substantial substitution of Zn for Fe (*e.g.,* the early analyses of Cornish stannites shown in Table I).

Little research was carried out on the stannite group until the 1950s, but since then several additional related minerals have been identified, predominantly by reflected light microscope and electron microprobe studies. Ramdohr (1969) was one of the first to describe a variation in the optical properties of (apparent) stannites and he called these new phases stannite (*zinnkies* in the original German) I, II, III and IV. With the advent of precise microchemical analysis these additional unidentified phases could be characterised. Thus the Zn end-member of the stannite group was described from Kёster (N.E. Siberia) by Orlova (see Spencer, 1958) and named kesterite (= kösterite, custerite), Markham and Lawrence (1965) found mawsonite in bornite-rich ores from Mount Lyell (Tasmania) and Tingha (New South Wales), Kato (1969) described stannoidite in Japan (probably equivalent to Ramdohr's stannite (?) II), and Springer (1968) described rhodostannite as an alteration product of stannite from Vila Apacheta (Bolivia). New stannite-related minerals continue to be discovered, and more recently two Cu-Sn sulfides (kuramite and mohite) have been found by Kovalenker and co-workers (1979; see also Hey, 1982), in the gold-sulfide ores of Uzbekistan, and Cesbron *et al.* (1985) have described a Cu-Fe-Sn-As-Sb sulfide (vinciennite) from the Chizeuil pyrite deposits of France.

Kissin and Owens (1979, 1989) have highlighted the problems of working with the stannite group of minerals, in particular the complex intergrowths which make accurate and unequivocal chemical and structural analysis difficult. Furthermore, stannite and kesterite have tetragonal (pseudocubic) symmetry, but the differences in unit cell dimensions are so slight that normal X-ray powder methods will not distinguish the two and it is necessary to resort to the much more
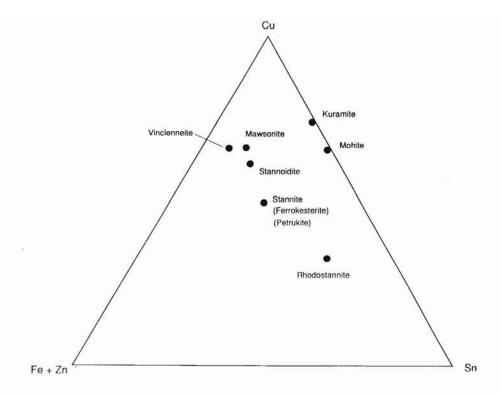
FIGURE 1. The composition of tin-bearing sulfides on a triangular Cu-(Fe + Zn)-Sn diagram.
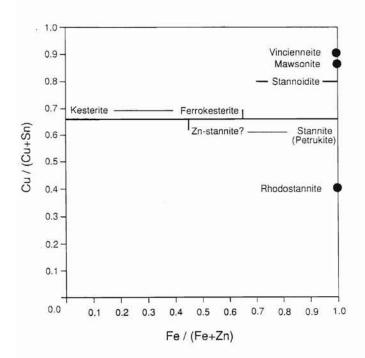

FIGURE 2. The position of analysed tin-bearing sulfides from southwest England on a Cu/Cu + Sn against Fe/Fe + Zn plot

difficult method of single-crystal X-ray crystallography. It has been known for some time that stannite

and kesterite are not completely miscible, but during their studies of material from Cligga, Kissin and Owens (1989) identified an Fe-rich counterpart of kesterite which they called ferrokesterite (see below). They also identified a third mineral of stannite-like composition from several localities which they called petrukite; there are thus 3 different minerals with (identical) stannite-like compositions!

The current status of the stannite group is summarised in Table II (see also Figs. 1 and 2).

STANNITE IN SOUTH WEST ENGLAND

After Raspe's initial discovery of stannite at Wheal Rock it was some time before mineralogists appreciated that more than one mineral might be present in these tin sulfide samples. With the benefit of hindsight, this is rather surprising considering the marked variation in chemical composition shown by some of the early analyses (Table I) and the constant references in the literature to the variation in colour of stannite.

'Stannite' has been recorded at several localities in southwest England (Table III, Fig. 3). The mineral has had little economic importance in the area, although it was so abundant at the Carn Brea Mines that it was sold as an ore of copper (Greg and Lettsom, 1858). Undoubtedly, however, the best examples of stannite can be found in the greisen-bordered vein 'swarms' located in small granite stocks, as typified by Cligga, St Michael's Mount, and Hemerdon. The restriction of stannite to such (relatively few) occurrences as

TABLE II

Cu-Fe-Zn-Sn sulfides belonging to the stannite group.

Stannite	(Cu_2FeSnS_4) – Zn substitutes for Fe, to give zincian stannite of Petruk (1973). Status of this mineral is still unclear, and the amount of Zn substitution is unknown (up to $Cu_2Fe_{0.45}Zn_{0.55}SnS_4$?).
Kesterite	(Cu_2ZnSnS_4) – Ferrokesterite ($Cu_2Fe_{0.65}Zn_{0.35}SnS_4$)
Petrukite	($Cu_2(Fe,Zn)SnS_4$)
Mawsonite	($Cu_6Fe_2SnS_8$)
Stannoidite	($Cu_8(Fe,Zn)_3Sn_2S_{12}$)
Rhodostannite	($Cu_2FeSn_3S_8$)
Kuramite	(Cu_3SnS_4)
Mohite	(Cu_2SnS_3)
Vinciennite	($Cu_{10}Fe_4Sn(As,Sb)S_{16}$)
Copper analogue of canfieldite (Cu_6SnS_8)	

compared to cassiterite is not easy to explain. However, the overall mineral paragenesis in the region involves an early high temperature phase of tin/tungsten/arsenic mineralisation, followed by a latter, moderate temperature phase involving Cu, Fe, and Zn. The earlier phase tended to produce an oxide facies (wolframite and cassiterite) and any sulfur was fixed as arsenopyrite; the later stage was sulfur-rich and produced sulfides such as pyrite, chalcopyrite, and sphalerite. In most instances these two phases of mineralisation must have been completely separate and only at some localities did they overlap to such an extent that Cu-Fe-Zn-Sn sulfides could form. Where stannite and cassiterite occur at the same locality, it is common to observe the stannite replacing cassiterite or as rims surrounding cassiterite (see for instance the illustrations in Ixer, 1990).

In common with the stannites from most localities worldwide, good crystals are rare. Collins (1892) shows no crystal drawings of stannite, and this lack of external morphology hindered an appreciation of the symmetry of stannite (it was at first thought to be cubic).

More recent chemical analyses of stannites from southwest England are presented in Table III. All were obtained by electron microprobe analysis, but it is important to realise that although the identifications were supplemented by optical examination, the main criterion for assigning a mineral name has been chemical composition. This is clearly not entirely foolproof, so in the light of recent developments, several of these identifications need to be confirmed by detailed X-ray structural studies. Even so, the majority of the chemical analyses result in good chemical formulae which approximate well to the ideal compositions.

ST MICHAEL'S MOUNT
The greisen-bordered veins associated with this small granite stock contain excellent examples of high temperature mineralisation. 'Stannite' is abundant and associated with a variety of other primary minerals including cassiterite, wolframite, löllingite, arseno-

pyrite, chalcopyrite and minor native bismuth (Moore, 1980). Hosking (1970) identified stannite and an additional phase which he thought was 'pink stannite' or mawsonite in the veins. Subsequently Moore (1980) identified stannoidite and kesterite as the most abundant phases here, whilst true stannite is a minor phase (see also Criddle and Stanley, 1986). It is probable that Hosking's 'pink stannite' was in fact stannoidite. It is also important to note that this site is protected and mineral collecting is not allowed.

CLIGGA
This well-exposed locality offers the best example of mineralised greisen-bordered veins in the area, and is the best site for collecting stannite-related minerals. Again, 'stannite' occurs with cassiterite, wolframite, arsenopyrite, löllingite, sphalerite, and lesser pyrite, chalcopyrite, and native bismuth (Moore, 1980). The tin-bearing sulfides have been identified as stannite, kesterite, ferrokesterite, and stannoidite (Moore, 1980; Kissin and Owens, 1989; Alderton, unpublished studies). This was the type locality for isostannite (cubic stannite, equivalent to Ramdohr's stannite (?) II; Claringbull and Hey, 1956), but this mineral has since been shown by Kissin and Owens (1989) to consist of ferrokesterite, and so the existence of isostannite is still not proven. The stannites from Cligga contain appreciable amounts of zinc, and Moore (1980) called them zincian stannite (ideally Zn/Zn + Fe should equal 40-55%). Kissin and Owens (1989) thought that Moore might have actually observed ferrokesterite, but even their analyses of stannite show marked enrichments of Zn (Table III, no. 10).

Analysis no. 15 in Table III is of an unknown phase found as thin cross-cutting veinlets in stannoidite. It appears to be homogeneous and does not represent a mixture of exsolved and host phases, but a simple stoichiometric formula was not attainable. Bearing in mind the problems in characterising such phases, its true identity must await confirmation.

TABLE III

Chemical analyses of tin-bearing sulfides from southwest England.

	1	2	3	4	5	6
Cu	31.37	29.05	29.2	29.5	29.1	28.98
Fe	8.31	8.12	10.5	11.3	7.9	2.98
Zn	5.14	5.84	3.1	1.8	5.8	10.91
Sn	25.99	27.74	27.7	27.9	27.4	27.96
S	28.47	29.30	30.0	29.6*	30.1	29.30
Total	99.28	100.05	100.5	100.1	100.3	100.13
Cu	2.17	1.99	1.97	2.01	1.97	2.01
Fe	0.65	0.64	0.81	0.87	0.61	0.23
Zn	0.34	0.39	0.20	0.12	0.38	0.73
Sn	0.96	1.01	1.00	1.02	0.99	1.03
S	3.88	3.98	4.01	3.98	4.04	4.00
Total	8.00	8.00	8.00	8.00	8.00	8.00

	7	8	9	10	11	12
Cu	28.72	29.48	29.2	29.2	39.42	38.83
Fe	1.11	2.34	4.1	8.2	9.79	10.25
Zn	13.28	12.29	10.9	5.2	3.27	3.01
Sn	28.15	27.83	26.7	27.5	18.19	18.58
S	29.00	28.70	29.7	29.6	29.62	29.43
Total	100.26	100.64	100.6	99.7	100.29	100.10
Cu	1.99	2.04	1.99	2.00	8.07	7.98
Fe	0.09	0.19	0.32	0.64	2.28	2.40
Zn	0.90	0.82	0.72	0.35	0.65	0.60
Sn	1.04	1.03	0.97	1.00	1.99	2.05
S	3.98	3.92	4.00	4.01	12.00	11.98
Total	8.00	8.00	8.00	8.00	25.00	25.00

	13	14	15	16	17
Cu	38.75	44.07	34.25	38.8	61.5
Fe	9.53	12.85	11.55	5.0	0.2
Zn	3.79		1.40	1.5	
Sn	19.23	13.35	22.86	26.8	15.0
S	29.01	29.50	29.06	27.8	23.1
Total	100.31	99.77	99.12	99.9	99.8
Cu	8.01	6.03	2.31	2.69	7.99
Fe	2.23	2.00	0.89	0.39	0.03
Zn	0.76	–	0.09	0.10	–
Sn	2.13	0.98	0.83	0.99	1.04
S	11.87	7.99	3.88	3.82	5.94
Total	25.00	17.00	8.00	8.00	15.00

1: Stannite, Hensbarrow. Manning (1983); 2: Stannite, Cligga. Mean of 6 analyses. Moore (1980); 3: stannite, Wheal Agar. Springer (1968); 4: Stannite, Cligga. Kissin and Owens (1989); (* Stated as 26.9%; presumed to be 29.6%); 5: Stannite, Cligga. Kissin and Owens (1989); 6: Kesterite, St Michael's Mount. Mean of 8 analyses. Moore (1980); 7: Kesterite, Cligga. Mean of 7 analyses. Moore (1980); 8: Kesterite, Cligga. Mean of 5 analyses. Alderton (unpublished); 9: Kesterite, Cligga. Kissin and Owens (1989); 10: Ferrokesterite, Cligga. Kissin and Owens (1989); 11: Stannoidite, Hensbarrow. Manning (1983); 12: Stannoidite, St Michael's Mount. Mean of 8 analyses. Moore (1980); 13: Stannoidite, Cligga. Mean of 4 analyses. Alderton (unpublished); 14: Mawsonite, Hensbarrow. Manning (1983); 15: Unidentified phase, Cligga. Mean of 2 analyses. Alderton (unpublished); 16: Kuramite, Gunheath. Stanley (unpublished); 17: Cu analogue of canfieldite, Gunheath. Stanley (unpublished).
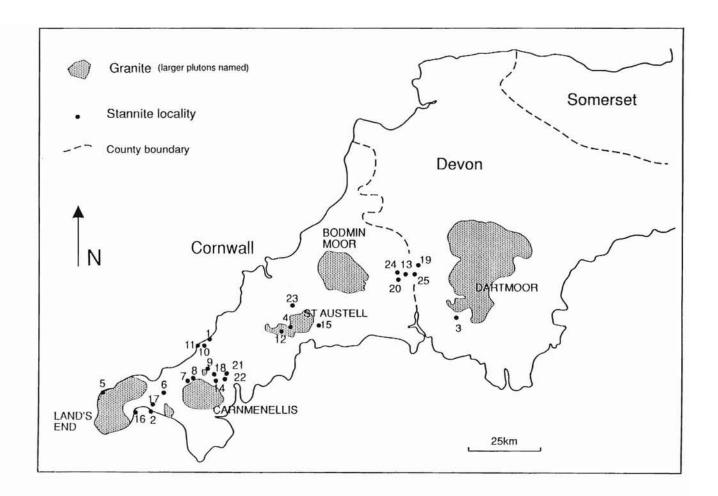
FIGURE 3. Localities in southwest England where 'stannite' has been recorded. 1: Cligga, 2: St. Michael's Mount, 3: Hemerdon, 4: Hensbarrow stock (including Bunny Mine and Gunheath), 5: Botallack and Geevor, 6: West Wheal Providence (Wheal Conqueror), 7: Dolcoath, South Crofty, East Pool and Wheal Agar, 8: Carn Brea Mines, 9: Wheal Scorrier 10: Wheal Rock, Wheal Primrose *(both West Kitty), 11: Wheal Kine (Polberro), 12: Stenna Gwynn, 13: Kit Hill Great Consols, 14: Barrier Mine *(Gwennap), 15: Lanescot Mine* (Fowey Consols), 16: Wherry, 17: Darlington, 18: Poldice, 19: Devon Great Consols, 20: Redmoor, 21:Wheal Jane, 22: Mount Wellington, 23: Mulberry, 24: Holmbush Mine, 25: Hingston Down Quarry. Sources: Dines (1956), Russell and Vincent (1952) (* signifies that these authors consider this a doubtful occurrence), Bromley and Holl (1986), Kettaneh and Badham (1978), Alderton (unpublished studies), and Stanley (personal communication regarding material in the British Museum (Natural History) collection).

HENSBARROW AND GUNHEATH CLAY PIT

The occurrence of stannite in this granite stock within the St Austell pluton is different to that of the other localities. Manning (1983) described pegmatitic vughs in the roof zone of the granite containing a variety of minerals. Primary phases included quartz, tourmaline, muscovite, K-feldspar, zinnwaldite, apatite, columbite, wolframite, cassiterite, arsenopyrite, chalcopyrite and bornite. These minerals were found in association with Sn sulfides, which were identified as stannite, stannoidite, and mawsonite.

Many collectors will have obtained 'stannite' from the Gunheath China Clay pit over the last few years. Stanley (personal communication) reports that the major tin sulfide minerals present are kuramite (only the second world occurrence) and stannoidite, with, in

fact, only minor stannite. The kuramite is altered to Cu_6SnS_8, an unnamed copper analogue of canfieldite. Representative chemical analyses of these phases are given in Table III.

OTHER 'STANNITE' LOCALITIES IN SOUTHWEST ENGLAND

Sn-bearing sulfides have been identified at several other localities in southwest England (Fig. 3), but especially at foci of high temperature Sn mineralisation. Stannites from some of these localities have been analysed by Springer (1968) and Alderton (unpublished data). Preliminary results suggest that the majority are stannites (*ss*) containing variable amounts of Zn.

Stannites from southwest England are characterised by an abundance of replacement and exsolution

21

features, resulting in an often complex, small-scale intergrowth of different species. Microscopic examination commonly reveals the presence of intergrowths, which previous authors have described as exsolution lamellae; for example, stannoidite lamellae in both stannite and kesterite, and kesterite in stannoidite and stannite are known (see for instance the photographs in Ramdohr, 1969; Moore, 1980; Kissin and Owens, 1989). Such relationships should in theory be usable for geothermometry, but although numerous studies of the stability relations in the system Cu-Fe-Zn-Sn-S have been carried out, problems still remain. Furthermore, these fine intergrowths present major problems during chemical analysis and, if care is not taken, analyses of mixtures are all too easy to obtain.

Surficial alteration (weathering) of stannite is a characteristic feature and has produced a range of secondary minerals. Copper-bearing phases appear to be the most varied and include covellite, native copper, malachite, azurite, turquoise, and rashleighite. The tin released by alteration forms varlamoffite (stannic acid gel, H_2SnO_3; see Russell and Vincent, 1952) and probably cassiterite, whilst the Zn appears to be entirely removed. It is also notable that arsenopyrite is a very common associated phase, and secondary Fe arsenates (scorodite, pharmacosiderite) also typically are present.

CONCLUSION

There are several localities in the mining district of southwest England where stannite can be found. The following Sn-bearing sulfides have been confirmed as occurring in the region: stannite (often with appreciable zinc), kesterite, ferrokesterite, stannoidite, kuramite, and mawsonite. Of these, stannite and kesterite appear to be the most abundant, but stannoidite is locally abundant, for instance at St Michael's Mount and Cligga.

Unfortunately, the different minerals in the group can be extremely difficult to distinguish, even with access to advanced analytical facilities. This problem is exacerbated by the abundant fine intergrowths of various phases, with the result that many samples are not homogeneous and consist of two or more minerals of the stannite group.

In hand specimen stannoidite does tend to have a more yellow/bronze appearance, compared to the greyer colours of stannite and kesterite. Mawsonite is similar to stannoidite, but so far has only been found as very small inclusions, typically associated with Cu-rich minerals such as bornite. Distinguishing stannite from kesterite or ferrokesterite appears to be much more difficult, if not impossible, in hand specimen.

It is unlikely that the long-running stannite story will end here. It seems likely that more phases will be identified in this complex group, and that southwest England will figure in these advances. With the abundance of Sn-bearing sulfides now identified from the province it is somewhat ironic to note that Klaproth's original analysis of stannite revealed no zinc, and thus

would represent the only example of pure stannite found in southwest England.

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THE MINERALOGY OF WAPPING MINE, MATLOCK BATH, DERBYSHIRE

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The mineralogy of Wapping Mine, at Matlock Bath, Derbyshire is typical of a number of localities in the Southern Pennine Orefield. The calcite-barite-fluorite-galena mineralisation is associated with a major fault-vein system (Moletrap Rake) and a replacement ore-body (The Maze). Some alteration has occurred producing fine specimens of hemimorphite, goethite pseudomorphs after marcasite, and some remarkable curved gypsum crystals. Cerussite is associated with altered galena, as are small amounts of anglesite and pyromorphite.

INTRODUCTION

Wapping Mine (SK 294575) and the associated Cumberland Cavern (SK 292577), known in the past as the Duke of Cumberland's Mine, form part of a series of solution caverns and old mine workings that can be traced north from Wapping Mine towards Masson Hill, on the hillside that forms the west bank of the River Derwent in Matlock Bath (Ford, 1967b; Flindall and Hayes, 1976). The location of these and the associated mine workings are presented in Figure 1, and form a series of rake, pipe-vein and replacement ore-body systems typical of the Southern Pennine Orefield (Ford, 1967a; Ford and King, 1968). Over the years these systems have been mined for galena, fluorite and, to a lesser extent, ochre (Flindall and Hayes, 1972, 1976; Ford and Rieuwerts, 1975).

Wapping Mine exploits Moletrap Rake, a vein emplaced along a major fault traceable WNW-ESE through the mine, together with a number of parallel veins and some associated replacement ore-bodies and small pipe veins.

HISTORY OF MINING

Although it is thought that the Romans worked mines in the Matlock Bath area, the first records of any mining activity are those of 1470 relating to work at the Nestus Mines (Rutland Cavern) on Masson Hill (Flindall and Hayes, 1976). The earliest evidence for mining at Wapping Mine is a shilling of George II (who reigned 1727–60) and an 18th Century work token found whilst the mine was being reworked in the 1950s (Ford and Rieuwerts, 1975). It appears that the mining activity during this early period was confined to the extraction of galena from the stringers in Moletrap Rake, although there is little evidence remaining of these operations (Flindall and Hayes, 1972).

It is known that Cumberland Cavern was a show cave in 1780, and that the connection with Wapping Mine appears to have been worked from both sides. This suggests that both systems were being exploited at the same time (Flindall and Hayes, 1972).

A number of specimens from 'Cumberland Mine, near Matlock Bath' are described by Rashleigh (1797). Most of these are of gypsum typical of that found in

Wapping Mine, thus it is reasonable to assume that they originate from Wapping Mine – Cumberland Cavern.

There are no records of any mining activity in the 19th Century but two periods of fluorite extraction have taken place in the 20th Century. Between 1924 and 1936, a Mr. Locke employed 2–6 men underground, with their activity being concentrated on Moletrap Rake and the SW side of the Maze, while between 1953 and 1956 a Mr. Barton worked the mine (Flindall and Hayes, 1972).

Following this latter period of working, the roof around the entrance partly collapsed making the initial sections of the mine dangerous to negotiate. Subsequently the entrance was walled-up and access to Wapping Mine is now *via* the inclined 'adit', staircases and passages of Cumberland Cavern.

A detailed survey of both Wapping Mine and Cumberland Cavern has been published (Flindall and Hayes, 1972) and a plan of the mine on the basis of this work is shown in Figure 2.

GEOLOGICAL SETTING

Wapping Mine is located in dolomitized Viséan (Brigantian) Carboniferous Limestone of the Matlock Group, in between basalts of the Upper and Lower Matlock Lavas ('Toadstones'). The beds have a regional dip of 15–20° to the east and the Lower Matlock Lava is close to the floor of the mine in a number of places (Ford, 1967a; Flindall and Hayes, 1972). The geology of the Matlock Bath area is shown in Figure 1 and a more detailed representation of the geology around Wapping Mine and Cumberland Cavern is given in Figure 3. For a more general description of the geology of the area the reader is referred to the Memoir for the Chesterfield (112) Sheet (Smith, *et al.*, 1967).

The most obvious geological structure in the area of the mine is the Moletrap Rake, and mining has resulted in the production of the First, Second, Third and Fourth Stopes and Funnel Cave. This rake is a WNW-ESE fault-vein system that appears to have a down-throw of 12.5 m on its northern side. It is a feature that can be traced eastwards from Wapping Mine (where it averages 3 m in width, with some of the workings being up to 10 m wide) across the River Derwent to Wild Cat Tor, Hagg Wood Level and Moletrap Mine (where it is

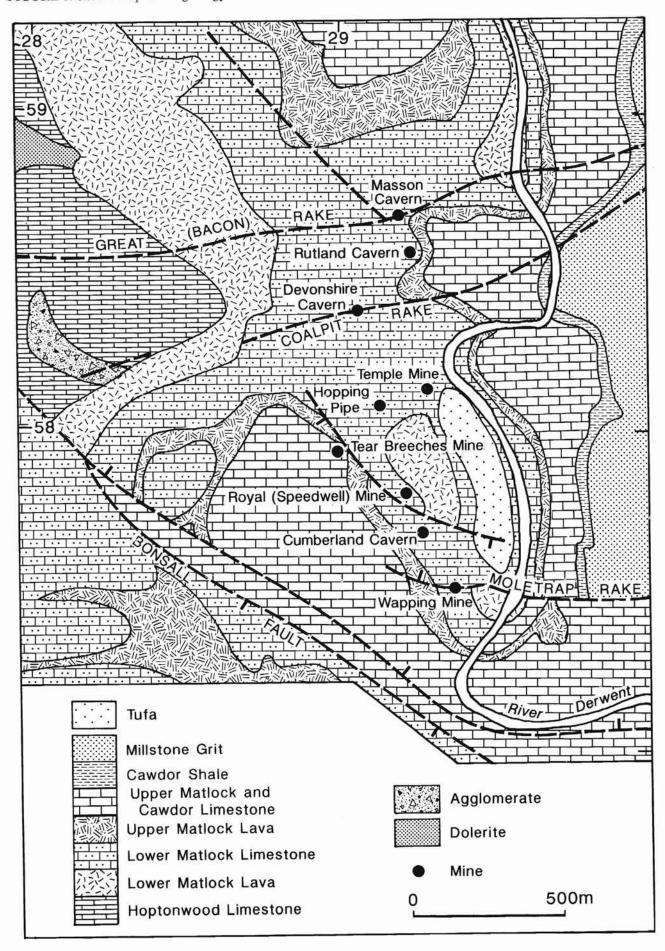**FIGURE 1.** Sketch map of the geology and mines of the Matlock Bath Area.

28
59
29

Masson Cavern

GREAT (BACON) RAKE

Rutland Cavern

Devonshire Cavern

COALPIT RAKE

Temple Mine

Hopping Pipe

58

Tear Breeches Mine

Royal (Speedwell) Mine

BONSALL FAULT

Cumberland Cavern

MOLETRAP RAKE

Wapping Mine

River Derwent

Tufa

Millstone Grit

Cawdor Shale

Upper Matlock and Cawdor Limestone

Upper Matlock Lava

Lower Matlock Limestone

Lower Matlock Lava

Hoptonwood Limestone

Agglomerate

Dolerite

Mine

0   500m

FIGURE 2. Plan of Wapping Mine and Cumberland Cavern (reproduced with permission from Flindall and Hayes, 1972).
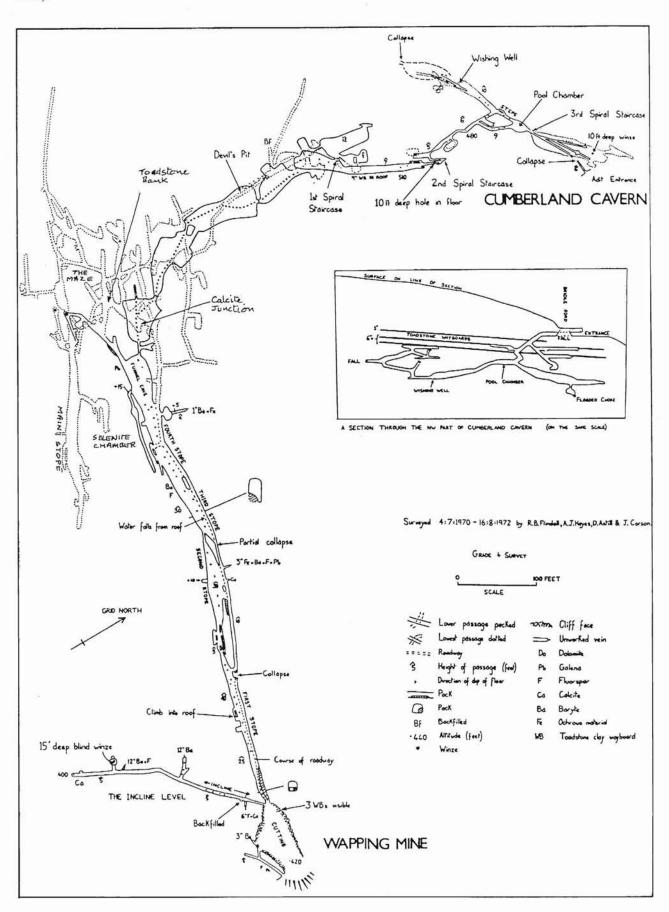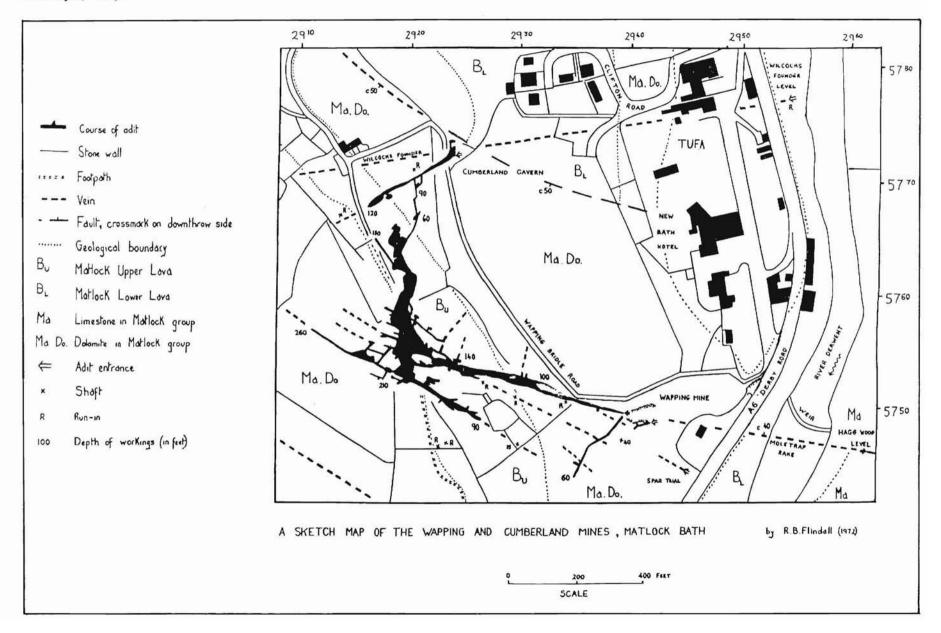
FIGURE 3. Sketch map of Wapping Mine and Cumberland Cavern showing the major geological features (reproduced with permission from Flindall and Hayes, 1972).

A SKETCH MAP OF THE WAPPING AND CUMBERLAND MINES, MATLOCK BATH   by R.B.Flindall (1972)

up to 0.7 m wide), further east for 0.7 km to New Bullestree Mine (where it is reputed to be 3 m wide) and on to Lea Mills (Smith, *et al.*, 1967; Flindall and Hayes, 1972; Butcher, 1976). It is also possible that to the west of Wapping Mine Ball Eye Rake is part of the same system (Butcher, 1976), although a major fault system (the Bonsall Fault) trends NW-SE through this area.

The other principal feature of the mine is the Maze. This is a series of passages in a replacement ore deposit which merges at its extremities into a network of scrins orientated NW-SE or SW-NE. It is this area of the mine that has the Lower Matlock Lava close to the floor and, although the lava is almost horizontal, a green clay derived from alteration of the basalt lava is only occasionally visible in the floor (Toadstone Bank) and at the bottom of trial winzes (Flindall and Hayes, 1972).

GENERAL MINERALOGY

The mineralogy of Wapping Mine is typical of many rake and pipe-vein deposits in the Southern Pennine Orefield containing as it does the barite-calcite-fluorite-galena mineralisation for which the area is so well known.

Although there have been no reports of work on the minerals from Wapping Mine in particular, studies carried out on fluid inclusions in minerals from Masson Hill (1 km to the NNW) (Atkinson, 1983) should provide some evidence for the conditions prevailing during the periods of mineralisation. From these studies it seems likely that the mineralising fluids were concentrated sodium chloride brines, with some calcium chloride (up to 20% dissolved salts based on fluid inclusion composition), that were circulating at temperatures of 70–140°C (based on fluid inclusion homogenization temperatures).

Dating of the mineralisation in the Southern Pennine Orefield in general and the Matlock Bath area in particular has been the subject of much discussion (Quirk, 1987). Dates derived from anomalous J-type galena lead isotope studies for samples from the Southern Pennine Orefield are misleading (Coomer and Ford, 1975; Mostaghel and Ford, 1986) and those from potassium-argon ratios in various altered volcanic clay minerals (Ineson and Mitchell, 1972) have been questioned recently (Quirk, 1987). Strontium isotope ratios in calcite and fluorite (Atkinson, 1983) provide some evidence for an Upper Carboniferous age for the date of mineralisation, a date that would be compatible with a diagenetic origin for the mineralising ore-fluids, being derived from the overlying Namurian shales during Upper Carboniferous times (Quirk, 1987).

The workings on the Moletrap Rake, i.e. the First, Second, Third and Fourth Stopes and Funnel Cave (see Figure 3) exploit the barite-calcite-fluorite-galena mineralisation. The first three minerals are very common, while the latter is rather uncommon. Some quartz is also present. A considerable amount of alteration has occurred such that the galena is usually coated with cerussite. Hemimorphite is locally quite common and

some smithsonite and aurichalcite have been found although sphalerite has not been reported. Minor amounts of pyromorphite and cadmium sulfide (possibly amorphous but perhaps greenockite or hawleyite) have also been tentatively identified.

The Maze section of the mine has yielded the barite-calcite-fluorite combination together with some smithsonite, secondary barite, goethite pseudomorphous after marcasite, ochre and wad.

In the Main Stope-Selenite Chamber area of the mine calcite is very common. Barite, fluorite and galena are much less common. Again some alteration has occurred; the galena is usually coated with cerussite and crystals of gypsum (var. selenite) are to be found in the Selenite Chamber.

A number of the minerals mentioned above were reported in 'The Peak District Mineral Index' by Ford and Sarjeant (1964) and also by Flindall and Hayes (1976) as occurring in the Wapping Mine-Cumberland Cavern area. For a more general survey of the minerals to be found in the Southern Pennine (Derbyshire) Orefield the reader is referred to Braithwaite (1983).

MINERALS AT WAPPING MINE

ANGLESITE, $PbSO_4$
Small amounts of anglesite were found in the mine in 1965 associated with altered galena, cerussite and pyromorphite (R.S.W. Braithwaite, *personal communication*).

ARAGONITE, $CaCO_3$
Aragonite has been recorded as occurring in both Cumberland Cavern (Ford and Sarjeant, 1964) and also as 'flos-ferri' in Wapping Mine (Braithwaite, 1983).

AURICHALCITE, $(Zn,Cu)_5(CO_3)_2(OH)_6$
Aurichalcite has been reported to occur in Wapping Mine (T.D. Ford, *personal communication*). It is interesting to note that the Matlock Bath area (Rutland Cavern) provided some of the earliest known specimens of aurichalcite and, more recently, rosasite (Braithwaite and Ryback, 1963; Braithwaite, 1983).

BARITE, $BaSO_4$
The majority of the barite occurs in the areas of the mine around the Moletrap Rake where it is intimately associated with fluorite and less commonly calcite and is usually to be found in a hard, cream, iron-stained nodular cocks-comb form. In various areas of the Maze, notably around Calcite Junction, some lustrous, colourless to grey-blue, thin, tabular secondary barite (up to 7 mm) is to be found coating both calcite and fluorite.

CADMIUM SULFIDE, CdS
It is reasonably common to find that hemimorphite from the Funnel Cave-Fourth Stope areas of the mine is associated with small areas (1x2 mm) of a bright canary-yellow material that appear to form a 'back-

FIGURE 4. Colourless cerussite (to 4 mm) on iron-stained barite, Wapping Mine.

FIGURE 5. Cream cerussite (to 6 mm) on calcite, Wapping Mine.

bone' when the internal structure of the hemimorphite is revealed. It is assumed that this is cadmium sulfide, probably amorphous but possibly greenockite or its dimorph hawleyite.

CALCITE, $CaCO_3$

Calcite is common in most parts of the mine. The scalenohedron is the common form although some scalenohedron-rhombohedron combination forms also occur. The crystals are usually in groups (up to 30 cm) showing parallel growth. The calcite is a pale brown-honey colour (Selenite Cavern) or colourless-turbid white to pale brown (Calcite Junction and Fourth Stope). In general the larger the crystals the greater the degree of etching of some, but not all, of the crystal faces. It is interesting to note that Rashleigh (1797, Plate 26) describes a specimen of 'Calcareous Spar from Cumberland Mine, near Matlock Bath' in the form of acicular crystals emerging from botryoidal growths. This is unlike material that has been found recently.

The presence of ghost forms and sulfide inclusion zones indicates at least three distinct phases of calcite mineralisation. In the nearby Masson Hill area the
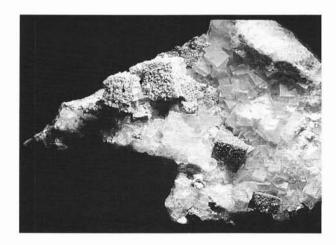

FIGURE 6. Galena (to 12 mm) altering to cerussite with colourless iron-stained flourite (to 7 mm) on altered limestone, Wapping Mine. John Cooper specimen.

sulfide inclusion zones were shown to contain bravoite, chalcopyrite, marcasite and pyrite (Ixer and Townley,

1979); it is likely that these minerals also occur in the inclusion zones in the Wapping Mine calcites.

CERUSSITE, $PbCO_3$
Cerussite is always associated with oxidised galena and it is unusual to find galena that is not partially or totally coated with small cerussite crystals, indeed in some cases it is obvious that the galena is being replaced by cerussite. It occurs in three distinct forms: a tabular, pale grey-yellowish form (up to 5 mm) with a vitreous lustre; a dipyramidal, pale grey-yellowish form (up to 6 mm) also with a vitreous lustre; and a thin lath-like, lustrous, pale brown form (up to 5 mm) that is much less common. The latter form is found in a passage off Funnel Cave-Fourth Stope, while the first two are quite common in the Funnel Cave-Fourth Stope area and in Selenite Cavern. Figures 4-6 illustrate cerussite crystals from Wapping Mine.

CHALCOPYRITE, $CuFeS_2$
Chalcopyrite has been reported to occur in Cumberland Cavern (Flindall and Hayes, 1976). Given that chalcopyrite has been identified in the sulfide inclusion zones in various minerals from the nearby Masson Hill (Ixer and Townley, 1979), it seems likely that some of the irregular sulfide inclusions in the Wapping Mine calcites and fluorites also contain chalcopyrite. Upon oxidation it could have provided the copper required for the formation of the aurichalcite reported above.

FLUORITE, CaF_2
Fluorite is common in the Moletrap Rake and the Maze. The cube is the only form to be found, although some crystals do show bevelled edges indicating the minor development of other crystal faces. Three different associations are common: small, colourless cubes (up to 5 mm) on hard, cream, nodular barite (both iron stained) on pale blue granular fluorite (Funnel Cave); larger, colourless cubes (up to 1 cm), with this form purple spots and edges are quite common, as are a number of zoned inclusions (some of which appear to be marcasite) indicating several episodes of mineralisation (Fourth Stope); and large colourless to pale greenish-yellow cubes (up to 2 cm), some partially covered with a heavy yellow-brown encrustation of poorly crystalline goethite (Maze).

GALENA, PbS
Galena is not common in the mine despite the assumption that the early mining activity was extracting this mineral, although a large mass of galena (up to 40 kg) was found c. 1965 in the south west wall of Funnel Cave (R.B. Flindall, *personal communication*). Small amounts are scattered throughout the Moletrap Rake, some occurring as a lining to vughs in the vein as partly exposed crystals (up to 3 cm) (Second Stope) but the majority is usually enclosed in cream coloured barite. The majority of the freely crystallised galena occurs as smaller cubic crystals (up to 1 cm), with some development of the octahedral faces, set on fluorite,
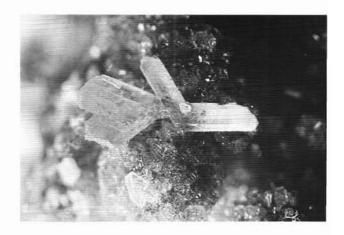

FIGURE 7. Colourless gypsum (to 1.5 mm) on hemimorphite, Wapping Mine.

locally calcite and less frequently barite (Funnel Cave). It also appears at the junction between the calcite infill and the wall rock (Selenite Chamber) as cubo-octahedral crystals (up to 1.5 cm). As oxidation has taken place most of the crystals of galena are coated with cerussite.

GOETHITE, $\alpha\text{-}Fe^{3+}O(OH)$
It is not uncommon to find coatings and crusts of yellow-brown material covering earlier generations of fluorite, barite and calcite. A sample of this yellow-brown coating on colourless-pale greenish-yellow fluorite (Maze) has been shown to be poorly crystalline goethite (X-ray diffraction, J. Faithfull, *personal communication*).

Brown crystals (up to 2 cm) of goethite pseudomorphs after marcasite have been found (Maze). They are more common in fluorite-rich areas of the veins, usually intergrown with banded fluorite and calcite. The replacement is not always complete as it is reasonably common to find a core of silvery-yellow marcasite within the larger pseudomorphs.

GYPSUM, $CaSO_4.2H_2O$
Rashleigh (1797) describes a number of specimens of gypsum from 'Cumberland Mine, near Matlock Bath'. Plates 28 and 29.2 show groups of curved crystals, 'which the miners call snow fossils', that are typical of material occurring in Wapping Mine. Plate 29.3 shows a large specimen (35 cm) of which 17 cm 'is composed of the minutest fibrous lines shot in all directions, like cotton wool'. It is tempting to speculate that these specimens came from the Selenite Chamber in Wapping Mine (see below) as this is the only area of the mine or Cumberland Cavern where such material can be found.

The most notable occurrence of gypsum in the mine is, as the name suggests, in the Selenite Chamber. In the past the walls and part of the roof of the chamber were covered with glistening white selenite. Unfortunately

FIGURE 8. Colourless hemimorphite (4 × 2.5 mm) on flourite, Wapping Mine.

FIGURE 9. Rosette of colourless hemimorphite (4 × 2.5 mm) on flourite, Wapping Mine

this is no longer the case, although enough remains for the former state to be imagined. The gypsum is present in three habits: as small colourless bladed crystals, commonly twinned in the usual fish-tailed form; as colourless or white acicular crystals (up to 4 cm); and in remarkable curved 'ram's horns' rosettes of colourless or white crystals that can reach 5–6 cm in diameter.

Gypsum also occurs as acicular crystals scattered over the surface of the goethite pseudomorphs after marcasite (Maze), the sulfate content presumably arising from the oxidation of the marcasite.

Colourless gypsum crystals on hemimorphite from Wapping Mine are illustrated in Figure 7.

HEMIMORPHITE, $Zn_4Si_2O_7(OH)_2.H_2O$

Despite the fact that sphalerite has not been reported to occur in the mine, hemimorphite is locally common, particularly in the area around Funnel Cave, where it is present in two distinct settings. Firstly it occurs as radiating groups or coatings of lustrous, colourless to light brown crystals (up to 4 mm) on iron stained barite, where it partly fills cavities in the vein on the Moletrap Rake. Secondly it occurs as smaller, but more lustrous, darker brown crystals associated with thin wafer-like barite crystals in cavities between calcite crystals and the host rock (in a passage off Funnel Cave-Fourth Stope). Examples of hemimorphite from Wapping Mine are illustrated in Figures 8 and 9.

MARCASITE, FeS_2

Both calcite and fluorite from the Moletrap Rake and the Maze areas of the mine contain zones delineated by inclusions of sulfide minerals. In particular, some zones in the fluorite contain pale yellow crystals (up to 0.3 mm) with a form typical of marcasite (Fourth Stope). Previously marcasite has been reported to occur in such inclusion zones in calcite, fluorite and barite from the nearby Masson Hill (Ixer and Townley, 1979).

Marcasite also occurs as a core to the pseudomorphs

of goethite after marcasite that are reasonably common in certain areas of the mine (Maze).

PYROMORPHITE, $Pb_5(PO_4)_3Cl$

Pyromorphite as pale apple-green to almost colourless microcrystallised alteration crusts on corroded galena and also on fluorite and secondary barite (which it seems to replace), associated with cerussite and a little anglesite, was collected in 1965 and identified by infrared spectroscopy (R.S.W. Braithwaite, *personal communication*). Pyromorphite has also been reported to occur in the nearby Hopping Pipe (Flindall and Hayes, 1976).

More recently very small amounts of bright green microcrystals (<0.2 mm) of pyromorphite have been found associated with oxidised galena and set on barite (in a passage off Funnel Cave-Fourth Stope). This material is similar to pyromorphite from other localities in the Southern Pennine Orefield (e.g. Hazard Mine, Dirtlow Rake, Castleton) although the present identification requires confirmation.

QUARTZ, SiO_2

Silicification has taken place locally and singly terminated, colourless quartz crystals (up to 2 mm) occur lining cavities in altered limestone (in a passage off Funnel Cave-Fourth Stope).

SIDERITE, $FeCO_3$

Siderite has been reported to occur in the Wapping Mine-Cumberland Cavern area (Ford and Sarjeant, 1964).

SMITHSONITE, $ZnCO_3$

Smithsonite is not obviously common in the mine, whereas hemimorphite is readily found. Several forms occur; small colourless to white, rounded rhombohedra (up to 2 mm) on calcite and fluorite (Calcite Junction) (X-ray diffraction, J. Faithfull, *personal communication*),
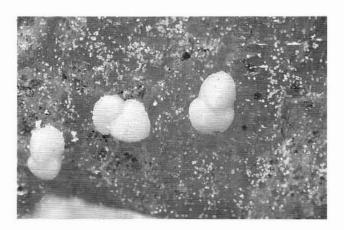
FIGURE 10. 'Snail-like' smithsonite (to 1 mm) on altered limestone, Wapping Mine.

and an unusual small snail-like form (junction of Funnel Cave and Cumberland Cavern) (J.C. Cooper, *personal communication*). The latter material, illustrated in Figure 10, has some similarity to a habit of rhodochrosite, 'trigonal wheat sheaves', from the N'Chwaning Mine, Cape Province, South Africa (Wilson and Dunn, 1978) although the trigonal symmetry is much less evident in the Wapping Mine material. There also appears to be some replacement of hemimorphite by smithsonite (Funnel Cave) (M.P. Cooper, *personal communication*).

WAD (amorphous manganese oxides)
Dark brown to black coatings on other minerals, usually calcite and barite, are assumed to be manganese mineralisation in the form of wad (Toadstone Bank).

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NOTES
PHOSGENITE, THE FIRST WELSH OCCURRENCE

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Although phosgenite has been known from Britain for nearly 200 years, there are still only a few recorded occurrences. It was first recorded from the British Isles by Mawe (1802) from Derbyshire, most probably coming from the Bage Mine, near Wirksworth. It was later recorded from Lossiemouth, Grampian Region (Greg and Lettsom, 1858; Starkey, 1988), Wheal Rose, near Sithney, Cornwall (Russell, 1927), Penberthy Croft Mine, St. Hilary, Cornwall and Driggeth Mine, Caldbeck Fells, Cumbria (Kingsbury, 1957), Ticklow Lane, Shepshed, Leicestershire (King, 1973), Newporth Beach, Falmouth, Cornwall (Dean *et al.*, 1983) and Clevedon, Avon (Starkey, 1984). A record of phosgenite from Wheal Confidence, Newquay, Cornwall (Greg and Lettsom, 1858) was later discredited (Russell, 1927). Phosgenite has now been found at Penrhyn Du Mine, near Abersoch, Gwynedd, and this represents the first recorded occurrence of the mineral in Wales.

Near Abersoch, phosgenite has been found in loose blocks of vein material occurring below high water mark in a gulley formed by the erosion and partial stoping of a vein formerly worked by Penrhn Du Mine (at Nat. Grid ref. SH 326 262). The near vertical vein, which cuts Ordovician mudstones of Arenig age (Cattermole and Romano, 1981), consists mainly of quartz, along with galena, minor sphalerite, barite, traces of pyrite and pieces of wall rock.

The phosgenite from Penrhyn Du forms pink-white striated prisms and colourless tabular crystals up to 1.5 mm in size. Some of the phosgenite has associated anglesite or cerussite and on one specimen anglesite has been replaced by platey phosgenite crystals. Phosgenite has also been found *in situ* as colourless tabular crystals to 0.25 mm in cavities in galena in a similar vein outcropping approximately 100 m to the south. It would seem likely that the phosgenite has formed by the reaction of sea water with galena.

A specimen of phosgenite from this locality has been lodged in the Mineral Collection of the National Museum of Wales, registration number NMW 91.1G M1.

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STRONTIANITE FROM BROWNLEY HILL MINE, NENTHEAD, CUMBRIA

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In the Northern Pennine Orefield, north of Stainmore, strontianite has been recorded as a rare, minor constituent of vein deposits at three localities: Greenlaws Mine, Weardale [NY 890 370] (Wray, *in* Sherlock and Hollingworth, 1938); Settlingstones Mine, near Hexham [NY 843 683] (Trestrail, 1931; Dunham, 1948); and Stonecroft Mine, near Hexham [NY 855 689] (Young, 1985). In a recent review of the mineral's occurrence in this area, Young (1985) was unable to confirm its presence at Greenlaws Mine; the only

specimen which could be traced and which was labelled as stontianite was shown to be calcite. Strontianite has recently been collected *in situ* at Brownley Hill Mine, Nenthead [NY 776 446].

At Brownley Hill Mine, the mineral was found in a branch off the West High Cross Vein, between that vein and the Jug Vein, close to the junction of the Great Limestone and overlying shales. The vein is up to 30 cm wide, and here consists mainly of calcite and barite with some ankerite. It is accompanied by several parallel veins and a few cross-cutting stringers.

The main vein filling is chiefly white to pinkish calcite which often encloses small patches of rather oxidised ankerite. Barite, which is the next most abundant mineral, is found near the centre of the vein; it is generally pinkish in colour, and occurs in vughs as thin, transparent, colourless plates in parallel groups. Calcite also occurs in vughs as aggregates of small, colourless rhombohedra, encrusting barite and ankerite. Ankerite is present both as aggregates of brown, curved crystals on barite in vughs, and also as compact, crystalline masses within the vein matrix. Chalcopyrite is present as tiny crystals (<0.5 mm) both in, and growing on, barite.

The strontianite occurs mainly as small, typically pure, white to pale green, 'feathery', divergent sprays of acicular crystals to 5 mm, grown mainly on barite in vughs, but also on calcite and ankerite. In most examples it appears to be the last of the primary minerals to have been deposited, although in one specimen calcite rhombs seem to overgrow one group of strontianite crystals. The strontianite was only found over about a one metre section of the vein. The identity of the strontianite was confirmed by X-ray diffraction (Royal Museum of Scotland number 4527).

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SECONDARY COPPER MINERALS FROM THE KNOCKMAHON AREA, COUNTY WATERFORD, REPUBLIC OF IRELAND

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Rich copper deposits in Knockmahon and adjoining townlands, *ca* 22 km S.W. of Waterford town, Co. Waterford, were extensively worked in the last century. The main ore mineral was chalcopyrite with smaller amounts of grey copper ores in near vertical quartz veins cutting Ordovician sediments and volcanics. Small amounts of erythrite, malachite, native copper and black copper oxides were found in the upper portions of some of the deposits. Occasional sphalerite, siderite, barite and galena also occurred (Holdsworth, 1834).

Examination of some of these mines in the early to mid 1980's led to the discovery of rare secondary copper minerals of post-mine origin at two localities, Tankardstown Mine and an adit on the Bonhiva lode, Knockmahon.

TANKARDSTOWN MINE

Tankardstown Mine, grid ref. X 450 988, in the southeast corner of Knockmahon townland, was the richest of the mines. In places the orebody was up to 21 metres wide. The ruined enginehouse and chimney still form a prominent local landmark. Atacamite occurs as bright green, powdery encrustations, while chalcanthite is found as bright blue, crystalline, water-soluble encrustations on wall-rock containing decomposing chalcopyrite on the side of a small opencast pit (now partly filled with rubbish) on the Tankardstown lode, near the ruined enginehouse. Both have been identified by X-ray diffraction (National Museum of Scotland, powder diffraction photograph no. 1933, and Geology Department, University of Edinburgh, respectively). The locality is only a few hundred metres from the sea

and it seems plausible that the salt spray provided a source of chloride for the formation of atacamite. This appears to be the first reported occurrence of atacamite in Ireland. On the other hand, chalcanthite has been reported previously from the copper mines at Avoca, Co. Wicklow (Greg and Lettsom, 1858; Phillips, 1823), and from Ballybunnion, Co. Kerry (Ainsworth, 1834).

BONHIVA LODE, KNOCKMAHON

The Bonhiva lode, grid ref. X 446 986, outcrops in sea cliffs midway between the Old Stage and Tankardstown lodes and almost opposite the Cassaunnagreana Rock, Knockmahon townland. An adit has been driven on this lode into the cliff and is still accessible. At the entrance, powdery (when dry), bright blue coatings occur on the walls of the adit. X-ray diffraction of a sample of this material (BM(NH) ref. no. 6859F) showed it to be composed of a mixture of connellite and langite. Simple wet chemical tests confirmed the presence of chloride and sulfate. The material was also found to effervesce slightly in acid suggesting that carbonate may also be present; carbonatian connellite has recently been reported as a new variety from Britannia Mine, Wales and Botallack Mine, Cornwall (Pollard et al., 1989).

Further inside the mine, large, soft, brown stalactites of iron oxides and brilliant green encrustations of malachite have formed. The presence of the chloride-containing mineral connellite only at the mouth of the mine may be attributable to exposure to salt spray.

Small amounts of langite and connellite have been found in the area previously, having been collected from a small mine dump at Bunmahon, 2.3 km to the west, in 1963 (G. Ryback, *personal communication*).

Specimens of atacamite, chalcanthite and the connellite/langite mixture have been deposited in the National Museum of Ireland (specimen numbers NMING:G1713, NMING:G1714 and NMING: G1712, respectively).
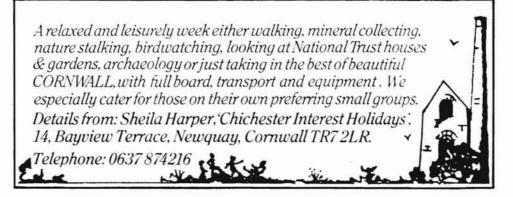
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CONSERVING BRITAIN'S MINERAL HERITAGE

31 MARCH - 2 APRIL 1992

at the University of Manchester

A symposium organised by the Conservation Committee of the Geological Society of London, the Mineralogical Society of Great Britain and Ireland, and the Joint Nature Conservation Committee.

The programme includes 1½ days of discussion papers, a pre-symposium ½ day field excursion to Alderley Edge, and a post-symposium 1 day field excursion to Coniston, in Cumbria.

Further information from: **Dr D. O'Halloran, Joint Committee for Nature Conservation, Monkstone House, City Road, Peterborough PE1 1JY.**

BOOK REVIEWS

Railton, C.T. and Watters, W.A. *Minerals of New Zealand*. Lower Hutt, New Zealand (N.Z. Geological Survey Bulletin 104), 1990, 89 pp., 38 photos., 3 maps. Price $NZ 60.00 ($US 60.00), including overseas airmail postage.

This publication is a welcome supplement to the widely used N.Z. Geological Survey Bulletin 32 (1927) by P.G. Morgan: *Minerals and Mineral Substances of New Zealand*. The main part is an alphabetical listing of minerals recorded in published form up to 1990 from New Zealand and its outlying islands. For each mineral the chemical formula, locality details, geological setting, availability of analytical data (with references), and associated minerals are listed. There is a bibliography of some 500 items, photographs of 38 representative minerals including photomicrographs in colour and SEM photographs. Appendices include an explanation of chemical formulae, a list of chemical elements and symbols, minerals arranged according to metallic elements they contain and Maori names for minerals.

The bulletin is intended for the professional geologist and mineralogist, but will also be of much interest to collectors and lapidarists.

R.A.Howie

Hurlbut, C.S. Jr. and Kammerling, R.C. *Gemology*. 2nd ed., John Wiley and Sons, New York, 1991, xiv + 337 pp. Price £43.70.

Developments in gem treatments and synthetic gems over recent years continue to provide the impetus for producing new books covering the field of gemmology. Although Hurlbut and Kammerling's 'Gemology' is a second edition and is designed to serve as a textbook for students, it contains a wealth of up-to-date information and is effectively a new and different book.

The book commences with origin and occurrences of gems, and this is followed by crystal chemistry, crystallography, physical properties and visual characteristics, the whole compactly and efficiently presented with excellent diagrams in 80 pages. Gem testing is covered in the next 58 pages, and then follow chapters on gem synthesis, imitation stones, gem enhancement and gem fashioning. The characteristics of gem species are clearly described and followed by a useful reference table.

Each chapter finishes with a comprehensive list of relevant references which research students will appreciate, and the book is considerably enhanced by the quality of the diagrams and the amount of information conveyed in the colour plates. The quality of the black and white pictures, however, is not so good and a few pictures are obscure.

The book contains a few errors and although most will not mislead the experienced gemmologist/mineralogist, some could puzzle a student: in the Table of Abundance of crustal elements, oxygen should have a value of 46.60%; in the major Rock-forming Minerals silicon should be included in the list of elements contained in feldspar; somehow a spectrum of zircon was printed in Fig. 9.2 instead of that of yellow diamond, and the garnet formula on p. 228 should contain (SiO_4); collectors will be a bit surprised about the occurrence of bowenite in Cornwall and kunzite was first found in the early 20th century.

Overall the presentation is matter-of-fact and efficient, and the ideas behind gem-testing instruments are clearly expressed. The book has the comprehensive and style of Hurlbut and Klein's 'Manual of Mineralogy' and is a fitting companion to this book.

R.R. Harding

Dunham, K.C. *Geology of the Northern Pennine Orefield. Vol. I. Tyne to Stainmore*. Second Edition, Economic Memoir of the British Geological Survey; Sheets 19 and 25, and parts of 13, 24, 26, 31, 32 (England and Wales). British Geological Survey, London, 1990, x + 299 pp, 18 maps. Price £32.00.

This new edition summarises the economic geology of this area and reports in detail the wealth of new information which had become available during 40 years of mining activity since the publication of the first edition in 1948. During the past four decades lead ore production has continued but only one mine has been worked for this ore alone, the greater part having been a by-product of the working of fluorite and barium minerals. Fluorite production has quadrupled and barite output has doubled during the period; so far, the northern half of the orefield has contributed over 4 million tonnes of lead ore, 1/3 million tonnes of zinc ore, >2 million tonnes of fluorite, 1 million tonnes of witherite and nearly $1\frac{1}{2}$ million tonnes of barite. The deposits occur in fissure veins which form a geometrical pattern cutting rocks from the Asbian through the Brigantian to the Pendleian stage of the Carboniferous in an area of about 1700 km²; the incidence of orebodies is a little less than 1 per km². The intrusive Whin dolerite sills occur throughout the orefield and also act as wallrocks for some of the veins.

The first part of this memoir covers the general description of the mineral deposits and their environment and in this the area is treated as a whole. In the second part, details of the individual deposits are summarised and here for descriptive purposes the field is divided into nine areas. The chapter on mineral deposits includes details and analyses of galena (4–8 oz of Ag per tonne of Pb metal), sphalerite, ankerite, siderite, barite, witherite and barytocalcite; numerous other primary minerals and a suite of secondary carbonates and sulfates are also described. Primary mineralisation contemporaneous with Carboniferous

sedimentation does not occur in this orefield; all the stratified flat deposits in limestones are plainly related to crosscutting veins and feeders. The mineralisation process can not be explained without invoking substantial mixing with saline waters already impregnating the country rocks. The source of the elements introduced is still somewhat problematical. The balance of evidence favours a Hercynian age for the mineralisation, commencing soon after the cooling of the Whin sills, and continuing into Permian time. A later resurgence may have occurred but there is no evidence here of Tertiary mineralisation.

R.A. Howie

Hughes, F.E., Ed., *Geology of the Mineral Deposits of Australia and Papua New Guinea*, 2 volumes, Australasian Institute of Mining and Metallurgy Monograph 14. Australasian Institute of Mining and Metallurgy, Parkville, Victoria, 1990. xxiv + 1828 pp, 2 coloured geological maps.

This is a massive work containing a total of 261 papers of which 238 are concerned with Australian deposits and 23 with those of Papua New Guinea. It aims to reflect the considerable advances made since publication of Monographs in 1975; the latter was mostly concerned with Ni and Fe deposits whereas of the present volumes about half is devoted to Au deposits, mainly those in the Archaean (63 papers), but also the much younger deposits of N Queensland and Papua New Guinea (29 papers). Several new base metal deposits and provinces figure prominently, of which Olympic Dam (Cu-U-Au-Ag) in South Australia is outstanding. Other papers on types of deposits not previously described in these monographs include those on diamondiferous lamproites, carbonatites, Pt in layered ultrabasic complexes and U in Quaternary calcretes. Separately paged author and subject indexes for both volumes are included. The back pocket contains a map of Australian mineral deposits (1:5 million) in Vol. 1 and of those in Papua New Guinea (1:2.5 million) in Vol. 2.

Sir Kingsley Dunham

Van Rose, S. and Mercer, I.F. *Volcanoes*. British Museum (Natural History). 1991, 60pp. Price £5.95.

This second edition of *Volcanoes*, previously published by the Geological Museum, has been re-written totally and in addition contains many new photographs and diagrams. The text provides a basic insight into volcanoes, their various products, and the processes leading to their formation. Technical terms are carefully avoided, yet there can be no doubting the book's authoritative nature, reflected in the list of established volcanologists acknowledged for their assistance during compilation.

The book also touches on other phenomena associated with volcanoes and volcanic activity, such as geothermal energy, metalliferous mineral deposits, the use of volcanic materials for building purposes, and so on. Further sections in the book are devoted to particular topics such as the birth of the Atlantic Ocean, and the 340 million year old 'Edinburgh Volcano'.

As in the first edition, the final section of the book describes specific volcanic eruptions, including Vesuvius AD 79, Krakatau 1883, Mont Peleé 1902, and the Valley of Ten Thousand Smokes 1912; in addition, however, the second edition provides information relating to Taupo (New Zealand) AD 186, Santorini c.1645BC, the Skaftár Fires (Iceland) 1783, and, inevitably, the 1980 eruptions of Mount St. Helens.

Like other books in this series, such as *Gemstones* or *Agates*, this volume is aimed at the interested layperson. The text is very readable indeed, and superbly illustrated. Further, the line drawings are excellent and provide the reader with very evocative reconstructions of volcanic eruptions, cross-sections through volcanoes themselves, and, on an even larger scale, the earth and its constituent plates. At only £5.95 there can be no doubting that this book offers excellent value for money.

R.E. Bevins

Anthony, J.W., Bideaux, R.A. Bladh, K.W. and Nichols, M.C. *Handbook of Mineralogy, volume 1, Elements, Sulfides and Sulfosalts*. Mineral Data Publishing, Tucson. 1990, 588 pp. Price US $82.50 (+ US $5.00 for shipping and handling).

In the introducton to the *Handbook of Mineralogy* the authors state that the current volume in no way is intended to emulate *Dana's System of Mineralogy*, rather it is seen as a 'useful stopgap until a modern work comparable in scope and stature to the *System* becomes available'. To me this seems to be an extremely modest statement, given the fact that critical identification and locality data are presented for 588 minerals belonging not only to the elements, sulfides and sulfosalts, but also to the alloys, antimonides, arsenides, bismuthinides, intermetallics, selenides, sulfhalides, sulfoxides and tellurides. A massive amount of up-to-date information has been amassed, and presented in a uniform manner. It clearly represents an authoritative text, and an invaluable reference source.

Data for each species have been confined to a single text page, and present (usually) the following information: mineral name, idealized chemical formula, crystal data, physical properties, optical properties, cell data, X-ray powder pattern, chemistry, polymorphism and series, occurrence, association, distribution, name (significance and origin), type material (institute holding) and references. Some of these data, of course, are contained in the latest edition of the *Encyclopaedia of Minerals* by W.L. Roberts and others, published by Van Nostrand Reinhold, but other information is missing from the latter. The Handbook includes, for

example, reflectance data for opaque minerals, rather more complete X-ray data, chemical analyses (up to 3 analyses are presented), associated minerals, the origin of the name, and finally the location of type material. In addition references in the *Handbook of Mineralogy* are more extensive than those in the Encyclopaedia, the latter tending to concentrate on references in *American Mineralogist* or in *Dana's System of Mineralogy*. The authors of the Handbook state that major international literature 'through 1988' has been reviewed for this compilation.

Clearly this volume, the first in a series of five, is an extremely valuable contribution to the mineralogical literature. However, I was slightly disappointed to find one or two typographical errors in the locality information. For example, graphite is quoted as coming from 'Barrowdale, near Keswick, Cumbria', while tellurobismuthite is noted as being found in Wales

'from the Clogau-St. David's mine, Magtall Mountains, Dolgelly, and the Vigra mine, Llanaker, Merionshire'! These are only minor errors I admit, but ones which nevertheless leave one just a touch anxious. I don't think this detracts in any way from the overall achievement, and certainly I would see the book being on most professional mineralogists' shelves; at US $82.50, however, it may be just too expensive for most amateurs. Should anyone wish to purchase the Handbook it is available from Mineral Data Publishing, P.O. Box 37072, Tucson, Arizona 85740, USA; cheques to be drawn in US dollars on a US bank.

Incidentally, the following four volumes will cover Silica and Silicates, Halides, Hydroxides and Oxides, Arsenates, Phosphates, Uranates and Vanadates, and finally Borates, Carbonates and Sulfates. I sincerely hope all of these proposed volumes see the light of day.
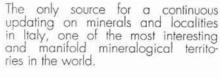
R.E. Bevins

NOTES FOR CONTRIBUTORS

TYPESCRIPTS

Papers should be typed, preferably on A4 paper, on one side only, with double spacing and wide margins (about 2.5cm) on good quality paper and submitted in triplicate to the Editor. Each paper will be read by two designated reviewers. Submission of a paper to the Journal is taken to imply that it has not being considered for publication elsewhere. Material accepted for publication can not be published elsewhere in the same form without the consent of the Editor.

Both full articles, covering all aspects of mineralogy including topographical mineralogy, and notes (up to 1000 words) are accepted for publication. Each full length paper should contain an abstract of up to 250 words summarizing the significant points of the paper. No abstract is required for notes.

The first sheet of the typescript should give, in order, the title of the paper, the names and addresses of the authors, and the name and address of the author for correspondence and to whom proofs are to be sent. Text pages should be numbered serially. Papers should be submitted in the style and format of the Journal.

FORMAT

The manuscript should be presented under various headings such as abstract, introduction, experimental results, discussion, references, etc. Not all sections will be necessary in any given paper and others may be appropriate. In these sections, the headings should be typed in capitals over to the left. Subheadings in the experimental, results and discussion sections should be typed in lower case, beginning with a capital and underlined, also to the left of the page.

PRESENTATION

Authors should present their material with clarity and conciseness. Experimental work should be accurately set out in sufficient detail to allow reproduction of results by other workers. When unusual new minerals are identified, sufficient proof of the nature of the mineral (X-ray diffraction data, analyses, etc.) must be supplied (along with analysis reference numbers), and should be compared with published data. Full lists of such data might not be necessary in the text, but should be supplied to the Editor if required by the referees in the course of their assessment. For mineral occurrences of particular note (eg. new occurrences in the U.K. or from a particular locality) authors are strongly encouraged to provide a note of the specimen number and a record of the institution or collection where the specimen is lodged. Specific localities should be referred to by National Grid references together with the 100 kilometre square letters (*e.g.*, SM 928476). Ordinarily, results and discussion should not be intermingled.

FIGURES

All figures should be numbered wiith consecutive arabic numbers. They should be mentioned in the text and must have a descriptive caption. A list of figure captions should be typed on a separate sheet and included with the manuscript.

All figures should be of a quality suitable for direct reproduction. Original line drawings, crystal diagrams, maps etc., should be prepared with black (india) ink on white art paper or tracing paper.All lettering and symbols should be included on the diagrams. The size of the lettering (not typed) should be appropriate, if the diagrams are to be reduced in size. For example, if a figure is to be reduced by one half, lettering 4mm high should be used. Where relevant, a metric scale should be provided, along with National Grid reference or co-ordinates of latitude or longitude.

Photographs, where necessary, should be submitted as good, glossy original prints of maximum possible contrast.

Each figure should be labelled on the reverse side with the author's name and the figure number. The tops of all figures and photographs should be marked as appropriate. Originals of photographs should be supplied at the time of manuscript submission. Only photocopies of figures, however, should be sent initially with the manuscript; the Editor will request originals once the manuscript has been accepted for publication.

TABLES

Tables should be numbered consecutively with Roman numbers. No vertical lines should be used. A clear title should be provided separated from the bulk of the information by a horizontal line. Another line should mark the end of the tabulated data, and beneath this any footnotes, referred to in the table by superior case letters, should be included. Footnotes, however, should be kept to a minimum. Each table should be typed on a separate page, continuing as necessary to further pages.

MATHEMATICS

Where possible any mathematical equations (or chemical equations) should be typewritten with subscripts and superscripts clearly shown. Equations referred to in the text should be numbered consecutively by arabic numbers in parenthesis at the right hand margin.

MINERALOGY

Nomenclature and terminology of the International Mineralogical Association must be adopted. If the authors are uncertain about any aspect of these rules, the Editor should be consulted. As a guide to correct mineral names, Fleischer's most recent compilation should be used (at present this is M. Fleischer, Glossary of Mineral Species (Fifth Edition), Mineralogical Record Inc.; Tucson, 1987).

If varietal names are employed in the text, these should appear underlined (for italics) after the formal definition and should be referred to in the same way throughout the text. Chemical formulae for minerals, wherever appropriate, should be included.

CHEMISTRY

Nomenclature should be that adopted by the International Union of Pure and Applied Chemistry. If authors are in doubt, they should consult the Editor. Crystal structure studies should be reported in the manner outlined by the International Union of Crystllography (*Acta Crystallographica*,**22**, 45 (1967)). Tables of anisotropic thermal parameters and observed and calculated structure factors should be deposited with the Editor.

REFERENCES

References and notes should be indicated in the text by the author and year of publication, thus: (Brown, 1967) or, 'as stated by Brown (1967)'. If two authors are involved, both should be named: (Green and Brown, 1985), and if more than two authors: (Green *et al.*, 1986). When more than one reference is quoted, each should be separated by a semicolon thus (Brown, 1969; Green *et al.*,1986). A list of references should be provided in alphabetical order. References should be given in full. Some examples are given below.

Manning, D.A.C. and Henderson, P., 1984. The behaviour of tungsten in granitic melt-vapor systems. *Contributions to Mineralogy and Petrology*,**86**, 286–293.

Pankhurst, R.J., Sutherland, D.S., Brown, G.C. and Pitcher, W.S., 1982. Caledonian granites and diorites of Scotland and Ireland. *In*: Sutherland, D.S. (ed.) *Igneous Rocks of the British Isles*. Wiley, London, 149–190.

McGarvie, D.W., 1985. Volcanology and Petrology of mixed-magmas and rhyolites from the Torfajokull Volcano, Iceland. Unpublished Ph.D. thesis, University of Lancaster.

Ramsay, J.G., 1967. *Folding and Fracturing of Rocks*. McGraw-Hill, New York.