

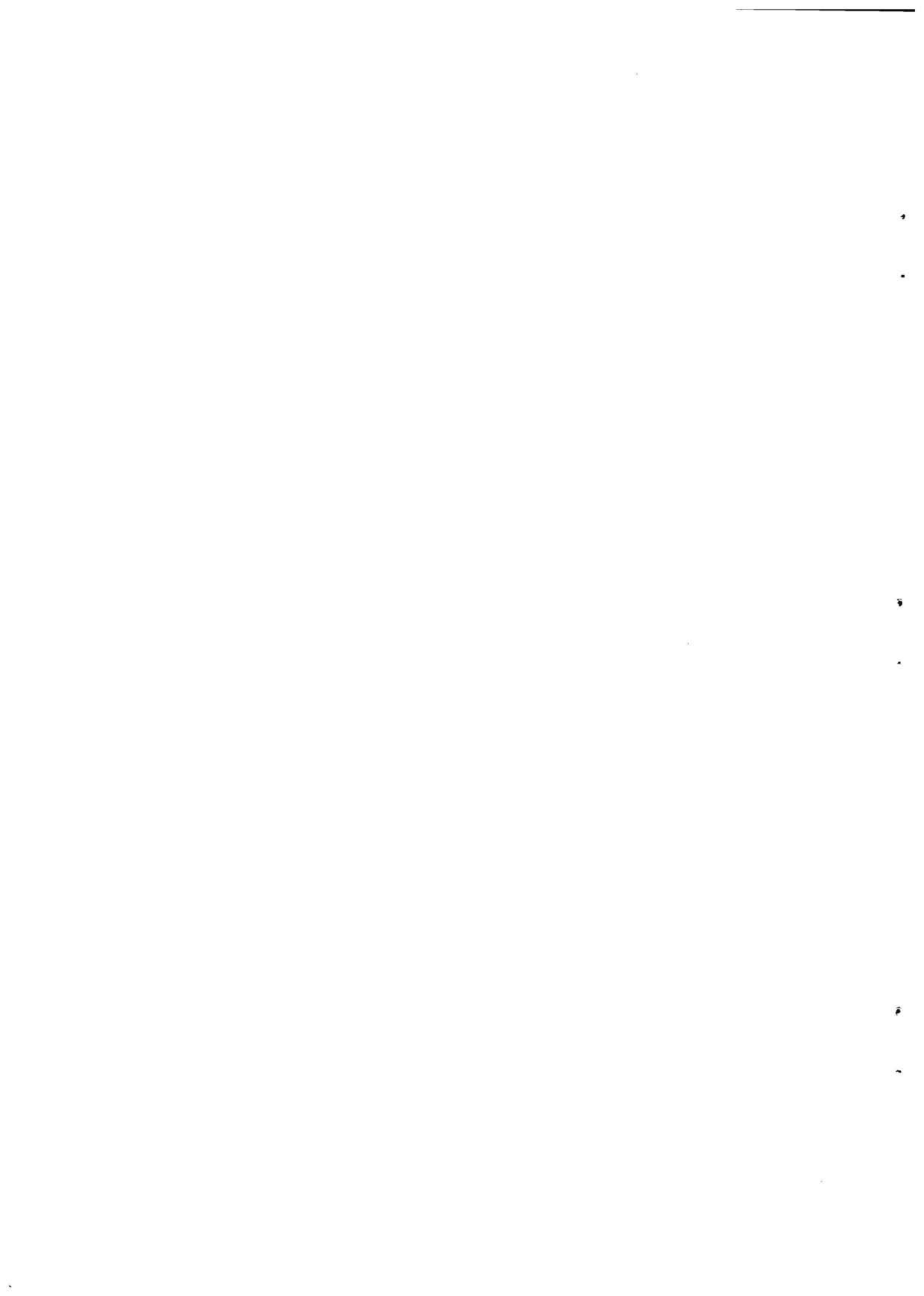


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COVER PHOTO: Liroconite from Wheal Gorland, Cornwall.



EDITORIAL

The editorial of the first number expressed a wish that the Journal of the Russell Society would provide an opportunity for amateur mineralogists to set down their scientifically valuable observations for all to read – observations which professionally oriented scientific journals might find unacceptable.

From an examination of the contents of Number 2 it would seem that the wish has been granted. Of the eleven articles accepted for publication, including a short communication, only one has been written by a practising professional mineralogist. The remainder have been written by people from all walks of life. It is hoped that this represents a tentative beginning, for we wish to see the journal greatly enlarged, not only by the amateur, but also by the professional mineralogist who might find it a useful outlet in which to express topographical or related data not in context with his principal lines of research.

The majority of topographical observations described in this number hint at the growing difficulty mineralogists are experiencing in their field work. Mineral occurrences where macro-minerals are available for collection and study are becoming of increasing rarity year by year. Gone are the halcyon days where the few pioneers in the art and science of mineral collecting for any reason, though thought to be psychologically deprived or financially well endowed, collected from a wealth of high quality material from many working mines and ancient but untouched mine dumps.

The metalliferous mining industry is now working at a small fraction of its former activity, and high quality material formerly enriching more ancient mines has long since been exploited by the dealers. Mineralogists, amateur and professional alike, are being forced increasingly into working quarries where mineral bodies are often incidental to the economic potential of the site, and to the ancient mining sites where the frugal remnants of ore bodies on waste dumps are the only source of material.

In both cases conflict is occurring where the mineralogist is confronted by rival claimants. Conservationists are actively erasing traces of mining activity or insist on measures which drastically curtail the normal activities of mineralogists. New legislation has enabled members of the extractive industry to clamp down on entry agreements. Somehow in this jungle of legislation, systemised or otherwise, the mineralogist has to find his place. He must examine situations hitherto untouched.

He must either seek his material underground in disused mines where the less determined does not dare to go; in working quarries where access is agreeable, but where in both cases he has the enormous advantage seeing the material as *in situ* remnants, or he must look for material in the more conventional places in remnants so small that they escape the eye and he must use a microscope to see them. The disadvantage in both situations, apart from the expense, is personal risk to the individual; the risk of life and limb in the former and myopia in the latter. In both situations, however, the journal could benefit and obviously has done so in numbers 1 and 2. It is hoped that an increasing number of collectors who have braved these physical hazards, will brave the not so painful hazard of editorial comment and put pen to paper to describe their findings.

Though the individual collector's days are unnumbered, it would seem that the **bona fide** society party, backed by massive insurance coverage and goodwill, can do most to cement long term good relationships with land owners, company operators and national bodies. It is the wish of the Russell Society that it belongs to this category and will make its mark on British mineralogy in this way.

No editor wishes to include obituaries in a journal and it is with great sorrow and a sense of personal loss that he has to include three: Mr. R.C. Agabeg, Mr. R.W. Barstow and Dr. R.S. Harker, one a founder member of the society and all good friends to its ideals and promoters of its ambitions. They will be sadly missed.

R. J. K.

OBITUARIES

RICHARD AGABEG

Richard Agabeg's interest in mineralogy was of long standing, but his interests were wide ranging and included bridge, squash, cricket and philately. His professionalism and enthusiasm pervaded all his activities: as a teacher and in his naval duties as a reserve Commander. This patience and generosity helped many students and mineral collectors.

He was never ostentatious; the treasured specimens in his collection were the self-contained ones, obtained from such sites as Wheal Gorland, by carefully planned excavations and dedicated digging and sifting. He became a member and keen supporter of the Russell Society in 1978.

Now his untimely death last August has left a great gap and he will be greatly missed by his wife and three daughters and his many friends.

A.F.

RICHARD WILLIAM BARSTOW

Richard William Barstow, mineralogist and mineral dealer, passed away on the 14th September, 1982, aged 35 years, following a long illness. He leaves his wife Yvonne, and son Jeremy.

The mineral business began in January, 1973, from his home in the small village of Tregeseal, near Botallack in Cornwall. Prior to this he had been employed in the sampling office at South Crofty Mine, and later on, in the same capacity at Geevor Mine.

In 1978, Richard and his family moved to Gunnislake, near the Devon border, and re-established the business at Drakewalls House.

Richard was one of our 'long distance' members, and consequently we rarely saw him at our winter meetings, but he never failed to send a selection of minerals for our annual mineral auction, and he proved to be a very able field leader on a Society meeting in East Cornwall in 1980.

He was highly respected by both professional and amateur mineralogists alike, and many mineral collections have benefitted from his generosity and expertise over the years.

I was privileged to be with Richard shortly before he died. We were far underground in a disused Cornish mine, and although he was very weak due to this illness and the exertion required getting through the mine, followed by two hours hard work with hammer and chisel, it was I who had to insist that it was time to go — Richard would rather have stayed to collect minerals. It was this same enthusiasm and dogged persistence which were only two of the many characteristic qualities that made Richard Barstow a highly successful collector and mineral dealer, and the world of mineralogy will be a very much poorer place without him.

J.A.J.

DR. ROGER STUART HARKER

It with great sadness that we report the death of one of our founder members, Dr. Roger Stuart Harker, who died on the 15th March, 1983, after a short illness at his home in Rothley, Leicestershire.

Roger's untimely death at forty years of age is a great loss to our Society, and his passing leaves a gap within our ranks which can never be filled.

He was a regular lecturer at Society meetings, and always an enthusiastic field leader – often to the Grassington Moor and Greenhow Mining Fields in his native Yorkshire, where his knowledge of local mining history and industrial archaeology were expertly blended with geology and mineralogy to make what could have been an ordinary week-end meeting, into an unforgettable experience.

As a schoolboy in Grassington, Roger was a member of the Wharfedale Fell Rescue Organisation, and was later to become a founder member of the Northern Cavern and Mines Research Group.

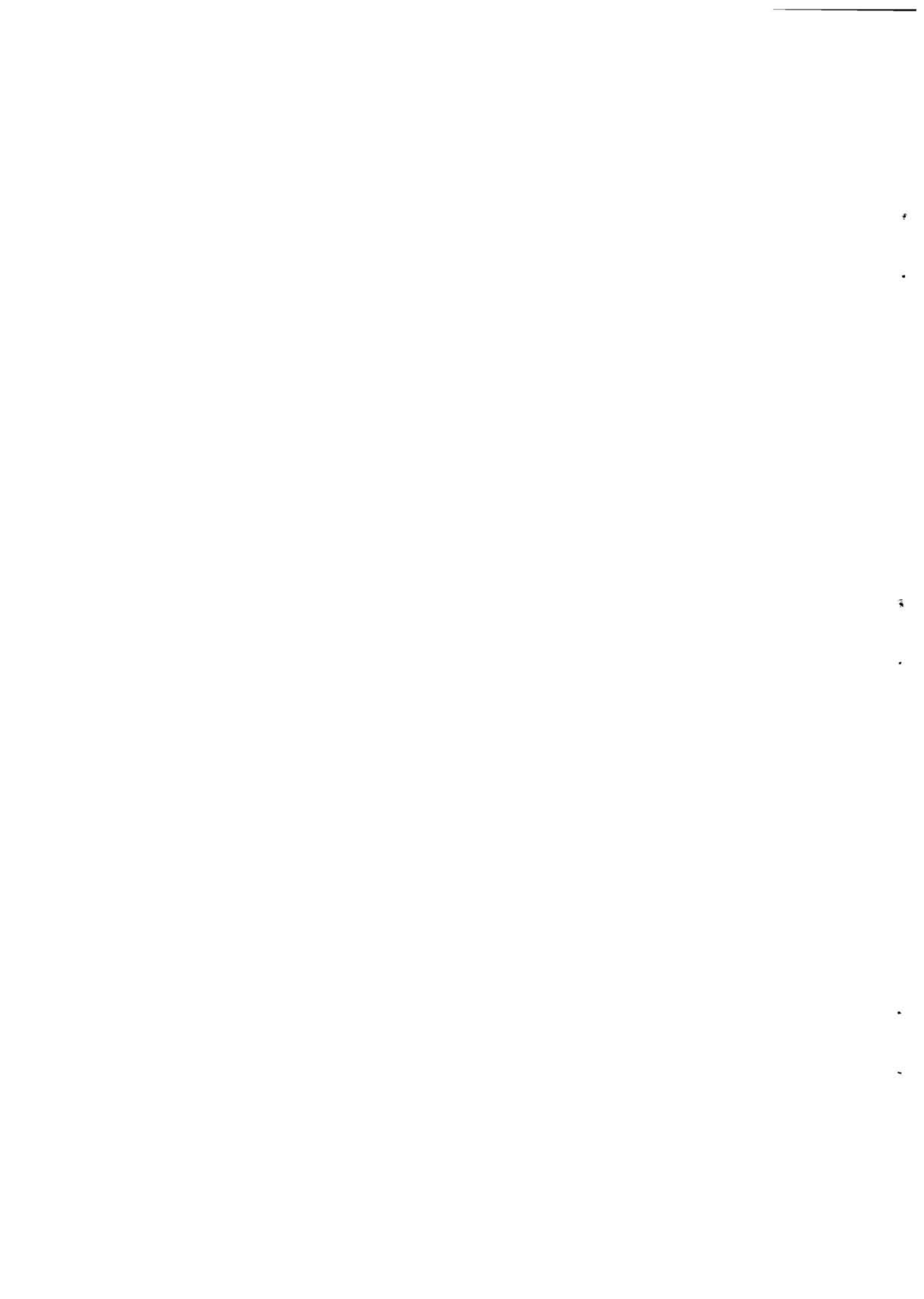
He came to Leicester as a student of geology at the University, in 1961, and he graduated in 1964. This was followed by a position in the Surveyor's Department at the Geevor Tin Mine, at Pendeen, in Cornwall, and later with Consolidated Goldfields, in Scotland.

In 1966, Roger moved back to Leicester and began studying again. He opened his shop 'Lythe Minerals' and in 1970 he married his wife, Susan. He achieved his Ph.D. in 1971, and two years later he and Susan moved to Rothley, a village five miles north of Leicester, where their children Rachel and James were born.

Many within the Society were first introduced to mineralogy either as a casual, inquisitive visitor to 'Lythe Minerals', in Oxford Street, Leicester, or as pupils at Roger's evening classes at Leicester, Derby and Nottingham.

To many of us Roger Harker was a close friend, and to have been privileged to enjoy such a friendship is one of life's great treasures.

J.A.J.



PHOSGENITE AND MATLOCKITE IN DERBYSHIRE

(Part 1)

T. Bridges and M.E. Smith

Abstract

A historical review of available literature concerning the minerals phosgenite and matlockite is presented. This summarises the early mineralogy, mining history and geochemistry of these minerals and lists available specimen material.

In the opinion of the writers, the evidence suggests that the main source of the phosgenite was a specific area of Wallclose Vein worked from Bage Mine. It seems likely that matlockite was found at the same time but remained unidentified for nearly 50 years. However, the main occurrence of matlockite was probably from a different location in Wallclose Vein, resulting from the lowering of water levels by the Meerbrook Sough.

Introduction

The rare minerals phosgenite and matlockite have excited much mineralogical interest for a period of over 150 years. The precise source of the minerals is not known, possibly because early dealers wished to exclude competition. This discussion attempts to set down the data available in chronological order, endeavouring to reconcile the mineralogical and mining histories. Since the early geochemistry is of interest a review of this is also included.

Geographical Setting

The geographical setting is within the parish of Bolehill on the south-west edge of the Peak District of Derbyshire. Bolehill village is north of Derby, midway between Wirksworth and Matlock Bath, just east of the B5023. The geological location is on the crest of the Bolehill anticline under the scarp edge of the Millstone Grit to the east and the limestone to the west.

Nomenclature

The use of the name cromfordite in Derbyshire presents an element of confusion. This name was given to the mineral by Greg and Lettsom in 1858, but the same phosgenite has precedence, being nominated by Breithaupt in 1820 and is used in all scientific literature. It will be used here, except where quotations are made.

The name matlockite (Greg 1851) has no complication of nomenclature.

Mineralogical History

The two minerals have, within the context of the locality, always been referred to as an associated pair and it has been assumed that discovery was simultaneous. However, historical facts suggest that phosgenite was the first to be discovered followed by matlockite at a later date, which was co-incidental to the working, and subsequent drainage of the mines of that area.

The first reference to phosgenite is in Mawe's Mineralogy of Derbyshire (1802), and notes "Muriate of lead in perfect crystals of a beautiful transparent yellow colour". This was closely followed by an analysis and fuller description by M.H. Klaproth in 1803. The third reference is more helpful; it is Sowerby's British Mineralogy (1817). This publication was at that time considered to be the definitive catalogue of British minerals. Phosgenite is referred to as 'Plumbum:— Carbono-muriate of lead', a new variety of lead ore. The specimen described is one which was 'found' by Charles Grenvill in 1785. The term 'found' must not be taken too literally but more probably was collected by a miner and acquired by Grenvill at a later date, since it was not described for another 15 years. This may in fact be the specimen referred to later in this discussion (BM 59-296). Sowerby then goes on to say that it was first discovered to be a new mineral by the Count de Bournon (for whom Bournonite was named). The locality is given as 'Cromford Level'. A very adequate physical description is then given.

There is now a gap in documentation of some 50 years, during which time it would appear that this mineral was forgotten, apart from Phillips (1822) quoting Sowerby (1817).

At this point in time the name Brice Wright appears in print (Greg, 1851). This was the dealer, originally based in Liverpool (1843-1855) who supplied Greg with the material subsequently nominated as matlockite, accompanied by a mineral described as a murio carbonate of lead, which Greg and Lettsom (1858) subsequently incorrectly re-named as cromfordite. As Wright's name is associated with bibliographic data, it may be useful to clarify his personal nomenclature. Styled personally as Brice (M.) Wright before 1858, he re-styled his title to Bryce M. Wright for the period 1858-1879, and finally Bryce-Wright from 1880. (Embrey, 1977).

It is interesting to note that following the brief reference to phosgenite, in Mawe's Mineralogy of Derbyshire (1802), is a mention of a mineral which he refers to as 'glass lead', the description of which vaguely equates to that of matlockite. A few years later in 1858 Greg and Lettsom published their treatise on British Mineralogy, describing in detail both matlockite and a mineral they named cromfordite (phosgenite), in which Greg states that there has been "a specimen unrecognised in the British Museum for some years". The writers have been unable to trace this specimen positively. There are no matlockites in the collection with a known date of acquisition prior to 1851 nor are there any in the collection of the Museum of Geological Science preceeding this date. There is a specimen acquired by the British Museum from the Grenvill collection via the T. Davis Collection (BM 57894) and it is possible that this is the one surviving specimen collected by Grenvill at about the same time as the phosgenite was discovered and overlooked for 50 years. If this is so, then Mawe's vague description (1802), may well be that of matlockite. There is, however, a specimen of phosgenite (BM 59298) labelled "Cromfordite, Wallclose, ex. Grenvill collection" with a note written by a Dr. Cantrill, dated 1870 – "murio-carbonate of lead, sold to Grenvill by Tom Pearson of Matlock and obtained from Wallclose mine on Cromford moor. Pearson told me (Cantrill) that it has been found likewise in Raven Tor mine at Middleton-by-Wirksworth. (I found this label in papers from Mr. König and supposed it may have belonged to one of the two Grenvill specimens of 1862)".

Mining History

At this point some discussion with regard to the location of the matlockite and phosgenite is required.

The locations for matlockite and phosgenite are for the most part vague and at best are confusing. Many of the specimens seen have labels giving the locations as either Cromford, Wirksworth, Matlock or a little more specifically Bolehill. More detailed locations are mentioned in literature: these are:—

1. Level mine
2. Arkwright mine
3. Rutland mine or cavern
4. Wallclose
5. Bage mine, variously spelt as Bag, Baige, Boge or Bage
6. Meerbrook Sough mine – Phosgenite only
7. Raventor mine, variously spelt as Ranter, and Rentor and Rantar
8. Mill Close – Phosgenite only

With regard to the Level and Arkwright mines, there is no reference in the Barmasters' Records to mines of these names but it may be supposed that these refer to Cromford Sough, and indeed Richard Arkwright was involved in disputes with the Cromford Sough Company with regard to water usage at his mill. The Rutland mine locality is unsupported by any evidence other than the reference by Bannister (1974). The name Rutland mine or cavern came into common usage when opened as a show cave in 1810 but would have ceased to be a working mine by 1850 (Flindall, 1976).

Bannister (1934) reported that "Bryce-Wright was successful in collecting good specimens of the new mineral from old heaps of the mine at Cromford" not underground or in an air shaft as has been stated elsewhere (Greg 1851). One suspects that Wright, being a dealer, was not as specific with the precise locality as he might have otherwise been and in fact may have deliberately been vague, or even purposefully misleading. It has been said that Wright employed miners to re-open a shaft at Bolehill and after several days was successful in re-locating the original site of discovery. (Catalogue note Re: BM 915.70)

Meerbrook Sough mine is not specific. Meerbrook Sough did not reach the Bolehill area until about 1850. This is a locality quoted by Stokes (1880) but is unsupported by any existing specimen.

Raventor mine is a sound possibility as it is only about 1 mile away from Bolehill but once again there is no existing specimen so labelled; the only evidence is from the note previously quoted.

The Mill Close locality for phosgenite (Ford and Sarjeant, 1963) is confirmed by existing specimens.

The foregoing lack of evidence effectively leaves the Bage/Wallclose mines as the only positive documented locality for matlockite.

History of Bage Mine

Cromford level was commenced from the mill in Cromford village in 1672 with the purpose of draining mines on Cromford moor as far as Bonsall and reached the principal area of mineralization on Gang vein in 1709. A branch to Wallclose vein was commenced about 1769 and intersected the vein in 1777, between this date and about 1800 the sough was driven in Wallclose vein for 760ft. to its intersection with Butler vein, which was one of the major veins working from Bage mine. A second branch out of Cromford Sough, the Hollyhole and George levels continued from the Wallclose intersection between 1788 and 1807 and the Bage branch out of George level to Bage mine, commenced in 1807 and reached Bage in 1826.

The second drainage scheme to affect the Bage and Wallclose mines was the Meerbrook Sough which was commenced in 1773 with the intention of unwatering both Gang vein at a lower level than the old Cromford Sough, and the mines west of Cromford Hollow. Whilst Meerbrook was progressing in 1790 a serious collapse of Cromford Sough at Rantor mine occurred, where the level was driven in Toadstone and this may have caused water to back up in the Wallclose area. Prior to this occurrence, Bage proprietors were working Wallclose from the Bage mine. By 1845/1846 Meerbrook Sough had reached a series of veins south of Bolehill and indirectly relieved Bage mine of water by a further 20ft. but there was no direct connection at that time. The Bage proprietors had been unable to work Wallclose North End prior to 1846 (Anon., 1846). The Bolehill branch of Meerbrook Sough was not commenced until 1855 and intersected Wallclose vein in October 1856. It is recorded that the water level at Bage was lowered by some 50ft. Bolehill Engine shaft is recorded at this date as being 50 fathoms (300ft.) and is above sough level by 17 fathoms (102ft.). Recent exploration of Bage engine shaft has shown the depth of the shaft to be 306ft.

Greg and Lettsom refer (1858, p. 422) to phosgenite as occurring in an air shaft to a level at Bage mine and also to the fact that its supply was cut off by the flooding of the mine, but that, subsequently, a deeper level having been driven, the air shaft being drained. Greg and Lettsom went on to state: "Hearing of this, Mr. Bryce-Wright, an intelligent and zealous dealer in minerals, now residing in London, determined to take the matter up, and succeeded in making out, in 1851, the precise shaft in which the crystals had been originally met with. His further labours were rewarded by the discovery of a few fine specimens of this very rare species, in cavities of decomposed galena, here and there associated with Anglesite and Matlockite. The exact spot where the crystals were originally met with was then called the Bage mine, and is in the middle of a little village named Bole Hill. In speaking of the crystals of this mineral rediscovered, Mr. Wright says, "they are only found at certain places in the mine where decomposition of the galena has taken place. I have examined every mine in the neighbourhood, and have not met with a single crystal of this mineral, except at the spot referred to; and as the mine is no longer in work, I do not think it likely that this locality will furnish any more specimens." "

It would therefore appear that the shaft in question was flooded possibly by the collapse at Rantor as previously mentioned and that the deeper level referred to must be Meerbrook Sough. The reference to an air shaft is suspect, as an air shaft is usually associated, as the name implies where bad air exists and this would most likely be in an area of shales, not limestone and therefore be associated with drainage work in a level and not mineral workings in a vein. Furthermore Bryce-Wright is referred to as residing in London between 1858 and 1894 (Embrey, 1977), yet in the description of Matlockite (Greg, 1851) reference is also made to the same air shaft and "the zeal

Mr. Wright of Liverpool". Bryce-Wright lived in Liverpool between 1843 and 1855 and indeed qualifies the 'air shaft' as being in an old level. This discrepancy adds further to the confusion and we are left with doubt as to whether the re-discovery was made during the period 1843 to 1855 or during 1858 to 1879.

Specimen Material

The existing specimens of matlockite and phosgenite in the British Museum and those in the Ludlam collection in the Museum of Geological Science have been examined as well as several from other sources. These are listed below:

a) British Museum (Natural History)

The British Museum numbers are not necessarily consecutive and jump from phosgenite to matlockite, nor are they in chronological order. Missing numbers are likely to be specimens from foreign localities, or may even be missing altogether.

<u>British Museum Ref.</u>	<u>Matlockite or Phosgenite</u>	<u>Sources and date of acquisition.</u>
2009	"Cromfordite"	Sir A. Russell specimen. Bage mine, Bryce-Wright, with Anglesite 1851 ex. Williams collection, Gwennap, Cornwall.
1241	"Cromfordite"	Kingsbury specimen 1926 ex. Trenchmann collection (1851-1917) Castle Eden, Co. Durham – Mineralog. mag. 1919, 18, 398 – sold to Kingsbury in 1904 from a Captain Dowler's collection.
2672c	"Cromfordite"	ex. Bryce-Wright, Cromford 1853
32996	"Cromfordite"	ex. Campbell collection 1861
38506/7/8	"Cromfordite"	ex. Bryce-Wright – no location 1863
53836	"Cromfordite"	ex. Henson 1881
53867	"Cromfordite"	ex. Henson 1881
54265	"Cromfordite"	ex. Chadney 1881 – Rutland mine – with comment that Rutland mine is a coal mine at Ilkeston.
54613/4	"Cromfordite"	Purchased from Mr. Howe, Matlock 1882
54601	"Matlockite"	ex. Henson Feb. 11th, 1882 – This is the specimen described by Bannister in 1934.
55806	"Matlockite"	ex. Mr. Damon 1884
55807/8	"Matlockite"	Col. R. Gregory 1884
56330/1/2	"Matlockite"	Col. R. Gregory 1885 Specimen 56331 is the only specimen seen which has both Matlockite and Phosgenite together.
57894	"Matlockite"	ex. Grenvill collection acquired from T. Davis. This is the specimen referred to by Greg and Lettsom (1858).
55855/6/8/9	"Matlockite"	ex. Gregory 1884 - 1885
59294	"Matlockite"	ex. Grenvill collection
59295	"Cromfordite"	ex. Grenvill collection – Wallclose 1883
59296	"Cromfordite"	from Gregory ex. Grenvill collection 1899 referred to in text.

<u>British Museum Ref.</u>	<u>Matlockite or Phosgenite</u>	<u>Sources and date of acquisition.</u>
29634	"Cromfordite"	ex. Kranz 1859
35509	"Matlockite"	ex. Bryce-Wright, 1863
42417	"Matlockite"	ex. Bryce-Wright, 1868
42753/5/6/7	"Matlockite"	ex. Bryce-Wright, 1869
51394	"Matlockite"	ex. Almston, Stockholm 1877
53829	"Matlockite"	ex. Henson 1881
54263/4	"Matlockite"	ex. Chadney, from Arkwright mine 20th October 1881.
54602	"Matlockite"	ex. Chadney, – no location.
89053/4/5	"Matlockite"	Cromford level 89055 is the specimen analysed by R.A. Smith for R.P. Greg in 1851
1958,473	"Matlockite"	Bage mine, Bolehill, ex. Kingsbury 'Presented to the British Museum 30th November 1957 from Gawthorpe collection, (1st Baron Shuttleworth)'.
1968,473	"Matlockite"	2 specimens returned to British Museum by Earth Science Imports, New Jersey, USA 1968.
915,70	"Cromfordite"	"Three crystal forms, each described and found by Bryce-Wright at the old Bage mine, between Matlock and Wirksworth in one of the old shafts after a week's work and excavating".
915,71	"Cromfordite"	Bage mine and Cromford level workings
915,72	"Cromfordite"	Old shaft belonging to Bage mine and Cromford level. No date is given for these three specimens.

b) **Geological Science Museum**

The only available specimens pertaining to this listing are in the Ludlam collection on display in a commemorative case. They are also referred to in Rudler's catalogue of 1905.

The Matlockites are Nos. 995 to 1002 and Phosgenite 1003 to 1006 – no specific localities or details are given except that Rudler's list states that 'Boge' was the accepted locality for Phosgenite.

c) **The Royal Scottish Museum, Edinburgh**

1867-6-2	"Matlockite"	Cromford Mine
1881-41	"Matlockite"	?ex. Bryce-Wright. Bage Mine, Bolehill, Derbyshire. Plate 1.
1890-114-253	"Matlockite"	Matlock
1921-17-23	"Matlockite"	
16-1-7	"Cromfordite"	Purchased from Bryce-Wright for £6.00
1882-55-3	"Cromfordite"	Purchased from S. Henson for £3.10.0
1890-114-1970	"Cromfordite"	ex. Dudgeon Colln. "A crystal in the primitive form. 1890 Matlock".

d) **Other Sources**

The only Matlockite collected at Bolehill, since the supposed re-discovery in 1851, was collected by Dr. R.J. King in 1940 from a tip adjoining a shaft as yet unidentified, but believed to be Bage engine shaft. Most of the specimens examined are on a matrix of earthy baryte which is referred to in old literature as 'cawk'. Other minerals associated are principally fluorite and galena with some cerussite in evidence, and minor anglesite. One specimen of Phosgenite has been recovered from above the 190ft. level close to the engine shaft during recent exploration. This specimen was not found in situ but on galena contained in an old kibble (Jones, 1983).

From the foregoing evidence it seems clear that the Phosgenite was from a specific area in Wallclose vein, worked from Bage mine, and discovered in the period around 1784 by Charles Grenvill when the drainage by Cromford Sough became effective in the de-watering of Wallclose. It would also seem likely that Matlockite was found at about this date but remained unidentified until 1851 and would therefore appear that the second 're-discovery' of Phosgenite and Matlockite were from a different location on Wallclose vein. This would have been brought about by the further lowering of water in Wallclose North End, by Meerbrook Sough when it reached veins adjacent to Bage mine in 1846, only a short time before the first description of Matlockite by Greg in 1851. It is possible that several other specimens may have been acquired by, but not collected by, Bryce-Wright, subsequent to this date.

Historical Geochemistry

No historical review of these two minerals would be complete without some mention of their early geochemistry, particularly that of Matlockite.

The earliest reference to the analysis of Phosgenite, found by the writers, is that by Sowerby (1817). It is headed "Plumbum carbono-muriatum (Carbono-muriate of Lead)". Muriate is the original name for chloride and is derived from muriatic acid now known as hydrochloric acid.

Two sets of analyses (by Chenevix and Klaproth) are quoted and used to justify the accepted composition $Pb_2CO_3Cl_2$. The analyses compared with theoretical are:

	Chevenix (1801)	Klaproth (1804)	Theoretical
Muriatic acid	8%	8.5%	13%
Carbonic acid	6%	6%	8%
Oxide of lead	85%	85.5%	79%

Considering this work was carried out by wet chemical means prior to 1804 (the date of the Sowerby summary) the results are quite good. However, by the time of Greg and Lettsom (1858) the analyses had improved considerably viz: and there could be no doubt about the chemical composition.

	Dr. R.A. Smith	Rammelsberg	Theoretical
Chloride of lead	51.78%	50.93%	51%
Carbonate of oxide of lead	48.22%	48.45%	49%

Before considering the early work on Matlockite it is worth setting the analytical scene. Firstly, to this day it is very difficult to detect and analyse for fluorine by conventional (wet chemical etc.) means. The element is easily overlooked, particularly if present in small amounts. Secondly, traditionally, oxide and hydroxide, which again are very difficult to confirm by conventional means, are determined by difference, i.e. that part left unaccounted when all other elements have been determined.

The earliest reference found for Matlockite is by R.P. Greg who reported work by R.A. Smith (1851) as follows:

Chloride of lead	55.177%
Oxide of lead	44.300%
Moisture	0.072%

From this it was deduced the mineral was PbO.PbCl_2 which has a theoretical composition of

Chloride of lead	55.46%
Oxide of lead	44.53%

The match is remarkably good and Matlockite remained a lead oxychloride for a period of over 80 years. Nieuwenkamp (1933) discovered that Matlockite had the same x-ray diffraction pattern as synthetic lead chloro-fluoride and did some confirmatory analysis. This work was expanded by Bannister (1934) into a proper study of the composition and structure of the mineral. For interest's sake the true composition of Matlockite in similar terms to the above is:

Chloride of lead	53.2%
Fluoride of lead	46.8%

Hey's analysis in Bannister (1934) gave results very close to these figures.

A theoretical study of the conditions of formation of phosgenite and matlockite has been completed and will be published in No. 3 of volume 1 of the Journal of the Russell Society as Part 2 of this paper.

Acknowledgements

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The authors also thank Mr. B. Jackson of the Department of Geology in the Royal Scottish Museum for his kindness shown to them during a recent visit to the Royal Scottish Museum, and for the production for Plate 1.

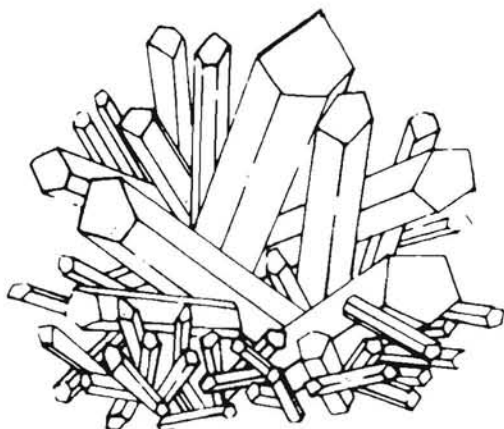
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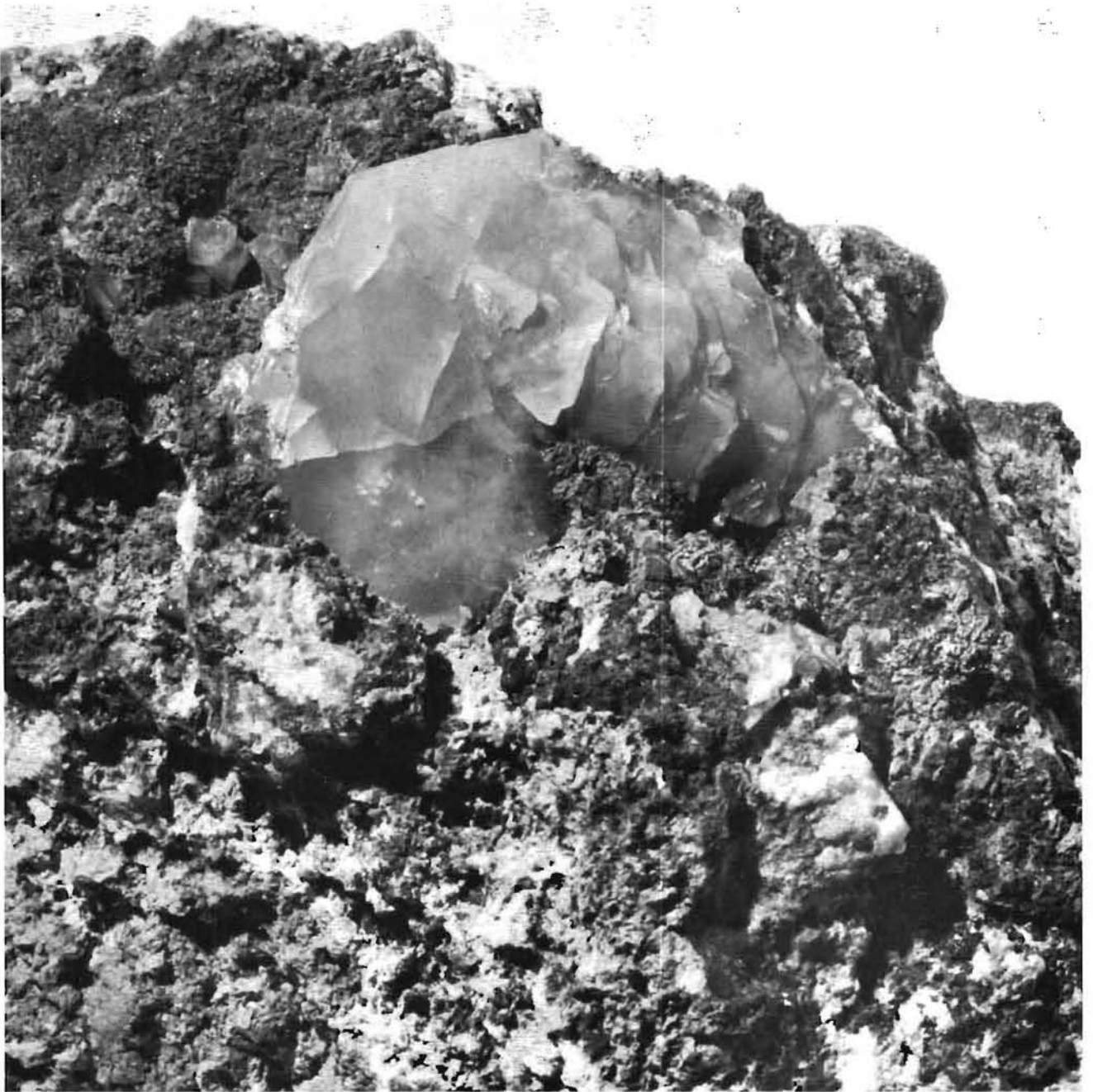


Plate 1. Matlockite — Bage Mine, Bolehill, Derbyshire. Large aggregate of small lemon — yellow plates, measuring 50mm x 38mm. Royal Scottish Museum Spec. No. 1881-41.



Plate 1 Pale blue Celestine and white Calcite with a single golden needle of Millerite (centre). Field size 51mm x 66mm.



Plate 2 Coarse white crystals of Calcite with golden Millerite and brassy yellow Pyrite scattered over the Calcite. Field size 51mm x 66mm.

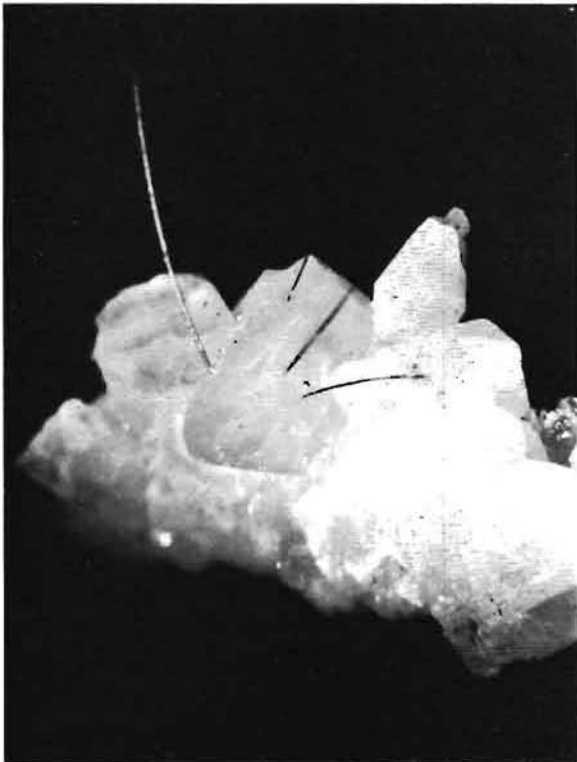


Plate 3 Curved golden needles of Millerite growing from Calcite scalenohedron, with encrustation of bright green Morenosite. Field size 15.5mm x 20.4mm.



Plate 4 Gold needles of Millerite extensively altered to bright green Morenosite, on Calcite matrix. Field size 28mm x 37mm.

ON THE OCCURRENCE OF MILLERITE AT ECTON HILL STAFFORDSHIRE

R. E. Starkey

Abstract

On a recent visit to the Ecton Hill mines, a pocket of crystallized celestine was noted. Closer inspection revealed small golden acicular crystals of millerite showing alteration to bright green morenosite. Neither mineral has previously been recorded from Ecton.

Descriptions of the occurrence are presented, together with photographs and a discussion of the deposit.

Introduction

The Ecton Hill copper mines, located in the northeastern corner of Staffordshire, near Wetton, have been worked more or less continuously between the 17th and 19th centuries. There are many shafts and workings scattered over the hill, which attains a height of some 367m above OD, and is bounded to the west by the River Manifold. The chief workings were Chadwick, Waterbank, Ecton, Clayton and Dutchman mines, and there is still considerable evidence of the past activity today, both at surface and underground.

Geology

Ecton Hill is a complex anticline formed of thick beds of Carboniferous limestone, with intercalated shale horizons. The fold axes trend roughly north-south, and the form of the folds is well exposed in the underground levels of Clayton Mine, and at Ape's Tor at the northern end of the hill.

The deformation is post-Carboniferous, and has been dated at around 285my ago. (Robey and Porter 1972). Associated with the fold movements were fault fractures showing slip along lithological boundaries, and also lesser tension fractures. The principal ore-bearing veins follow WSW-ENE or N-S to NNW-SSE trending fractures. The major ore bodies form vertical pipe-like deposits, with their vertical extent far exceeding the lateral dimensions, and were worked down to 400m below surface.

Minerals

At the Waterbank end of Clayton Adit, a small pocket of pale blue, transparent celestine crystals was observed, amongst a series of minor calcite veins criss-crossing the host rock - a dark limestone and shale sequence. Removal of one side of the cavity yielded a large specimen 210mm x 160mm, showing a rich area of pale blue celestine. The celestine is largely crystallized although massive cleavages are also present, and the largest crystal is 11mm x 4mm. The celestine is extremely lustrous and free from damage. Simple chisel - terminated orthorhombic crystals form the greater part of the specimen, but more complex crystals of an equant habit also occur.

The celestine occurs in a matrix of coarsely crystallized calcite of scalenohedral habit, which ranges in colour from white to pale pink (plate 1).

Millerite occurs as golden acicular crystals, both free-standing, and as inclusions in the celestine and calcite. The largest millerite crystal attains a length of 7.5mm, with a diameter of 0.1 - 0.4mm. Many of the millerite needles show pronounced curvature (plate 3) along their length, and some exhibit alteration to bright green nickel secondary minerals.

On the free standing millerite the green encrustation is thought to be morenosite - $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$, and this also sheathes the included needles inside celestine crystals (plate 4). Where the millerite is included in calcite crystals the emerald green alteration product is more likely to be zaratite - $\text{NiCO}_3(\text{OH})_4\text{H}_2\text{O}$.

Associated with the millerite, micro-crystallized pyrite cubes up to 0.2mm across, encrust the faces of the calcite crystals. This pyrite also encrusts a small number of the celestine crystals. It is possible that these sulphide grains are nickelferous pyrite, or bravoite, but this has not been determined. Ixer (1978) reported the occurrence of bravoite and nickelferous pyrite at Ecton, associated with pyrite, marcasite, chalcopyrite, sphalerite and galena, but did not record millerite.

Discussion

The occurrence is of interest because nickel minerals are not commonly found in the British Isles. Millerite has been recorded from the South Wales coalfield: from Drws-y-coed Mine, Gwynedd; from several localities in mid-wales; from Redburn Mine, Co. Durham and Hilton Mine, Cumbria. In the Peak District millerite has been recorded from Fall Hill Quarry, Ashover (Ixer 1978 and Smith 1982).

At Ashover, the millerite occurs in calcite veins in the toadstone and one may speculate that the host rock may have been the source of the nickel – nickel minerals often being associated with basic rocks. In Clayton Adit however, the host rock is limestone/shale, there are no adjacent basic igneous rocks, and the source of the nickel is open to conjecture.

With regard to the celestine, which is recorded from no other locality in the Peak District, the Keuper marls which outcrop to the south and southwest of the area are a possibility, and these horizons do contain workable celestine deposits in the Bristol/Yate area.

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Short Communication

An Occurrence of Annabergite in Smallcleugh Mine, Nenthead, Cumbria.

During the course of a visit to Smallcleugh Mine in 1979 Mrs. S. Bridges found in the Wheel Flats a block of wall rock coated on one side with a green mineral partially encrusting a white flaky crust of calcite.

Wet chemical analysis showed the mineral to be annabergite and this has been further confirmed by SEM X-ray analysis. Minor amounts of cobalt and manganese are also present.

The mineral takes the form of small pale green spheres and botryoidal crusts on the calcite. There is no sign of individual monoclinic crystal development.

Subsequent visits to the mine failed to produce more of the mineral and there is no indication as to the precise location in the Wheel Flats of the occurrence.

Specimens have been lodged in the British Museum (Natural History), South Kensington and the Museum of the Institute of Geological Sciences, Exhibition Road, London.

T.F. Bridges

A NEW LOCALITY FOR PHOSGENITE

Allan C. Dean

Abstract

Phosgenite, has been found in Cornwall, associated with cumengéite and other secondary lead and copper minerals, within a hypogene lead copper antimony sulphide vein. The chemical conditions conducive to the formation of phosgenite are analogous to those permitting the formation of cumengéite (Dean, 1982). The oxidation of lead sulphides and their combination with aqueous chloride ions from sea water can produce the two minerals under restricted physio-chemical conditions.

Introduction

Though not uncommon in other countries, phosgenite is rare in Britain. Perhaps the most striking occurrence is that described by Greg and Lettsom (1858, p. 421) where the mineral was found in crystals up to 60mm in length in an air shaft to a level at the Bage Mine near Cromford in Derbyshire. Greg and Lettsom also referred (1858, p. 421) to its discovery as micro-crystals at the Lossiemouth Mine at Elgin in Scotland, and at Wheal Confidence near Newquay, St. Columb Minor in Cornwall, which occurrence apparently occurred in a submarine section of the mine.

Phosgenite has now been recognised from the same mineralized body as that in which cumengéite was discovered (Dean, 1982). The site is on Newport beach, approximately 2 km southwest of Falmouth in Cornwall. (G.R. SW 799303).

Geology

The rock forming the cliffline at Newport beach consists of Middle Devonian shales, siltstones and minor sandstones, comprising part of the 'Mylor Beds' (Edmonds et al., 1975). They underwent low temperature regional metamorphism, to form phyllites, during the latter part of the Middle Devonian period. The phyllites show extensive small scale folding, with well developed false cleavage oblique to the bedding, the cleavage dipping about 60° to the south east and the beds about 50° to the south east (Hill et al., 1906). Minor faulting is in evidence.

Into this strata was intruded a late stage siliceous hydrothermal phase of mineralization, bearing metallic elements; probably during the Upper Carboniferous period when the Carnmenellis Granite was intruded (Edmonds et al., 1975). This hydrothermal phase indurated the phyllites, forming veins, made prominent by quartz lenses.

Careful search along the coastline between Swanpool and Maenporth beaches has revealed no further evidence of similar mineralization as that described by Dean (1982), but a further examination of the latter site (G.R. SW 799303) was rewarded by the discovery of a small block of similar vein material which, upon breaking open, was found to be full of many small glassy crystals up to 5mm in length. Four small hand specimens yielded a total of 80 crystals. Subsequently the re-examination of previously collected material yielded additional small crystals not exceeding 2mm in length, and more sparsely distributed on the quartz matrix. Upon examination these crystals were found to be phosgenite. They were found associated with cumengéite, the latter frequently coating cerussite, cerussite and bindheimite, and were usually emplaced on quartz crystals. One specimen exhibited the hypogene minerals bournonite and tetrahedrite.

Mineralogy

Phosgenite ($Pb_2CO_3Cl_2$) (Dana, 6th Edn., p. 292) obeys tetragonal symmetry and it is perhaps in the great variety of habit that the Falmouth material is most remarkable.

The most common habit is short prismatic [001] with an almost equant cross section, but there are other crystals where the prism is dominant, with strong development of [011]. The termination [001] is usually dominant.

Cleavage is distinct and parallel to the prism faces, forming angles of 90° and 135°.

There is a wide range of colour variation and its relationship with transparency is striking. Colourless crystals are usually transparent. Others which range in colour from pale honey-brown to pink are either translucent or opaque. The rarer orange-pink or white crystals are always opaque. All are characteristically adamantine in lustre.

Chemical Environment

The chemical conditions which allowed for the formation of cumengéite (Dean, 1982), would also appear to be conducive to the crystallization of phosgenite; a product of the oxidation of the lead sulphides and their combination with aqueous chloride ions from sea water; as must have been the case at the Wheal Confidence site, where sea water had invaded the lode system.

Acknowledgements

The author wishes to thank Mr. J.A. Jones and Dr. P.A. Williams for their identification of the phosgenite.

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SECONDARY SILICA IN FLINT

P.K. Monk

Abstract

Secondary deposition of silica, represented by quartz crystals and chalcedony, is a widespread phenomena in flint. Some observations about secondary silica deposition are presented here.

Introduction

Flint is a compact cryptocrystalline silica which is found as layers, nodules and pipe like bodies in the Cretaceous Upper Chalk. In its unweathered state it is commonly grey or black, with a white cortex. It is translucent on thin edges. Flint has a well developed conchoidal fracture and a hard cutting edge. It is these features that led to its widespread use by ancient man for making tools.

This origin of flint has been debated, without agreement, many times and it is not the purpose of this paper to enter into this argument. However, a large proportion of flint appears to be composed of the skeletons of silica bearing animals, mainly radiolaria and sponges.

The distribution of flint

Flint is very common and widely spread in Southern and Eastern England. Besides being found *in situ* in the Chalk, due to its general resistance to weathering, it is incorporated in many other younger deposits. These include the Eocene and Oligocene deposits of the London and Hampshire Basins, the Pliocene and Pleistocene deposits of East Anglia, as well as the widespread plateau gravels, terrace gravels, clay-with-flints and Boulder Clays.

The solubility of flint in water

This matter will not be discussed in depth. Various investigations have been made into the solubility of silica and although the results appear to be at variance with each other, mainly about mechanisms, there is agreement that silica does have a measurable solubility in water. The effects of organic acids (i.e. derived from humus etc.) are also open to dispute. In simple terms, flint is also porous, though most of the pores are so small that normal capillary action cannot be assumed. It seems probable that most secondary silica phenomena are associated with cracks in the flint.

Secondary silica phenomena

Secondary silica phenomena fall into two main groups: quartz crystals and botryoidal chalcedony. Both crystals and chalcedony are commonly found lining cavities within the flint. It would seem that most of these cavities represent fossil sponges that have become engulfed in the flint. It is to be noted that not all such cavities show the development of secondary silica. Neither is it entirely restricted to an association with fossil sponges. Fossil sea urchins (*Conulus* sp. etc.) have been found with quartz crystals attached.

Where quartz lines a druse, the crystals are usually prismatic and seldom exceed 2mm in prismatic length. They occur in all types and colours of flint. It has been noticed that crystals in red, iron stained (possibly jasperised) flint remain colourless.

Chalcedony also forms linings to cavities, taking the form of white or cream coloured botryoidal crusts with a waxy lustre. It is not as common as quartz in the cavities of flint.

Some Occurrences

These observations are based on the author's own experience and are not complete in any sense.

a) Primary flint in the Upper Chalk

Quartz crystals have been found in flints from the Upper Chalk of Salisbury Plain, Wiltshire and St. Margaret's Bay, Kent. The flint in both localities shows no sign of alteration.

b) **Lower Eocene of the London Basin**

Flint pebbles are widespread in the Lower Eocene deposits of the London area. Thin bands of pebbles occur in the Thanet Sands, Woolwich Beds and the London Clay Basement Bed. However, the Blackheath Pebble Beds show up to 15 metres of highly rounded flint pebbles in a sparse sandy matrix. Many of the pebbles show alteration by colour staining, commonly red and yellow, some banded and some showing a bluish tinge. A few pebbles have become devitrified. Quartz crystals are relatively common in these pebbles. It is possible that they were formed before the high energy erosion that the pebbles have undergone. However, two recently collected specimens have shown quartz crystals on the devitrified cortex of the pebbles, suggesting a mechanism for growth occurring within the Pebble Beds. Examples of chalcedony have not yet been found. Specific localities where crystals have been found include: Bostall Woods, Abbey Wood, London; Blackheath, London; and Oldhaven Gap, Herne Bay, Kent.

c) **Clay-with-flints**

Clay-with-flints is a widespread residual deposit found overlying much of the Chalk. Most of the flints in it retain their nodular or lamellar form. Quartz and chalcedony are both common. Whether formed in the chalk or the clay has not been ascertained. The clay-with-flints of the North Downs of Kent especially at Longfield, Meopham and Hempstead, near Gillingham, has yielded numerous specimens.

Conclusion

Secondary silica phenomena are relatively widespread in flint. Their origin may be in doubt, but they make interesting and attractive specimens, especially since they are from deposits that are not usually thought of as "mineral producing".

Further Reading

Shepherd, W., 1972. Flint. London. 255 pp. This book covers the chemistry, geology and the social history of flint.

JOURNAL

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A NEW OCCURRENCE OF AURICHALCITE AND HEMIMORPHITE FROM CORNWALL

D. Lloyd
and
R.W. Barstow

Abstract

Blue aurichalcite associated with colourless microcrystals and botryoidal masses of hemimorphite has been found in Greystone Quarry, near Launceston, Cornwall. It is thought that the occurrence may constitute the best examples of both species so far recorded from Cornwall.

Introduction

A visit was made to the English China Clay Company's Greystone Quarry, 3½ miles southeast of Launceston off the A384 road to Tavistock (Grid. Ref. SX 365806) in 1981. Following the examination of loose masses of quartz vein matter, patches of a blue mineral which has been identified as aurichalcite, associated with colourless hemimorphite were found. The quartz vein matter was found to occur in a vertical vein striking east north-easterly direction cutting the quarried late Viséan dolerite, in the southeastern corner of the quarry.

Geology

Recent research (Isaac, Turner and Stewart, 1982, and Turner, 1982) has shown the geology of Greystone Quarry to be extremely complex and the original survey (Reid, et al., 1911) inaccurate. Within the quarry area, five principal thrust planes have been recognised. The highest (T_1), the Greystone Thrust, marks the base of the Petherwin Nappe (Isaac, et al., 1982). This thrust has transported green Upper Devonian slates over a sequence of Lower Carboniferous black siltstones and slates, interbedded with thin layers of mudstone locally altered to chert and intruded by dolerite sills of late Viséan age, up to 40m in thickness. The latter are worked principally for road metal. Most surfaces are slickensided and covered by associations of dolomite, quartz and amphiboles.

A nearly vertical quartz vein, 50mm to 150mm wide was found cutting the dolerite in an east northeast – west southwesterly direction on a 6m high bench in the southeastern corner of the quarry. Other hypogene minerals present associated with the quartz included minor chalcopyrite, galena and sphalerite and there was much limonite. Upwards the vein pinched out as it approached the overlying sediments. The dip became shallower (75°) and underlay to the south. Below the sediments the vein also became weathered and gossan-like in appearance with much friable limonite and manganese dioxide. Along the strike of the vein the vein walls were also coated by iron and manganese oxide.

Although much of the vein on the opposite face of the quarry (NW) had been quarried away, at a distance of 20m along strike a vertical quartz vein 70mm to 150mm wide, with limonite and iridescent chalcopyrite could be seen.

It seems likely that the mineralization seen in Greystone Quarry may be related to the hypogene mineralization seen in an adjoining property the Greystone Mine, though supergene material of a similar nature has not been seen to date. The mine, known locally as Greeson or North Tamar mine is situated three miles west by north of Milton Abbot. It was first worked in 1831 when at 11 fathom from surface a lead lode was encountered and a copper-bearing lode at 20 fathoms. (Hamilton Jenkins, 1969, p. 52). De la Beche stated (1839, p. 616) that the mine raising "some of the purest sulphuret of zinc (sphalerite) which we have seen The ore which is found mixed with galena and bisulphuret of copper (chalcopyrite) is yellowish and abundant, though entirely cast aside and neglected at present". The small dumps show black and dark grey shales and grits with spots of pyrite and a little pyrolusite (Dines, 1956, p.715). Quartz vein matter with minor galena and sphalerite has also been found. These two occurrences constitute almost the entire lead-zinc-copper mineralization in an area which is dominated by manganese mineralization.

Description of the Minerals

Aurichalcite $(\text{Zn,Cu})_5 (\text{CO}_3)_2 (\text{OH})_6$

Occurred richly lining vughs in the limonite and more rarely as coatings on black manganese oxide films. The most common habit was spheres or flattened spheres of radiating acicular crystals up to 3mm in diameter of a rich blue colour. Other specimens were found loose in a vugh in the centre of the vein associated with a more powdery form overlying quartz crystals. It was also found in cavities in quartz veinstone with minor chalcopyrite. The most striking specimens were of aurichalcite overlying hemimorphite crystals.

Hemimorphite $\text{Zn}_4 \text{Si}_2 \text{O}_7 (\text{OH}) \cdot 2\text{H}_2\text{O}$

Hemimorphite also occurred lining vughs in limonite and on joints in the altered rock adjacent to the vein. In one place very rich specimens of hemimorphite encrusting quartz crystals were collected. Individual crystal size was c. 1mm on average. It also took the form of milky white botryoidal masses on brown limonite coated joints.

Malachite $\text{Cu}_2 \text{CO}_3 (\text{OH})_2$

Malachite occurred as small botryoidal masses covering joints on limonite associated with minor aurichalcite and hemimorphite. Several specimens collected subsequently showed crystal sprays in cavities in quartz associated with chalcopyrite.

Other minerals recorded include: anglesite; cerussite; chalcopyrite; dundasite; galena; pyrite; pyromorphite and sphalerite.

Acknowledgements

The authors acknowledge the help they have received from Peter Golley. They are grateful to Messrs. M.J. Ainsworth and W.G. Williams (Manager) of Messrs. English China Clays Quarries Ltd., for permission to enter Greystone Quarry, and for their help, and to Mrs. Y. Barstow for access to her late husbands notes.

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A NEW LOCALITY FOR WULFENITE ON THE MENDIPS

N.J. Eastwood

Abstract

Wulfenite has been discovered at Batts Combe Quarry, near Cheddar in the Mendip Hills of Somerset. The mineral was found, associated with cerussite and hydrocerussite in pockets of wad in a calcite vein cutting Dinantian limestones. The mineralization is analogous to that described at Higher Pitts mine, near Priddy and Merehead Quarry near Frome.

Introduction

The Mendip Hills have long been known as an area that has produced wulfenite from a few localities, notably Merehead Quarry, near Frome and Higher Pitts Farm, near Priddy. These have been described previously (Spencer, 1923 and Kingsbury, 1941). During quarrying operations in 1982 at Batts Combe Quarry, situated on the hillside immediately above and north of the village of Cheddar in Somerset, an iron manganese vein was exposed in one of the north faces. Within areas of this vein crystals of wulfenite were found up to 1.5mm across. As far as can be ascertained this mineral, along with some others such as cerussite, has not been recorded from this quarry before. This quarry, owned by Amey Roadstone Corporation, is currently working and access is restricted.

Geology

Batts Combe quarry is working facies of the Burrington Oolite of Dinantian age. The beds dip to the south at a uniform angle of 15° and are occasionally bisected by calcite veins. Most of the veins are nearly vertical though some follow bedding planes. On one of the production benches a nearly vertical vein, of ferruginous material appeared, striking north west. It was approximately 0.5m wide and on examination was found to contain sporadic pods of manganese-rich wad. Other veins in the quarry contained small amounts of iron-rich material but to date have shown no obvious manganese mineralization. A few veins contain very small quartz crystals but the majority are just pure calcite occasionally crystal forming, and may be up to one metre in width.

Mineralogy

Within the manganese-rich portions of the vein the following minerals were collected by the author and are now discussed:—

a) Wulfenite

This occurred as crystals almost invariably associated with cerussite and was occasionally enclosed within massive cerussite, which itself was surrounded by manganese-wad. The crystals varied in size from 1.5mm down to 0.5mm and ranged in colour from deep red to bright orange. Single crystals tended to grow on the exterior of the cerussite but a few were contained within the massive cerussite. One group of orange crystals (5.0mm x 2.5mm) were grouped together on a small piece of cerussite set in wad and exhibited a definite platy structure. A total of 20 specimens of wulfenite were recovered from the vein.

b) Cerussite

Cerussite was plentiful wherever the manganese wad occurred and masses up to 30mm x 15mm x 5mm in size were observed. Occasionally the cerussite exhibited a prismatic habit but mostly formed massive growths within the wad. The cerussite ranged in colour from greyish-white to almost colourless.

c) Hydrocerussite

This formed thin coatings on the cerussite and as yet has not been found crystallized. The majority was white in colour but pale green has been observed.

d) Rhodochrosite/Manganocalcite

In certain pods thin veins (50mm thick) of these minerals were found but they were often not fully formed and crumbled when handled. Some pieces exhibited a crystalline structure and were pink in colour.

e) **Malachite**

At the interface between the iron-rich outer skin and the inner manganese core small botryoidal masses of malachite could be found but were comparatively rare. Individual sphaeroidal masses were usually less than 1mm in diameter.

f) **Other Minerals**

There were other lead minerals found but as yet they have not been identified. One of these associated with cerussite is of a bright blue colour and resembles Diaboléite but this awaits confirmation.

Discussion

The origin of the iron and manganese mineralization of the Mendips has been discussed at length by Alabaster (1982) and is still speculative. It is thought that the veins at Batts Combe quarry comply generally with this theory with one or two differences. Certainly on examination the vein does not appear to be silicious but does show the differentiation inwards from the iron-rich outer skin to the manganese-rich core.

The mineralization contained within these veins appears to be concentrated in the centre but occurs sporadically throughout their length. The suite of minerals found is notable but the absence of minerals such as mendipite and chloroxiphite is possibly more of a mystery considering the presence of both lead and copper and the similarity between Merehead and High Pitts deposits.

However, as this vein has now disappeared and the quarry is working deeper, it is unlikely that we will ever be able to determine the true origin of the mineralization or complete the suite of minerals.

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THE OCCURRENCE OF GALENA IN LEICESTERSHIRE

Robert J. King

Abstract

The occurrence of galena in Leicestershire is examined historically from the earliest known record in the late 18th century up to the present. Many occurrences cited are from sites long since lost, but provide scientific continuity to those sites still available and under some form of research. The latter are examined below in stratigraphical order of the host rocks in which they occur. Galena has been found in rocks of Precambrian age in veins cutting the younger Charnian diorites; rarely in granitic hydrothermal veins in the Caledonian Mountsorrel Granodiorite; as veins in Lower Carboniferous limestones and grits which form diapiric inliners in the northern part of the county; in Upper Carboniferous Coal Measures facies as nodular masses, in cleats of many coal seams and in septarian nodules, especially in the Pottery Clays Series of the Middle Coal Measures; in arenaceous Triassic sediments as the cementation of sandstones and conglomerates of the Sherwood Forest Group; strata bound flat-lying sheets in the Bromsgrove Sandstone and finally and stratigraphically highest in the skerries (sandy limestone bands) of the Blue Anchor Formation.

Introduction

In Leicestershire galena (PbS) has been known and exploited as an ore of lead for nearly 200 years, but its widespread occurrence in the county has not been appreciated. In the majority of the records in the literature it is restricted to one locality, namely Staunton Harold, and these follow each other in monotonous, almost annual, repetition usually with little added factual data. Seventeen different localities are known to the writer. Many of these are of particular interest, two verging on the unique, and their value to the student of ore genesis is great. Detailed work on two occurrences is in progress.

History

The earliest published record is that of Prior (1779). His map of Leicestershire shows a lead mine situated on the Leicestershire - Derbyshire border in the little valley of Dimminsdale at approximately SK 375218, where the new road crosses the southern end of the Staunton Harold reservoir. Private papers of the Ferrers' family confirm that lead mining had been in progress here for at least four years, previous to Prior's publication. Throsby (1789, p. 131), in his **Select Views in Leicestershire**, when describing the Seats in Leicestershire, mentioned that Earl Ferrers had "... some veins of lead ore upon this estate (Staunton Harold)." In the following year (1790, p. 428), in his **Excursions in Leicestershire**, Throsby spoke of "... excellent lime, coals, lead, iron and copper on his lordship's estate." In his **History and Antiquities of the County of Leicester**, published in four volumes between 1795 and 1815, Nichols (1795, p. clxvii) implied that mining was flourishing at Staunton Harold. He gave details of the petition placed before Parliament for the construction of a canal to assist in transportation of lime, lead and coal from the mines at Staunton Harold, Ticknall, etc. In volume three of the same work (1804) Nichols placed a dampener on his previous enthusiasm for he stated, on page 718: "Some veins of lead also are upon the estate (Staunton Harold); and formerly a shaft was driven to pursue a vein of lead in the lime-stone: but no very considerable quantity was obtained; and the expence of getting proved very great." Sowerby (1806), for some reason missed figuring the fine groups of galena, calcite, chalcopyrite, etc., which have become famous from Staunton Harold, although he did mention (2, p. 107): "... a few crystals of Galena . . .", when describing hemimorphite from there. Pitt (1809, p.8) referred to lead mining on: Earl Ferrer's estate of Staunton Harold . . . in the fissures of the limestone is found a good and rich lead ore, which is here smelted into metal." The smelter is probably that of the cupola at Coppy Nook (Farey, 1811, p. 385). In the same reference, mentions are also made of Staunton Harold. Thus on page 257 there is a reference to "lead" at "Dimsdale in Calke, adjoining Leicestershire"., while on page 267 an occurrence of "Lead" in "Stanton Park, in Stanton Harold, Leicestershire.", is noted. Phillipps (1823, p. 535) mentioned: "... galena in the mines of Earl Ferrers in Leicestershire." Curtis (1831, p. 164) spoke of; "... some veins of lead ore (are) partially worked." (at Staunton Harold). In 1834, that remarkable man and accomplished observer Mammatt, published his Collection of Geological Facts. On page 5, in his Introductory Observations, he provided a series of geological itineraries, one of which took the "curious observer" past "large masses of metalliferous limestone, . . . affording lead . . .". He reported, for the first time, on the occurrence of galena in the Coal Measures, and his observations are accurate and valuable. In his chapter dealing with faults, he described, (page 57-8): "The slips (small-scale faults) do not appear to hold any metal worth pursuing, although lead is occasionally found both in them and the Measures. In working a seam of coal in Measham, at about eighty yards deep from the surface, and twenty-seven yards below the main coal, a considerable quantity of lead ore was found in

fissures of the coal, and in slips passing through it. A sparry substance accompanied the lead ore, in general, although the ore was sometimes intermixed with the coal only, adhering to it. The coal adjoining this ore, was not altered in quality. The fissures where this ore appeared, were thin and wrought for some distance in the superior strata, but without profit. In another situation, also in Measham, towards the outcrop of the main coal, and where the cap of gravel was about twenty yards thick, much lead, connected with sparry concretions, was found sinking a shaft through the conglomerate deposit; and, where water had been poured over the bank-earth or debris of the shaft, the lead ore was washed clean, and shovelled up in quantities." Mammatt provided a number of greatly detailed geological sections taken from coal mine shafts. Section No. III p.xv, showed the Hastings and Gray Shaft "on Ashby Wolds, sunk in 1832." At 25m from the surface in: "No. 34 stratum". A 0.6m bed of sandstone is labelled: "Sandstone with Lead Ore." Bakewell (1838, p. 62) also spoke of galena occurring in the Coalfield: "In some of the sand-stone strata, in the Ashby de la Zouch coal-field I have seen the joints occasionally coated with thin laminae of lead ore, galena." A reference in Jukes (1842, p. 16) drew the attention of the reader to Staunton Harold again. He did add a few geological facts and described the ore body as ". . . bunches of galena . . . which are extracted in what is technically called a pipe work, the ore being followed by a small horizontal gallery or pipe". White's *History, Gazetteer and Directory of Leicestershire and Rutland* (1846, pp. 294/5) stated that "Lead, limestone and ironstone are found on it (Ashby Wolds), 1 to 4 miles west of the town." The mention of limestone would imply that the author was referring to Staunton Harold, and the specific reference to that place, on p. 330, does mention "veins of lead ore." Subsequent editions of this work repeated the statements and will not be dealt with here. It is of interest to note, however, that in the 1863 edition the statement is made that, ". . . it (lead ore at Staunton Harold) hardly pays for the working." The mines were still working at Staunton Harold in 1852, as evidenced by Mammatt (1852, pp. 119 and 165), who, describing Excursion VII, stated that: "Quitting Calke, we shortly pass on the left a curious little valley called Dimsdale, where lead mines are worked to some extent . . .". A most interesting geological account of Staunton Harold was given by Jukes in Allen's *Illustrated Handbook to Charnwood Forest* (1857, p. xii). He described the area as a miniature model of the Lower Carboniferous of the North of England. His structural facts on the ore bodies are obviously copied from his previous appendix in Potter (1842) outlined above. Gregg and Lettsom (1858, p. 414) showed the first mineralogical enthusiasm for the Staunton Harold lead minerals. In their locality list for galena they listed Leicestershire as follows: "Leicestershire; in fine crystals at Ticknill Hall; recently at some localities, antimonial. The antimonial galena occurring in Tuscany, is found to contain also copper, iron and zinc; having seen no analysis of the Leicestershire mineral, we are unable to say what are its precise constituents." Hull (1860, p. 16), added further data on the structure of the ore bodies at Staunton Harold. He quoted a personal observation of a Mr. Bauerman, of the Geological Survey, who: ". . . called my attention to the curious fact, that most or all of the lodes in Dimmingsdale are formed of a quartzose conglomerate or breccia, and that the galena principally occurs in ribs at each side of the walls of the lode, while crystals of the remaining minerals are formed in the druses of the veinstone. The ore is extracted in what is technically called "pipework", being followed by means of small horizontal galleries or pipes." Ansted (1866, pp. 22 and 62), repeated the above statements made by Hull (1860). The first reference to an occurrence of galena in Triassic sediments, although no geology was mentioned as such was that of Mott (1868, p. 23) who talked of: "A vein of lead has been found near Garendon but was soon worked out." He was referring to the Tickow Lane Lead Mine, a deposit of galena in the Bromsgrove Sandstone Formation of the Sherwood Sandstone Group (Warrington et al. 1980, p. 39), formerly the Building Stones Formation. Plant, (1875, p. 45) in his Special Reports to the Leicester Literary and Philosophical Society on accessions to the Town Museum collections, quoted: "galena (sulphide of lead) etc." from "Carboniferous Rocks", but he gave no localities. Harrison (1877a, p. 129) spoke of ores of lead, etc., being found in the Carboniferous Limestone at Dimmingsdale and, in the same year, in his appendix to the 1877 edition of White's *History, etc.*, (1877d, p. 16), repeated the now wellworn statements on the occurrence of galena at Staunton Harold. He also made the unfortunate statement that: "This little spot is interesting as being the only place in Leicestershire where galena has been obtained." A refreshing break from Staunton Harold was given by Hutchinson (1877, p. 40). In his list of minerals found at Mountsorrel main quarry he included: "Small quantities of crystallized galena, . . .". In his series of papers on the *Minerals of the Midlands*, Woodward (1881, p. 258) listed galena as occurring at "Dimmingsdale in Mountain Limestone." Shipman (1882, p. 280) provided a highly perplexing, but nevertheless valuable and entertaining account of his discovery of old lead mine workings in the new railway cutting below Tickow Lane bridge. Several of his statements will be examined in detail when the actual occurrence is examined below. Phillips (1884, p. 29) described an occurrence of galena-rich Lower Triassic sandstones at Commern, at the extreme northern end of the Eifel in Germany. He went on to mention other German localities of similar character, as well as: ". . . Nottinghamshire and Leicestershire in this country." One must assume that he referred to Tickow

Lane mine, the only occurrence then known in which Triassic sediments contained an economic deposit of galena. In July 1886, members of the Chesterfield and Midland Institute of Engineers held a field meeting in the Burton on Trent and Ashby area. In the anonymously written account of the excursion (1886, p. 167), mention was made of the fact that lead ore occurred in Staunton Harold Park, though it appears to have been copied from White's Directory. Bragge (1886, p. 206) spoke of: "... lead ore and spathic iron ore being worked at Dimingsdale." The Coppy Nook cupola must by then have fallen into disuse for he said: "The lead ore was sent by road to Derby to be smelted." An ambiguous comment at the July 7th meeting of Section E (then Zoology and Geology) of the Leicester Literary and Philosophical Society, (published in the **Quarterly Reports**) stated: "... that lead had been found on the Forest, ..." Anon (1890, p. 207). The author probably referred to Tickow Lane lead mine, which is situated immediately on the northern flanks of Charnwood Forest. Paul, who was probably the author referred to above, found and later donated a specimen of galena to the Town Museum. His find was mentioned in **Recent Geological Notes**, also published by the same society (1891, p. 407): "... a piece of lead ore taken from a vein in the white sandstones of the Keuper (f.5) near the Whitehorse Wood, on the railway between Ashby and Loughborough." This is Tickow Lane mine. Binns and Harrow (1897, p. 253) provided a valuable factual account of galena in the Netherseal Colliery in Leicestershire. The text of this is worth quoting in full, although the chemical analysis given in the account as adding little to the description of the mineral, is omitted here.

"About the year 1874 or 1875 one of the writers found in a band of clay-ironstone a minute crystal, which he believed to be of this mineral (galena): ... Lately, however, a remarkable deposit has been met with in a fault in the roof of the eureka coal-seam ... The vein is not crystalline or clearly defined, and varies in thickness from 6 inches downwards. The gangue is clay, and the galena occurs in masses of irregular height and length, up to 1½ inches in thickness. Its lateral extent was proved to be at least 75 feet. The fault passes down into the coal-seam, which is about 3¼ feet in thickness; but the galena does not continue beyond the roof rock." Page 254: "Another interesting occurrence of galena was recently met with in the eureka rock, where a small vein, about 1/8 inch in thickness, of ankerite was exposed by a fracture of the stone. Perfectly covered with glistening white mineral, which was studded at intervals of about 2 and 3 inches with small groups of galena crystals, approximately 1/3 inch in diameter, this specimen presented an unusual and brilliant appearance. So far as could be ascertained, the vein extended at least 9 feet horizontally and 2 feet vertically, but its upward extension was not proved." In the discussion which followed the reading of this paper, William Spencer of Leicester said that he had frequently found galena in faults in the Coal Measures.

According to Keay (1902, p. 203) lead mining had ceased at Staunton Harold by 1902. He spoke of the "lost minerals" of the county and included the lead mine at "Dimmingsdale". In the **13th Annual Report** of the Leicester Town Museum: 1891-1902 (1902, p. 144) Paul's donation of the galena specimen from Tickow Lane appeared: "1891/2. Specimen of Lead Ore, 5 feet deep under the Old Canal Bridge, near Whitehorse Wood, Leicestershire. — Mr. J.D. Paul, F.G.S.". This report is analysed in detail later.

In Kelly's Directory for 1904 (pp.11 and 561) Harrison stated that "... lead ore has been found" at Staunton Harold. Fox-Strangways (1905, p. 17) stated: "... galena was formerly worked at Dimmingsdale, ..." Rudler (1905, p. 178), in his description of the Ludlam Collection mentioned galena associated with calcite, "... from the mines which were at one time worked near Ashby-de-la-Zouch in Leicestershire.", and went on to repeat Hull's comments of 1860. Fox-Strangways (1907, p. 110) quoted Binns and Harrow's observations of 1897 and Mammatt's of 1834. Horwood (1913, pp.24 and 113) referred to Shipman's observations of 1882, concerning the latter's finding of lead works and ore samples at Tickow Lane. He marked with great interest Shipman's comments that the galena occurred in "rolled lumps" of Carboniferous Limestone, assuming from this that a concealed ridge of limestone must lie beneath Tickow Lane area. The writer has been unable to confirm Shipman's observation, and considers it to be a case of lithological misidentification. Still having Shipman's statement in mind, Horwood (1916, p. 362) fell into the trap of attempting to establish a current direction for the derivation of the Keuper Sandstones, towards the southeast from the galena-bearing limestone of Staunton Harold, where, in actual fact, current directions measured in these fluvial sediments, suggest a southerly derivation away from Charnwood Forest. The next reference to the finding of galena in the county appeared in the 49th Annual Report of the Leicester City Museum: 1954-5 (1955, p. 21). This spoke of the activities of the Museum Club. "As a result (of field work by the club), a number of notable specimens were collected (galena from Groby, ...)." A specimen from this Groby find was kindly given to the writer by Mr. C.P. Watkins. The specimen, now accessioned under No. 19437, is preserved in the collections of the University of Leicester, Department of Geology, and will be discussed later. The Leicestershire volume of **The Victoria History of the Counties in England**,

(1955, 3, p. 36) provided the statement that: "By 1775, a lead mine was being worked at Heath End, near Staunton Harold. The amount of lead ore available was small, though of good quality. Lead mining in this area continued for most of the 19th Century, but never became important." King (1959, p. 25) mentioned and described the occurrence of galena at Mountsorrel, placing it in his Hydrothermal Stage 1, that is, the granitic hydrothermal mineralization of the complex. In the same account he mentioned the manuscript note made by Mr. W.L. Tucker on the occurrence of galena in ". . . a granite matrix" at Mountsorrel. The acquisition of a specimen of calcite with galena was mentioned in the 54th Annual Report of the Leicester City Museum: 1959-60 (1960, p. 31). The specimen was localized at Cloud Hill, near Breedon on the Hill and accessioned under No. 260 '1959'. In November 1866, the Squire of Garendon, Ambrose L.M.P. de Lisle, donated a specimen of galena from his Tickow Lane lead mine, then working, to the Geological Survey Museum in London. This specimen was subsequently borrowed by Moorbath and used in his work on Lead Isotope Abundance Studies in the British Isles. The results of this work were published in 1962. No physical data was added to that on the original label: "Galena disseminated in Triassic Keuper Marl." In table VI of Moorbath's paper (p.320), this specimen (listed as No. 24) was given the model age of 210 ± 80 m.y., although some doubt as to the validity of this data has been expressed recently by Moorbath himself (personal communication).

Sylvester-Bradley and King (1963, pp. 729-730), mentioned the association of galena with hydrocarbon compounds at Cloud Hill, near Breedon on the Hill, and at Staunton Harold. An additional specimen of galena from Cloud Hill was added to the collections of the Leicester City Museum, under accession No. 177'1963, and its acquisition appeared in the 58th Annual Report: 1963-4 (1964, p. 37). In the 59th Annual Report of the same institution (1965, p. 44), a specimen from Staunton Harold was added, donated by Mr. K. Spink, under accession No. 187'1964. It was described: "Baryte, galena and calcite. Dimminsdale." King (1966, p. 294) used Binns and Harrow's account (1897) of galena deposition in the Coalfield as evidence to support his concept of "Epi-syngenetic mineralization". He also referred to galena, associated with chalcopyrite, etc., and its occurrence in Trias filled wadis and open joints in the Carboniferous Limestone of Cloud Hill (page 296). King (1967, p. 62) described the rare development of sulphur on galena cleavage surfaces at Staunton Harold. Ford (1968, pp. 345, 347), in his account of the Charnwood Forest excursion of the Yorkshire Geologists Society in April 1968, mentioned the occurrence of galena at Newhurst Quarry near Shepshed, and the finding of a loose block of galena and malachite fallen from the unconformable basal Keuper of Cloud Hill Quarry. Ford (1968, p. 123) recalled the records noted by Mammatt in 1834, on the occurrence of galena in some of the collieries around Measham. King (1968) noted the finding of galena at Groby (page 113); at Mountsorrel (page 116); in the Blackbrook area of Charnwood Forest, now known to be Tickow Lane (page 126); at Cloud Hill, near Breedon (pages 129 and 135); at Staunton Harold (pages 130 and 135), and in septarian nodules in the Lias (page 132).

Taylor (1968, p. 172) spoke of rare specimens of galena being found in the vicinity of Shepshed, ". . . presumably from the basal Keuper." Poole (1968, p. 143) in his geological description of the cuttings of the M1 Motorway, during the course of its construction through Charnwood Forest, reported the occurrence of small crystals of galena and patches of malachite in the dolomitized basal breccias of the Mercia Mudstone Group in the Birch Hill cutting (SK 481134). King and Ford (1969, p. 87) described the visit of the East Midlands Geological Society to the site of Tickow Lane lead mine, and outlined the finding of the formerly completely hidden adit. In 1969, King and Ludlam described the history, short working life and the finding of the old Tickow Lane lead mine. An outline of the mineralogy was provided, establishing the form of the mineral body as a flat sheet of galena, accompanied by a "dyke" of white soft sand full of nodules of galena. They reported that both occurrences of galena were thoroughly oxidized, but that there were relics of octahedral crystals which showed that the upper surface of the sheet of galena was well crystallized. A comprehensive and detailed account of the mineralogy and genetic implications of this almost unique occurrence is in course of preparation.

Spink (1971, p. B58) referred to the scattered minor occurrences of galena in the Coal Measures in Leicestershire, and put forward a case for their derivation from the sediments which enclose them. He also referred to the galena deposit at Staunton Harold as probably a sinkhole in the Carboniferous Limestone surface; a point of great significance.

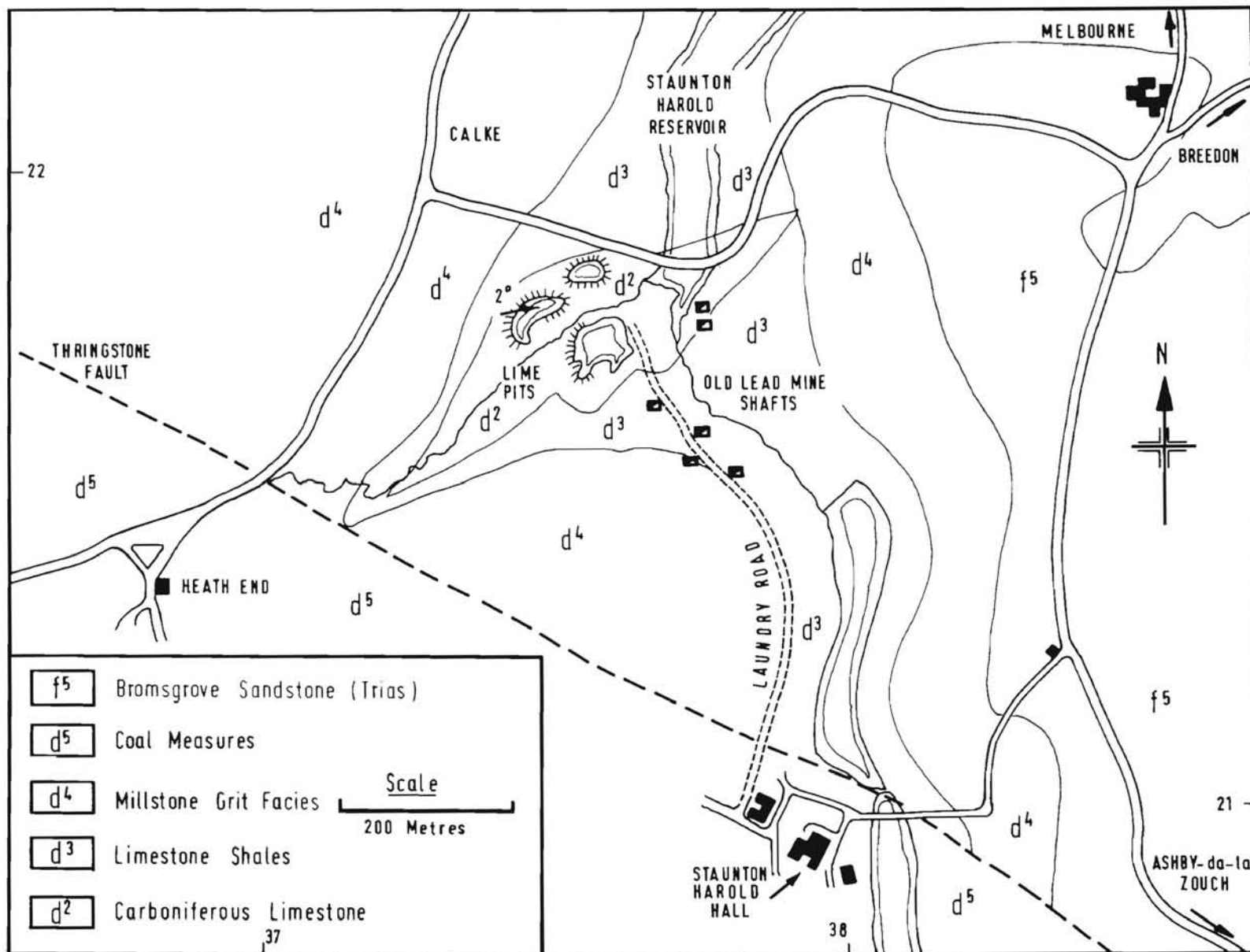


Figure 1.

Geological sketch map of the immediate environs of Earl Ferrers' Mine, Staunton Harold, Leicestershire.

OCCURRENCES

Almost all occurrences described below are thought to be epigenetic in character, and the difficulties of assigning any one galena-bearing association to a particular age are often insuperable. This is due largely to lack of data. Until this is forthcoming the several descriptions below are placed in stratigraphical order of the host rocks. Where known, accession or field reference numbers of specimens which illustrate the described physical features are listed, the writer's being preceded by the letter K and appearing in brackets.

1. Precambrian

Apart from one doubtful occurrence, galena was unknown in rocks of Precambrian age in Leicestershire until 1974.

- (i) The doubtful occurrence took the form of a mention in the 49th Annual Report of the Leicester Museum for 1955. This reported the discovery of galena at Sheethedges Wood Quarry at Groby by the members of the Leicester Museum Geology Club. The data provided by the writer of the report could not be substantiated in the field, however, and the specimen alleged to have been found there, and now lodged in the collections of the University of Leicester, Department of Geology, under accession No. 19437, is more typical of a northern Pennine derivation.
- (ii) Hypogene galena was found in 1974 in veins cutting Northern Type diorite (Watts, 1947, p. 73) in Newhurst Quarry near Shephed (Natn. Grid Ref. SK 488179).

During the construction of a new access road (1974) a vein was exposed on the southern face of the quarry, flanking the new road at a point approximately two thirds down its length from the ground surface. A length of 1.65m of the vein was exposed. It was seen to strike in a NW-SE direction in keeping with the persistent structural trend present in the quarry, with a variable dip from vertical to 84° east. Its average width was 86mm., but it attained a maximum width of 400mm. At a point 1.65m from the road surface vertically, the vein split into strings and died out completely above 2.8m.

The principal mineral present was massive white milky quartz, but strings of ferroan dolomite and calcite appeared intermittently on the footwall. Associated with the carbonates were sulphides dominated by chalcocite, bornite and chalcopyrite, but at the base of the section galena, associated with minor chalcopyrite replaced both chalcocite and bornite. The galena, microcrystalline in character, took the form of thin veins of maximum thickness 16mm, between the carbonate gangue and the country rock on the footwall side of the vein (K8424-74).

A varying thickness of chlorite-rich fault gouge occurred on the footwall side to the vein. Some of this was examined by Dr. P.R. Ineson of the University of Sheffield, who reported in 1976 that he had established an age of 232 ± 7 m.y. (Triassic) for the clay by potassium/argon isotopic age determination methods. (Personal communication).

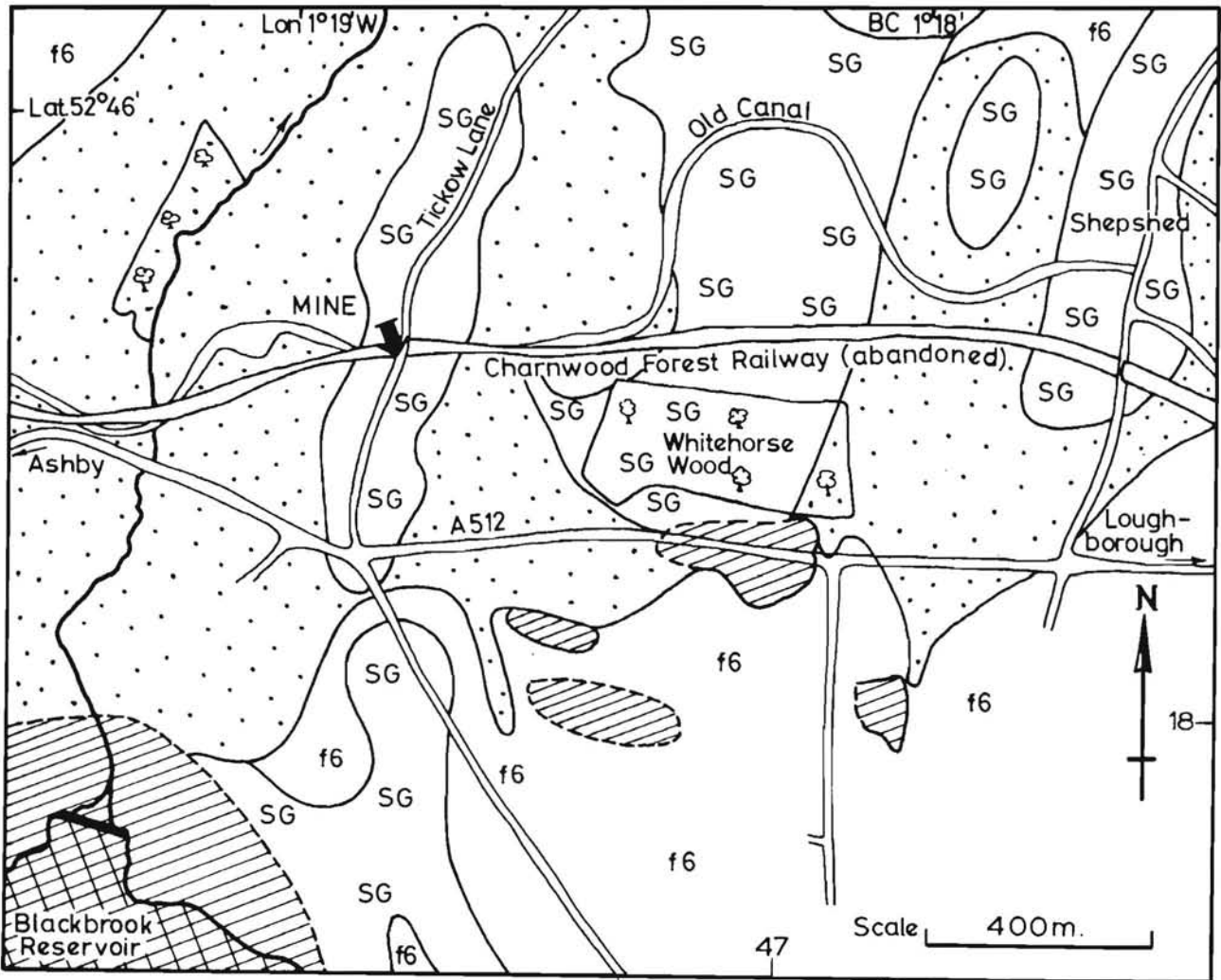
2. Caledonian






Tucker first recorded the occurrence of galena in rocks related to known Caledonian events at Mountsorrel. In the form of a manuscript note in his copy of W.J. Harrison's book *A Sketch of the Geology of Leicestershire and Rutland*, published in 1877, he stated: "also galena has been found (in the Mountsorrel Granite Quarries) surrounded by a granite matrix." King (1959, p. 25) assigned Tucker's occurrence to his Hydrothermal Stage 1 of the mineralization of the granodiorite. The latter author subsequently (1973, p. 99) reported the rare occurrence of galena in the former Main Quarry at Mountsorrel in the form of small crystallized masses associated with ferroan dolomite and pyrite, again relating it to granitic hydrothermal activity.

3. Lower Carboniferous (Dinantian (George, T.N., et al. 1976)).

- (i) By far the most outstanding locality for finely crystallized galena in the county is that of Staunton Harold, namely Earl Ferrers' Lead Mine (Fig. 1). This mine with its many synonyms is an ancient one, and was in work as far back as 1775. From the writer's explorations of many collections, and there are certainly more unknown to him, it would appear that the value of Staunton Harold ore as cabinet specimens was known right from the earliest workings of the mine. Unfortunately the older generation of mineral collector was not too particular about preserving data, and thus the value of otherwise priceless material is greatly reduced. Fortunately there are one or two exceptions;

Philip Rashleigh of Menabilly in Cornwall was careful to preserve any data on the material which came his way. He acquired some fine Staunton Harold specimens from Sir Walter Synot of Ballymoyer, Co. Armagh in Eire in 1790. These specimens were amongst that portion of the Rashleigh collection purchased by the late Sir Arthur Russell in 1923. He very kindly gave two of these specimens to the writer in 1954. (K1084-1790, K2251-1790). The bulk of cabinet specimens from Staunton Harold were produced in the early part of the 19th century, as evidenced by dates of accession, etc., seen in museum collections. A further period of cabinet specimen production took place in 1939-40, when the mine was re-opened by the 12th Earl Ferrers. Sir Arthur Russell visited the mine at this time, and specimens were collected which now form part of his bequest, and are in the collections of the British Museum (Natural History). The Earl Ferrers kindly presented the writer with a specimen (K1232-39) from this exploratory opening, during a visit in 1948.



 f6	Mercia Mudstones	} Triassic	 BC	Boulder Clay	} Pleistocene
 SG	Bromsgrove Sandstone		 SG	Outwash Gravels (The Old Gravels)	
 Hatched	Charnian (Precambrian)	Figure 2.			

Geological sketch map of the immediate environs of Tickow Lane Mine, Shepshed, Leicestershire.

When one comes to examine the genetic aspects of mineralization at Staunton Harold, the end product is usually frustration. There is so much tantalizing evidence of a highly complex pattern of mineralizing events, none of which can be put into perspective owing to a complete lack of accurate field data. However from a careful study of many specimens, certain facts emerge which do provide some evidence of the mineralizing events. The mineral associations follow a well-marked paragenetic sequence. Sand is very often present and is itself mineralized, and there is some evidence of cavernization of the limestone. A number of specimens which are particularly valuable for genetic study will be described below.

In the paragenetic sequence of events, dolomite always preceded the base metal mineralization. This dolomitization has produced highly cavernous ground and presumably provided an ideal host rock. To what extent cavernization developed is unknown. Hull (1860, p. 16) stated “. . . limestone is worked in caverns”, though he may have been referring to the method of working the limestone for lime production. Indeed any further exploration of the mines seems unlikely due to the immediate proximity of the Staunton Harold reservoir. The presence of sand is also a puzzling aspect of the problem. The coarse sandstone which crowns the face above the water-filled laundry-pit was considered to be of Millstone Grit facies by Mitchell and Stubblefield (1941, p. 215), but the few observers to enter the mines always spoke of an anticlinal structure in the limestone, with a conformable cover of limestone shale on its flanks. Millstone Grit facies crop out beyond the valley bottom, (Jukes, 1857, p. xii). Hull (1860, p. 17) shows this structure in cross section in his Fig. 2. Sir Arthur Russell, who recalled his visit in 1940, spoke of a shale roof above the limestone. He also recalled the fact that the orebodies were in the form of thin irregular veins (? following joints) and died out at very shallow depths. That the sand entered the limestone after dolomitization is also evident, and there are not many specimens without some quartz grains enclosed in the matrix. If the sand is of Millstone Grit age, then there must have been a sinkhole in early Middle Carboniferous time. On the other hand it is much more likely that the anticlinal structure was ‘holed’ after Carboniferous time. Cavernization took place and younger sediments, possibly Permo-Triassic in age, occupied the caverns.

The reader will recall the remarks made by Mr. Bauerman in Hull (1860, p. 16), who spoke of the lodes being formed of “quartzose conglomerate or breccia.” The age of the sand is unknown, but it is hoped that this might be resolved in due course. Following dolomitization, the next mineralizing event was the formation of a strong deposit of characteristic baryte, which crystallized where it could in very thin pink to white rosettes of tabular crystals. Following, and in part contemporaneous with it, was the deposition of sphalerite. In certain specimens this is the end of the sequence, but in most the pattern of events continued, with pyrite and/or marcasite precipitation. Each new generation may completely cover the preceding one, but at Staunton Harold this is exceptional, abundant ‘windows’ being left to see the previous event in each case. The fifth event was a heavy deposition of 1st generation galena. This constitutes the bulk of the ore mined. It is always cubo-octahedral in form, the average proportion of cube: octahedron being 8:92 (Plate 1). Crystal sizes vary, but individuals average 18.1mm across the equatorial region. The smallest measured has been 7mm and the largest 26mm, of 32 crystals measured. The crystals may be tarnished. When they are, the tarnish takes on a violet-brown colour (10E7)* or even ruby-red (12D8). They are also highly composite and made up of sub-individuals, presenting a rough appearance. Occasionally the sequence ends here, but in most cases a 6th event occurs – the deposition of 1st generation calcite. This, like the galena, constitutes the main influx of that mineral. It formed modified scalenohedra, quite characteristic of the occurrence. This last event was a vigorous one, and the calcite often obscured previous events to varying degrees, though never to completion. Following calcite, a 2nd generation galena was deposited. This is a remarkable event, the galena being entirely skeletal. Occasionally it added a rim of galena to pre-existing 1st generation cubo-octahedra, although it restricted its deposition to the octahedral portion of each crystal, completely missing the cube faces, so that hollow forms were produced. Elsewhere it is deposited on 1st generation calcite, as rather beautiful skeletal octahedra and fills in the spaces between 1st generation galena crystals in a bizarre fashion (Plate 2). At times, the skeletal development is so strong that only the crystals rims exist. As far as can be observed, vicinal faces are not present. This generation of galena is not so liable to tarnish as the first. Another striking feature is that the skeletal faces all reflect light from the same set of angles as the specimen is rotated. The crystals vary only slightly in size, being on average 15mm across.

*FOOTNOTE

The bracketed number and figure combinations which follow the names of colours are positions on individual plates in the Methuen Handbook of Colour (Kornerup and Wanschler, 1963).

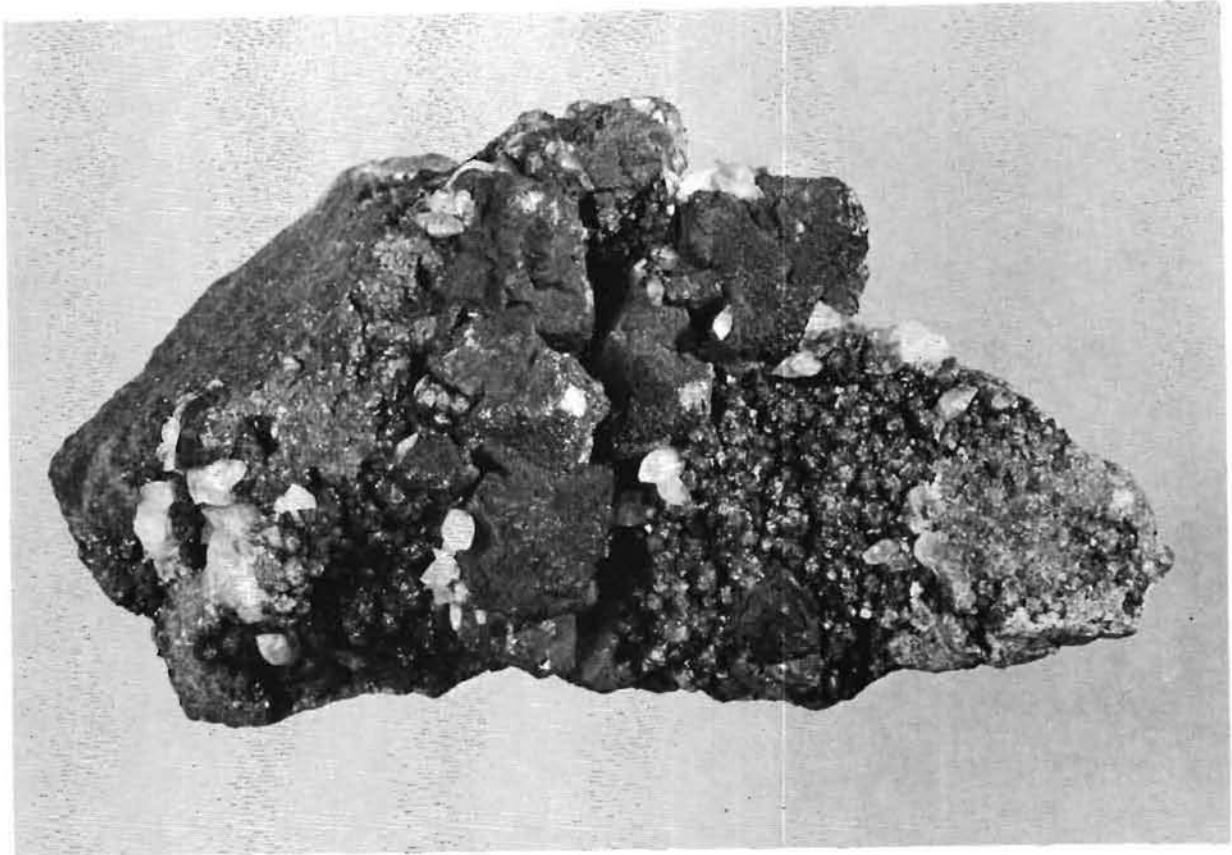


Plate 1 Cubo-octahedral development of first generation galena associated with sphalerite and first generation calcite. Earl Ferrers' Mine, Staunton Harold, Leicestershire. K3334-1794.

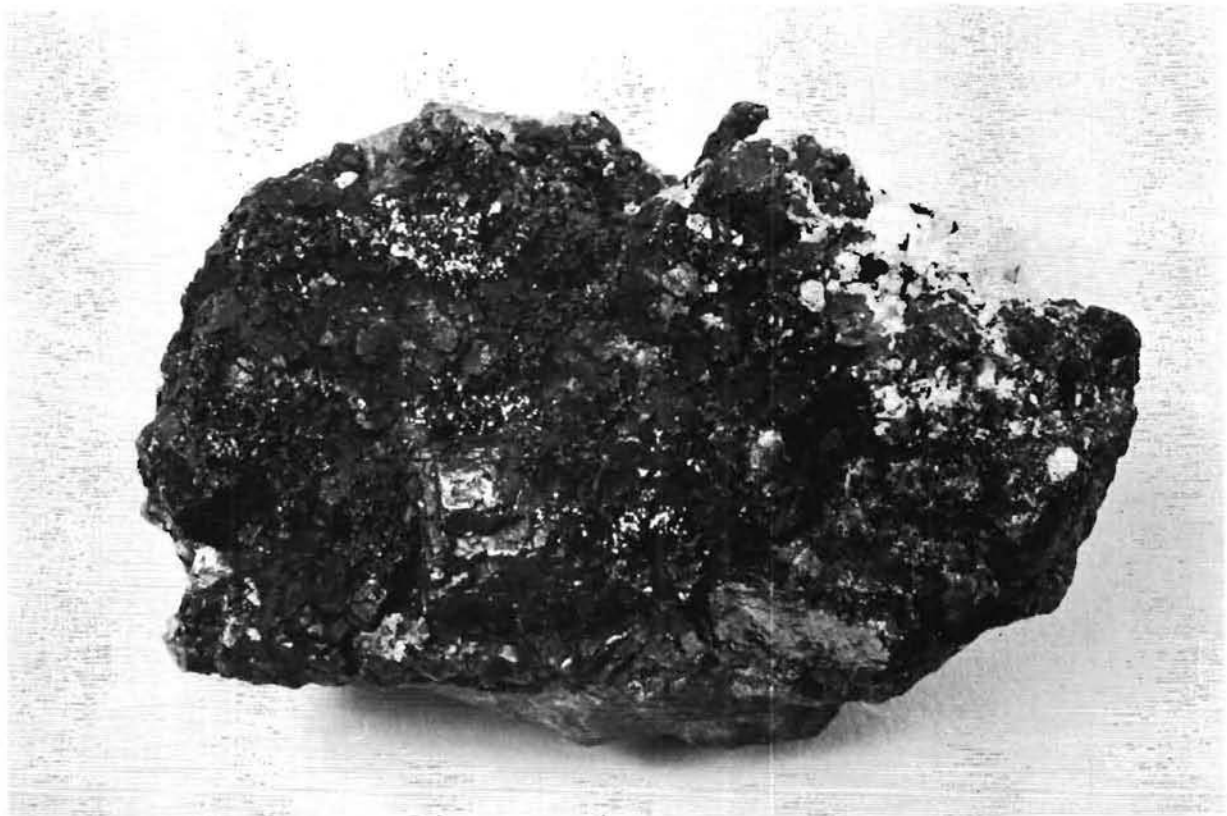


Plate 2 Skeletal second generation galena infilling interstices between cubo-octahedra of first generation galena. Note reflection from octahedral planes of the second generation galena. Earl Ferrers' Mine, Staunton Harold, Leicestershire. K1048-1790.

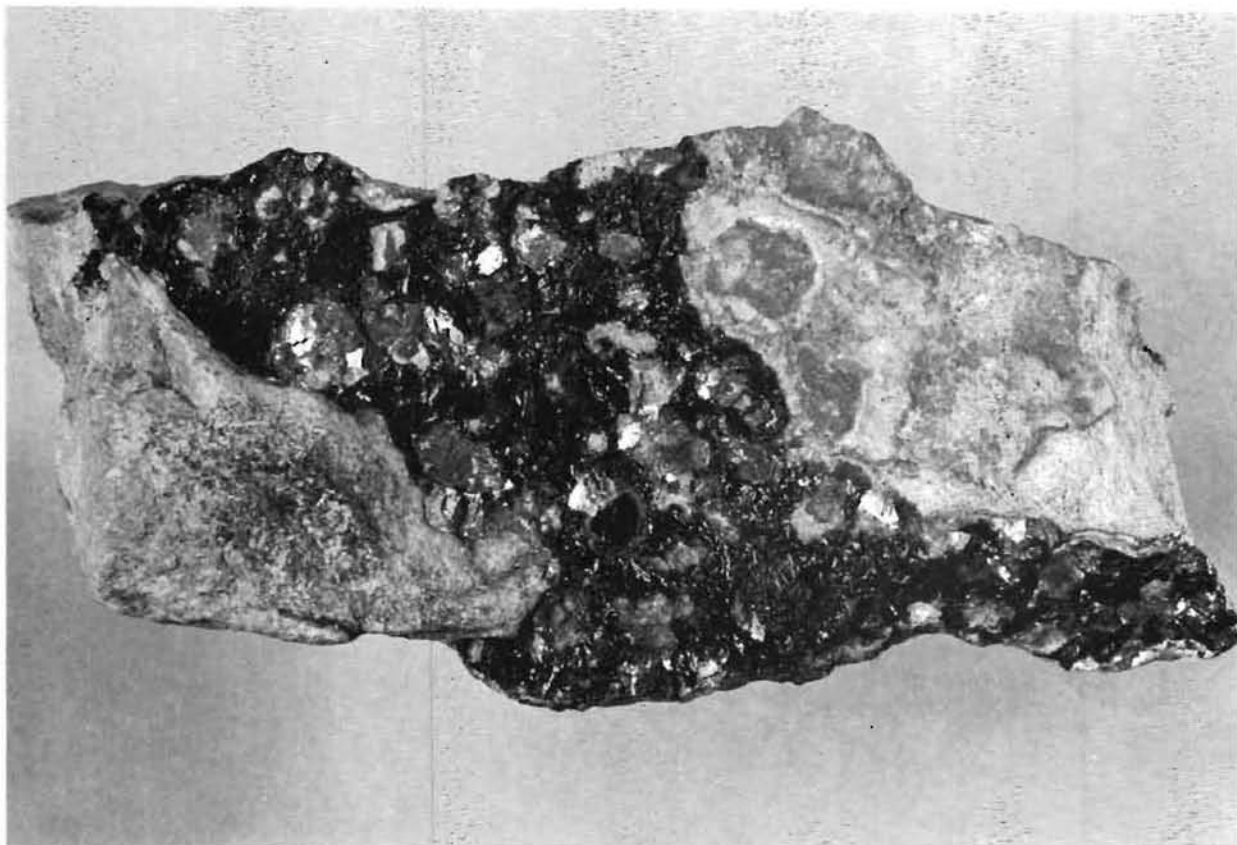


Plate 3 Veinlet of an intimate association of galena and asphaltum cutting dolomitized Lower Carboniferous Limestone and red baryte. Earl Ferrers' Mine, Staunton Harold, Leicestershire. K788-1947.



Plate 4 Galena associated with complexly twinned sphalerite. "Ticknill Hall, Leicestershire". K2251-1790

The 8th mineralizing event is that of the deposition of 2nd generation calcite, although this is uncommon, and the only specimens showing a strong development of this stage are in the collections of the Sheffield City Museum, accessioned under Nos. 1971.576, 7, 581, 2 and 3, and presumably came from one area of the mine. The final event at Staunton Harold is that of chalcopyrite deposition in the form of small tetrahedra. This assemblage makes some of the most attractive mineralogical material of the country. An association which must also have been restricted to one area of the mine, is that of galena and asphaltum. Rarely, the latter forms small globular masses associated with the whole gangue, but usually it is restricted to 1st generation galena, where it forms unusually attractive intergrowths (Plate 3), much sought after by German mineral collectors.

The most outstanding collection of high quality specimen material from Earl Ferrers' Lead Mine is lodged in mineral collections of the Department of Earth Sciences of the University of Cambridge. Although variously labelled as "Ashby de la Zouch; Derbyshire; Leicestershire; Lord Ferrers' Mine and Breedon Hill", all the specimens are typical of Earl Ferrers' Mine – a point noted by one T. Davies. Davies (1837-1892) an assistant in the Department of Mineralogy of the British Museum (Natural History) (Fletcher, 1893) visited Cambridge for some reason and while there was quick to note the typical and unique mineralogical association of the mine and amended labels, as for example, with specimen No. 1638, which now reads: "Ashby de la Zouch ~~not~~ Derbyshire. T.D."

Much of this Leicestershire material acquired by Cambridge University is from two important collections: The Sir Abraham Hume Collection (acquired ca 1841) and the G.M. Treveleyan Collection (acquired towards the end of the 19th century). The Hume Collection has many of its labels written in french by the late Count de Bournon. Apparently Bournon went about enjoying the hospitality of wealthy collectors, occasionally cataloguing their collections in return (personal communication: Dr. G.A. Chinner). Notable specimens include Nos. 1638, 1639, 1645, 1649, 1662 and 1723. Most show the species habits typical of the occurrence such as cubo-octahedral first generation galena; skeletal second generation galena; brick-red baryte and calcite in rhombohedra {4041} modified by the scalenohedron{2131}.

Several specimens in the writer's collection illustrate the many mineralizing events at Staunton Harold, and those together with specimens examined in other collections are listed: 1st generation galena and calcite: K949-47, K1231, K1232-39, K2844, British Museum (Natural History): B.M. 57328, Institute of Geological Sciences: 209, 10991, 11000, 16408, Sheffield City Museum: I.88.11. 2nd generation galena, etc.: K1084-1790, K1232-39, K2251-1790, K2278. Institute of Geological Sciences: 210, 11003. There is also non-accessioned material in the Wollaton Park Museum at Nottingham.

It should be pointed out that in this latter selection, specimen K2251-1790 is not anomalous to the locality, though labelled as Ticknall, which is 2 miles north of the county boundary, in Derbyshire. The matrix and associations of this specimen all point to the specimen having been obtained from Staunton Harold. Correspondence with Harpur Crewe Estate Office in Ticknall confirms that no base metal mining has been conducted at Ticknall within recorded time, even though there is a minor 'showing' of galena, baryte and a little chalcopyrite in the old lime yards. Sir Arthur Russell, who donated the specimen, expressed his doubts to the writer about the verity of the label (Plate 4).

A specimen, lodged in the collections of the Camborne School of Mines in Cornwall, is typical of the occurrence, being composed of two thin strings of coarsely crystalline galena, set in a matrix of characteristically red baryte. Other associates include crystalline calcite and minute (3mm max.) crystals of sphalerite. It is labelled: "Lead ore, galena, calcite and baryte (pink). Leicestershire. No. 3955 Hunt Collection." Robert Hunt, formerly Keeper of Mining Records, who died in 1887, did much to promote an interest in the mines of the west of England and in the welfare of the men who worked in them. In his honour, the Robert Hunt, F.R.S., Memorial Museum was opened in Redruth in 1891. A collection of minerals, of which the above was one, formerly presented to the Redruth Institution by Messrs. John Garby, Davey, Thurston C. Peter and others, was then re-housed in the Hunt Memorial building, and made available for inspection by the public. These facts date the collection of the specimen as being at least pre-1891. When the Redruth School of Mines building was sold to the Cornwall County Education Authority in 1953, the mineral collection was transferred to the Camborne School of Mines, where it is still preserved. The accession number 3955 was allocated by the curator appointed to maintain the re-housed collection and is not a Hunt number.

Leicestershire Museums have in their geological collections a valuable specimen labelled: "Carboniferous Limestone (Dolomitic) (Conglomerate) Dimminsdale and galena. 1647". The matrix is not limestone, but a conglomeratic sandstone, with well-rounded quartzite pebbles up to 12mm in diameter, and sub-rounded clasts of soft reddish and greenish clay. The whole specimen is cemented largely by dolomite and the typical red baryte of Staunton Harold. Running through the specimen are thin veins of calcite and galena lying conformably with the bedding traces or lineation of the pebbles. This could be the "thin pebbly grit" of Mitchell and Stubblefield (1941, p. 215), "resting on the Carboniferous Limestone", immediately beneath the Limestone Shales. A paper dealing with the historical and genetic aspects of this old mine is in course of preparation by the writer.

- (ii) Galena is quite common at Cloud Hill Quarry, near Breedon-on-the-Hill (SK 413214), and occasionally quite spectacular developments of it occur there. Some of this material may be rather beautiful, especially as it invariably has a very high lustre or is associated with malachite. Galena, at Cloud Hill, is restricted to the basal beds of the Bromsgrove Sandstone of the Trias; to the line of unconformity between the upturned beds of Carboniferous Limestone and the overlying Trias; and in swallow holes (swallets) or open solution-widened joints in the intensely dolomitized limestone. These swallets are usually filled with a yellow sand of decalcified limestone, and it is in these structures where small spheroids of galena develop, usually at the neck of the swallets. These spheroids are a radiate development from a seeded centre. Unlike the Golconda mine in Derbyshire, where the radiate pattern had developed into radius lengths of up to a metre (Ford and King, 1965), the spheroids at Cloud Hill aggregate to form masses, weighing up to 29.2kg. This development has reached a climax on the high eastern face of the quarry. Occasionally these masses fall out of their situation and drop to the quarry floor. The exterior of these masses is dull and ochreous and is the relic of a skin, up to 4.6mm thick, composed originally of chalcopyrite, but now completely oxidized to goethite, malachite, cuprite and strings of native copper. When these large masses are sawn open, the aggregation mechanism of the spheroids becomes apparent. Each spheroid has an average diameter of 10mm, and shows the roughly radiate structure, each crystal diverging from a common centre, which may be a quartz grain, or even a minute sphere of baryte. (K3256, K3268-70). Late growth, post aggregation of the spheres, more or less fills the interspaces between them. The interiors of the masses are usually quite fresh, and there is no other mineral present except for a few scattered dolomite rhombs enclosed by galena. Towards the rim, cerussite may develop, but this is young and contemporaneous with chalcopyrite oxidation. In certain cavernous areas of the oxidized shell, cerussite may crystallize in euhedral forms, either as acicular single crystals or equant crystals which are often twinned. All are extremely small, highly lustrous and transparent. A modification of this nodular aggregation of spheres occurs when chalcopyrite has intergrown with the galena inside the overall nodular mass. Then the galena takes on an almost filigree form, consisting of very irregular plates. Each plate, on average is 6mm in length and 3.1mm wide, and usually coated with a transparent colourless or greyish white (IBI) crystalline veneer of cerussite. As is usual with oxidizing galena, once the film of cerussite has formed, no further chemical action has taken place. This is not so with the intergrown chalcopyrite, which has completely oxidized, leaving a residue of brightly coloured malachite and yellow and brown limonitic films.

Where deposition has continued below the line of unconformity, vein-like structures of microcrystalline galena may develop below the surface in open joints in the limestone. In these cases, the galena is often precipitated with stalagmitic calcite. These veins are usually very narrow, less than 35mm wide, and die out downwards with a maximum depth of 12.2m from the ground surface. The final 'showing' of galena at the base of the depositional system, is that of spheroids up to 9mm in diameter, scattered through heavily dolomitized limestone. They are often associated with calcite and baryte. Calcite often persists well below this level. A specimen illustrating this final stage is accessioned under No. 177/1963 in the City Museum Collections. This is the specimen which was cited in the 58th Annual Report.

4. **Upper Carboniferous (Silesian (Ramsbottom, W.H.C., et al. 1978)).**

Occurrences of galena are not uncommon in the Coalfield, though the majority are on a small scale. References and personal observations show that there is a degree of stratigraphical and possibly lithological limitation. The strongest development appears to be in the region between the Eureka and Upper Lount seams in the Lower Coal Measures, but there is an isolated account of an occurrence, probably sub-Kilburn in age. There is also a strong development in the Pottery Clay Series, especially in the region of the Overseal Marine Band. Other accounts cannot be localized or placed in stratigraphical position. Bakewell (1838, p. 62) stated: "In some of the sandstone strata, in the Ashby de la Zouch coal-field I have seen the joints occasionally coated with thin laminae of lead ore, galena". Mammatt (1834, p. xv) provided a shaft section through the Hastings and Gray Colliery which showed an 0.6m "Sandstone with Lead Ore", 27m from the surface.

In a private letter to the writer dated 19/3/71, Mr. K. Spink kindly provided two useful pieces of information on the occurrence of galena in the coalfield.

- (i) The first concerns an occurrence immediately southwest of Ravenstone at SK 400135: "Galena, in grey siltstone, on the Jubilee opencast site, between the Eureka and Nether Lount seams."
- (ii) The second is localized at Lawn Plantation north of Lount at SK 388203: "I also have a note by P.G. Strauss, that he saw galena in a trial pit at Lawn Plantation. This is in highly disturbed and overturned strata, probably sub-Kilburn, and not far below the main thrust plane of the Thringstone fold-fault structure". The first occurrence is the one referred to by Spink in 1971 (p. B58).
- (iii) In an opencast coal site near Asbhy de la Zouch opposite the lane to Old Parks Farm, southwest of Spring Wood at Natn. Grid Ref. SK380183, a strong concentration of septarian siderite mudstone nodules was exposed immediately above the Middle Lount Coal. These nodules, dominantly rich in sphalerite, have yielded galena, either in the form of tiny cleavage masses associated with pyrite and partially covered by younger calcite and dickite (K8425-55), or as minute (0.23mm) but perfect cubes investing siderite crystals in the septarian cavities (K8426-55).
- (iv) The large pit opened by Messrs. Ellistown Pipes Ltd., at Albert Village (SK 301177) exposed a fine section in the Pottery Clay Series of the Middle Coal Measures. The section commenced 2.8m below the Ell Coal and ended just above the Soup Kitchen Coal. The "Pot A Mudstones", which lie above the Ell Coal, were rich in well formed septarian siderite mudstone nodules. The septa voids themselves are barren of sulphides, the only minerals present being crystallized siderite, sometimes sphaerosiderite, and an oily compound. Subsequently these nodules have been cracked. Galena and sphalerite and sometimes calcite have then been deposited in the cracks. Galena is present as brightly lustrous films, thick enough to show cubic cleavage. The maximum infiltration of galena into one of these cracks is 8.5mm from the exterior of the nodule. Its common associate calcite spreads completely over the cracked area. (K8427-69, 8428-69).
- (v) Perhaps the most dramatic of recent occurrences of galena in Upper Carboniferous strata is that reported by Mr. J.A. Jones of Kegworth.

The find was made in the summer of 1981 in the Albion Pit worked by National Strip Mining (N.S.M.) at Nat. Grid Ref. SK3117, near Boothorpe, by Mr. Cecil Beard (NCB Inspector).

It took the form of a large roughly rectangular mass weighing a total of 10.926kg, measuring 180 x 110 x 130mm. It occurred about 15m from ground surface on the surface of seam P40 of the Pot A Clay Series of the Middle Coal Measures, about 29m below the Overseal Marine Band (Sylvester-Bradley and Ford 1968, p. 105).

Its basal surface expression was flat with much included coaly debris and polycrystalline framboidal pyrite. Bedding traces were evident in the coal, suggesting that the flat base of the mass was conformable with the bedding. Upper surface expressions showed the development of highly modified cubo-octahedral crystals. The mass was sawn into three equal slabs, and upon slabbing, a well-developed arborescent structure within the galena was revealed, seeded at the base and finding free expression in the cubo-octahedral surface. Each arborescent structure attained the maximum length of 80mm.

On the receipt the pyrite was in a high state of instability and the mass reeked of SO₂. Since slabbing a fair degree of stability has been achieved by enclosing each slab in a sealed polythene bag with self-indicating silica gel.

One slab has now been accessioned under No. K8429-81. The second is in the collection of Mr. J.A. Jones. The third has been presented to the National Coal Board Mining Museum at Lound Hall, Bevercotes, Nottingham.

The thin layer of galena seen sporadically lying on the upper surface of the highest shales of the Overseal Marine Band in the Overseal district of Derbyshire, has not been found at the same horizon in Leicestershire. Neither has the writer found any galena in the seat earth below the Derby Coal as seen in the Overseal area, where it lined the tubes formerly occupied by stigmara.

5. Triassic

The remaining Leicestershire localities where galena has been observed are in Triassic sediments. Though none are syngenetic, all lie conformable to the bedding. Lateral migration of brine solutions through permeable host rocks is the most likely explanation to account for the presence of sulphides in the local basal breccias and sandstones.

- (i) Mammatt (1834, p. 58) described the occurrence of galena in conglomerates at Measham. By his account it was relatively plentiful. The conglomerate most likely belonged to the Sherwood Sandstone Group (Warrington, et al., 1980), but it may also have been Permian in age (Gresley, 1886). Galena has been seen in the role of a cementing medium in the gravels of the Sherwood Sandstone Group of the Swadlincote area of South Derbyshire.
- (ii) The most striking and interesting deposit of galena enclosed in Triassic sediments is that of the little ore body of Tickow Lane, near Blackbrook and southwest of Shepshed at SK 46261865 (Fig. 2). The history, working and re-discovery of this old mine were described by King and Ludlam (1969). The "ore" body took the form of a flat-lying sheet of galena conformably lying on the upper surface of a thin bed of red marly clay. Above and below the clay and the ore body, and restricted to the immediate vicinity of the ore body, the rest of the succession consists of bleached white current-bedded medium grained sandstones of the Bromsgrove Sandstone. Elsewhere these sandstones are dark red. The shape of the ore body was a sinuous one lying approximately north-northeast. It was 16m long, of an average width of 1.5m and approximately 60mm thick. Records of production have not been found, but the estimated output was just over 2 tonnes. A vertical "fault", striking 54° crosses the adit 1.6m south of the portal. On its eastern intersection of the adit wall, it is opened up in the form of a dyke-like body, 203mm wide, full of soft, white fine-grained uncemented sand, rich in nodules of galena. The galena from the main deposit is unique in its appearance. Mined ore, dump material and remnants of the ore body found in situ in the mine, have been available for study. The specimen which Squire Ambrose de Lisle donated to the Geological Museum in London, in November 1866, has been thoroughly examined. The maximum width of the specimen, which probably equals the thickness of the ore body, is 61mm. The lower surface of the specimen is more or less plane, and conformed to the upper surface of the clay upon which it was deposited. The upper surface is covered by coarse octahedral crystals, slightly oxidized and impregnated with sand. The average size of the crystals is 11.7mm the maximum being 15.8mm. In habit they most closely resemble the octahedral development of Staunton Harold, though the cube is not evident. The slight oxidation consists of threads of crystalline cerussite, often in a reticulate pattern, occupying open cleavages in the galena. Other oxidation products are wulfenite and phosgenite. This specimen is preserved in the collections of the Institute of Geological Sciences, under accession No. 1112. The large quantity of galena found during the course of the exploratory works, and in relics at the extremities of the ore body, though considerably more oxidized than the specimen described above, is, nevertheless, identical in form. The same plane lower surface and crystallized upper are constant features. On this heavily oxidized material, cerussite forms a white selvage, sometimes coated with a golden sheet of well crystallized wulfenite. The underlying presence of galena may be unsuspected until a fresh fracture is produced. (K2940-67).

The nodules of galena which occur in the sand-filled "fault" at the northern end of the mine are of particular interest. The galena is not detrital, but is dispersed through the sand as free-growth forms. Each nodule is dome-shaped, with a concave under surface (Fig. 3). When sawn through the long axis of the nodule, distinct growth shells may be seen developing upwards from the concave under surface. They vary only slightly in size, the average being 11mm in length, and are always encrusted with white powdery cerussite. The nodules always lie within the sand, convex surface upwards and, in every case, lie on a pellicle of clay which fits neatly into the concave under surface. The average percentage by weight of galena and cerussite present in this dyke-like body is just over 30%. The structure and colouration of the sand within the "dyke" points to the possible movement of solutions through it. The fact that the galena nodules appear to have grown upwards from the clay pellicle further suggests that the movement of solutions through the sand was downwards. The "dyke" closely resembles a large chromatograph, the layers of iron oxide and manganese dioxide lying at right angles to the walls of the fault. A remarkable feature of this soft, galena rich sand body is that its termination downwards coincides with the level of the main ore body sheet. The writer considers this to be a critical piece of evidence in the genetic history of the mineralization, and believes the "dyke" to be a conduit permitting lead-rich solutions to enter the sandstones, where precipitation occurred on the red clay parting.

- (iii) Galena has been found in Triassic sediments in Newhurst Quarry, near Shepshed (Nat. Grid Ref. SK488179). In 1966 a new access road to the quarries was cut on the upper level of the northern face. This cutting provided a fine section in the lower beds of the Mercia Mudstone Group (Warrington et al., 1980). A rapid alternation, 5.5m thick, of finely laminated mudstones and coarse to fine-grained sandstones with a basal breccia of Charnian debris set in a coarse-grained matrix, was exposed. It could be seen resting unconformably on the Northern-type diorite on the eastern side of the road, and on hornfelsed Blackbrook tuffs on the western side. The bottom bed of sandstone, here separated from the basal breccia by a bed of green mudstone 28mm thick, is 120mm thick. Restricted to a layer of coarser grain size, 45mm wide, in the lowest part of the sandstone bed, is a sporadic development of galena. It forms the cement of the sand in places, but in others has been precipitated on marl clasts or is associated with calcite in cavernous areas of the sandstone. Providing the sandstone is dry, it becomes very obvious, and occurs in brilliant cleavages up to 5mm across, and in masses as much as 17mm square. When these masses are extracted from the matrix, either by weak acids or mechanically, they are found to be crystallized aggregates, and composed of cubo-octahedra. The sandstone which lies above the one described, and which is parted from it by a mudstone 32mm thick is also sparsely mineralized by galena. This sandstone, which is 36mm thick, is principally cemented by calcite, which in places has been replaced by very finely granular galena. Because of this replacement phenomenon and the crystallized form adopted by the galena in the lower sandstone unit, the writer suggests that the deposit must be epigenetic. No galena in detrital grains has been observed. The mechanism may therefore be a hypogene one and similar to that which caused the deposition of the Tickow Lane ore body, and not the product of remobilization as seen in the copper mineralization at the same locality (K5367-73).

Subsequently, galena was found in the basal breccias of the Mercia Mudstone Group during face clearance on the southern face of Newhurst Quarry. Here it occurred as the sporadic cementation of white sandstone associated with malachite and hematite pseudomorphous after coulsomite.

- (iv) At the Gypsy Lane Pit worked by the Leicester Brick and Tile Company Ltd. (Nat. Grid Ref. No. SK 617069), galena occurs as small masses (average: 8mm in diameter) and as a cementing medium within skerry bands (thin calcic-dolomitic-barytic-cemented sandy limestones) present in the Mercia Mudstone Group, especially in the Blue Anchor Formation (Warrington et al., 1980, p. 40) (K8430-73).

The skerries, which are frequently rich in "salt pseudomorphs" most commonly on their bottom surfaces, also show small-scale current bedding features which are often brought into sharp relief by the deposition of galena on the bedding planes (K8431-73). The skerries are frequently full of small vughs which occupy persistent planes horizontal to the top surface of the skerry. They are usually lined or completely filled by crystalline baryte which may sometimes be in association with galena (K8432-73).

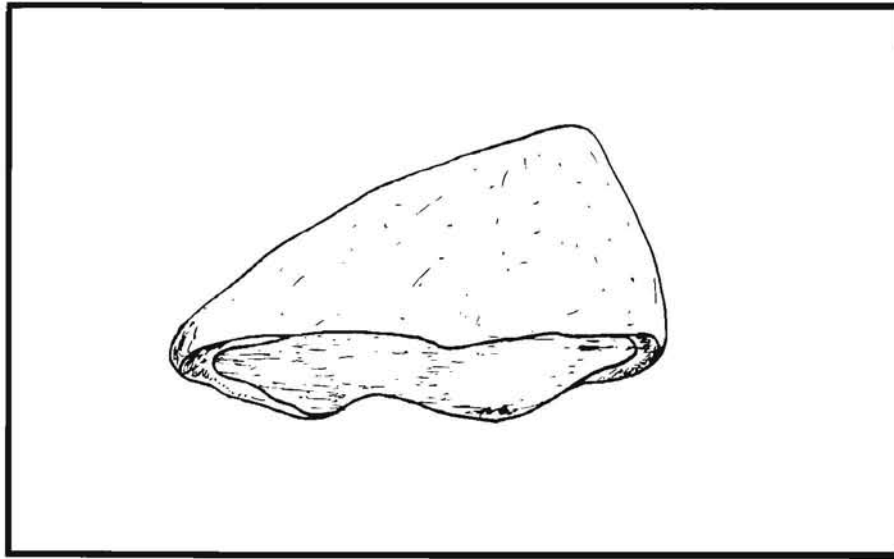


Figure 3.

Sketch of a typical nodule of galena from the sand-filled "fault" at the northern end of Tickow Lane Mine, Shepshed, Leicestershire.

Access

Legal access to quarries and certain other geological sites in Leicestershire referred to above is difficult and in some cases impossible. Much of the data accumulated dates from happier days when access was relatively easy.

There is no access to the quarries at Breedon-on-the-Hill, though there is limited access to the Gypsy Lane Pit worked by the Leicester Brick and Tile Company.

Two quarries are abandoned, though access on a limited scale may be possible in the long term. Newhurst Quarry at Shepshed is currently flooded and the former Main Quarry at Mountsorrel is being filled in to a certain level by industrial waste.

Although there are no mineralogical exposures visible at the site of the former Earl Ferrers' Lead Mine at Staunton Harold (Dimmingsdale), permission to enter what is now a nature reserve may be obtained through the Administrative Officer of the Leicestershire and Rutland Trust for Nature Conservation Ltd.

Opencast coal mining sites are transient operations, but it is possible to obtain access by seeking permission at site offices.

Bona fide research workers are welcome to go down the Tickow Lane Lead Mine at Shepshed, and permission to do so may be obtained through contact with any officer of the Russell Society.

Acknowledgements

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AN OCCURRENCE OF WULFENITE, ANGLESITE AND NATIVE SULPHUR IN THE OPENCAST ABOVE BALL EYE QUARRY, CROMFORD, DERBYSHIRE

T.F. Bridges

Abstract

Wulfenite, anglesite and native sulphur are reported in well developed crystals from a small flat of galena in an abandoned fluorite working in the Via Gellia near Cromford in Derbyshire. It is thought that the supergene association results from the development of low pH conditions produced by the oxidation of pyrite in a contemporaneous Dinantian lava.

Introduction

Although first reported in the 19th century, anglesite, native sulphur and wulfenite are all very rare Peak District minerals.

The first reference to anglesite is by Greg and Lettsom (1858, p. 394) who noted its occurrence at several localities in Derbyshire, including Rent Tor near Wirksworth. Native sulphur was noted as occurring at several localities by Mawe (1802). Mawe also mentions wulfenite as occurring at Odin Mine, but this does not seem to have been confirmed.

In 1977 and 1978 all three minerals were found by the writer in crystallized form, in the opencast quarry on the site of the Ball Eye Mine, Matlock. This find is described and discussed below.

Situation

The Ball Eye limestone quarry is situated on the north side of the Via Gellia, near Cromford at GR. SK 287573. Directly above the main quarry, to the north-west, is the abandoned fluorite working under consideration. At the time of working, it was known as the Masson Opencast, a name which is now potentially confusing in view of other workings on Masson Hill.

History of the working (Speed, 1982, Personal communication).

The old Ball Eye Mine worked lead veins on the south side of Masson Hill over several centuries. Activity was still in evidence as late as 1939 when Messrs. Derbyshire Stone Company were extending the old workings in the search for galena.

At this time Mr. P. Speed was searching for fluorite for the steel industry and old notes by Dr. H.H. Bemrose indicated the south side of Masson Hill could be of interest. A survey showed the presence of significant quantities of fluorite and the Derbyshire Stone Company commenced underground exploitation of this in 1940. However, the deposit proved dangerous to work by underground mining techniques and when it was realised the fluorite extended nearly to the surface, opencast working started in late 1940/early 1941.

The writer is not certain when fluorite opencasting ceased, but in the mid 1970's, the limestone ballast quarry was encroaching into the south-east side of the then abandoned fluorite working. The quarry workers occasionally dug into the bottom of the opencast adjacent to the Bonsall Fault which bounds the fluorite working to south-west. In so doing in 1977 several blocks of galena were brought to the surface and in 1978 a small flat of galena was exposed in situ. Cavities in the latter provided most of the specimen material described below, although minor anglesite and a fine specimen of cerussite after anglesite were found in the loose blocks.

Geological and Mineralogical Setting

The main quarry is working Dinantian limestones of late D₂ age. The Bonsall Fault runs into the quarry and is clearly visible in its northwestern face. As stated previously, the Fault forms the southwestern boundary of the old fluorite working above the quarry, as is evidenced by marked slickensiding in places on the wall.

In the main quarry, the fault is most distinctive, since the Matlock Upper Lava, which is clearly visible high in the quarry wall to the east of the fault, is faulted out to the west of the fracture zone.

The lava flow, which is dipping gently to the south or southeast, is capped by up to 8m of dolomitized limestone in the region of the opencast. It is this dolomite, above the lava flow, which has been substantially replaced by fluorite.

The bulk of the replacement resulted in a brown sugary fluorite matrix, but crystalline minerals formed in cavities, viz:

- a) Fluorite - abundant as colourless, pale yellow and pale purple to deep purple cubes.
- b) Calcite - also abundant as large cleavage masses and subhedral scalenohedral crystals to 200mm in length.
- c) Baryte - less frequent than the above, but easily found as buff to orange coxcomb crystals and white to pink crystalline masses.
- d) Pyrite - this occurs in the lava flow often as perfect small cubes to 5mm on edge.
- e) Limonite - iron ochres are much in evidence at the top of the lava flow.

The above are the only minerals to be found in quantity in the working. In addition to the minerals to be discussed below, small amounts of smithsonite, azurite, malachite and wad have been identified.

The Galena Based Occurrences

Cavities in the loose blocks of galena found in 1977 were largely lined with small stubby subhedral crystals of cerussite to 2mm in length. Intergrown with cerussite crystals in some minor cavities were colourless "sword-shaped" blades of anglesite up to 3mm in length. The most remarkable feature of the blocks were large crystals of cerussite up to 35mm in length with the crystallography of anglesite. These crystals were opaque, have ill-defined edges and show clear crystallite formation on their surfaces. They are clearly pseudomorphs of cerussite after anglesite.

The small flat of galena revealed in 1978 is illustrated in Plate 1. The galena reached a thickness of 11cm. The flat lay directly on top of the lava flow and was capped by dolomitized limestone. There was much ochrous clay above and below the galena.

Breaking out some of the galena revealed numerous small cavities, some of which showed cubo-octahedral face development. When free from ochre, these cavities could be seen to be lined with small crystals of a variety of minerals. Some of this material was removed for microscopic examination and the minerals found will now be described in more detail.

a) Anglesite

By far the commonest mineral in the cavities, occurring in crystals up to 10mm across. The larger crystals showed little to no distinct crystallography and lustre was poor. The smaller crystals frequently showed the "sword-shaped" crystal structure mentioned previously, although distortions in the terminations were common. Many of the crystals in the 2 to 3mm size had a good vitreous lustre.

Identification – Wet chemistry.

b) Cerussite

Much less frequent than anglesite, other than in ochrous surface cavities in the galena. Crystal shape was variable, but frequently showed good tabular orthorhombic symmetry. Pseudo hexagonal twins with pyramidal terminations also occurred. Sizes reached 2mm and many of the crystals had a near vitreous lustre.

Identification – Wet chemistry.

c) **Native Sulphur**

Within the cavities were numerous small yellow crystals of native sulphur showing good face development, though the faces usually had an etched appearance. The crystals were all under 1mm in size.

Identification – ignition.

d) **Fluorite**

By no means abundant in the cavities, a few small (2mm max.) colourless cubes of fluorite, all showing bevelled edges, were found.

Identification – visual.

e) **Wulfenite**

Inside different cavities, the writer found 3 crystals which remained unidentified for several years. These have subsequently been shown to be wulfenite. Two of the crystals are virtually colourless, with a faint yellow tinge. The third is a pale orange yellow colour. All are under 1mm in size and have a similar shape – a square based truncated pyramid, the degree of truncation varying from crystal to crystal.

Identification – SEM/Xray,
including comparison with known wulfenite.

Discussion

Ground water in a limestone district tends to become saturated with calcium and carbonate/bicarbonate ions. The commonest secondary lead mineral to occur in this type of environment is cerussite.

Anglesite cannot exist in equilibrium within such a system, which accounts for the rarity of anglesite in limestone areas. Its occurrence is normally restricted to small micro environments which do not approach a carbonate equilibrium status.

In the opencast of Ball Eye, it is quite apparent that conditions favoured the formation of anglesite over a region at least several metres across and probably for a substantial period of time, judging by the size attained by some of the crystals. It is interesting to speculate on the circumstances permitting this to happen.

It is difficult to judge the line of the original land surface in the region of the flat, but the overburden of rock could have been as little as 3m and was certainly well above the water table. The necessary oxidation conditions are thus easily explained.

The lava flow would have presented an impermeable layer to ground water, but proximity to the Bonsall Fault would have provided good drainage.

Despite the intense fluorite replacement in the area, the basic rock still retains a high carbonate level. Ground water must have tended to accumulate carbonate ions in the course of passing through the rocks, but might well have been some way from true equilibrium status by the time it became ponded by the lava layer. The latter contains much pyrite and oxidation of this could readily have provided sufficient sulphuric acid to lower the pH of the ground water to the point where anglesite formation was favoured. There are two pieces of evidence indicating this did in fact occur.

- a) The presence of considerable quantities of limonitic ochre around the deposit, this being the ultimate end product of the oxidation of pyrite.
- b) The native sulphur could have been derived from the oxidation of the galena or the pyrite, but in view of the clean nature of the cavities (free from limonite) probably the former. In either case, sulphur only forms as the result of sulphide oxidation at relatively low oxidation potentials and low pH.

A good treatment of the geochemistry underlying the above discussion is to be found in the well known work by Garrels and Christ (1965).

The wulfenite must be the result of the presence of molybdenum at a low level in the groundwater, but there is no evidence to suggest the source.

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Plate 1

KEEPING RADIOACTIVE MINERALS: SOME PRACTICAL ADVICE

R.P. Hicks

Abstract

The hazards of keeping radioactive minerals are outlined, and some measures are suggested for the private collector to deal with these problems.

The only significantly radioactive minerals are compounds of uranium and thorium. Their radioactivity comes from the spontaneous nuclear decay of these elements and their natural breakdown products.

There is always a low level of radioactivity in the environment but sources of higher level, including radioactive minerals, can be harmful and should be treated carefully. For safety in hospitals and industry, for example, radiation in accessible areas must be kept to specified levels; meters used for this purpose are much more accurate and expensive than the Geiger counters possessed by some amateurs.

With radioactive minerals the hazards arise from radiation emitted directly by the specimens, from swallowed and inhaled mineral particles, and from inhaled radon gas products. Although an amateur with only a few small specimens takes only a small risk, it should be a general principle to reduce radiation exposure to the minimum that can reasonably be achieved. A collector with more or larger specimens should be aware of the possible hazards, especially from uraninite (pitchblende), which is generally the most radioactive mineral. Bearing in mind that some minerals can be hazardous in other ways, the purpose of this article is to help collectors deal with the problems of radioactivity.

Storage

The basic principle is to store radioactive specimens away from people, outside the house if possible.

The strength of radiation decreases by the square of the distance from the source, thus, at two feet the level would be one quarter of that at one foot from the source and at three feet it would be one ninth and so on. This is one reason why the store, if it is inside, should be kept away from areas that are occupied, such as living rooms or bedrooms. If the store is within the house it should be sited against an outside wall, or one with a space such as a cupboard on the other side. In general, radioactive specimens should be put at the back of storage drawers or cabinets; and it may be desirable to have a lock on the store.

An air gap of at least two or three feet is generally effective enough for it not to be worth the effort and expense of using lead for shielding. Boxes made of two or three thicknesses (up to ¼" total) of roofing lead may be used as additional protection for larger specimens, but without an accurate meter the precise effectiveness cannot be determined.

As mentioned before, dust (dealt with under Handling) and radon can constitute a hazard through inhalation. Radon and its decay products are radioactive; small amounts are constantly produced and diffuse into the air (in the room) around the specimens. Concentrations can be avoided by not breathing in directly over freshly opened drawers; but to avoid the problem entirely the specimens should be stored, as previously recommended, outside the house. If the specimens have to be indoors, they should not be kept in bedrooms or living rooms.

Handling

The hazards here are twofold: radiation from the specimens, and from radioactive mineral dust which may contaminate the skin and be swallowed or inhaled. Radiation exposure can be reduced simply by restricting handling times; and the problem of dust is best overcome by keeping the specimens in sealed containers. Doing this not only prevents skin contamination, but also stops loose dust being dispersed into the air; it does not prevent radon gas from escaping. If this is not done, then it is sensible to wear washable rubber gloves, and even a dust mask. If gloves are not worn it is recommended that the hands are thoroughly washed with soap and water. This should be routine, even after handling sealed specimens, as a precaution against leaks. When handling specimens or washing afterwards always take great care not to contaminate food or food preparation areas.

If the problems sound too alarming, or the collector wishes to avoid even the slightest risk, it is best not to collect radioactive minerals at all. On the other hand a collector wishing to specialise in radioactive minerals would be wise to seek expert advice and perhaps monitoring; in which case the National Radiological Protection Board is the authority to contact.

The display of radioactive minerals will be dealt with subsequently in a future section, but, as a preliminary exercise it would be useful to read Hicks (1983).

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THE CARE OF MINERALS
Section 2
THE DEVELOPMENT OF MINERALS

Robert J. King

Abstract

Section 2 – The Development of Minerals, the second section of eight planned sections on the Care of Minerals, examines the development of minerals in the palaeontological sense. This concept, as opposed to cleaning *sensu stricto* describes the removal, by chemical processes, of associated minerals of a mineral paragenesis. The development techniques chosen it is hoped, will expose the more desirable underlying minerals in as chemically mild a manner as possible. The two principal development techniques: (a) removal of iron dioxide, and (b) removal of manganese dioxide have been dealt with at length. A list of common minerals, together with their recommended development techniques has been added. There are two appendices: 1. A list of chemicals referred to in the text with the hazards of using them, and 2. mechanical extraction – tools recommended.

Introduction

As explained in Section 1 (King, 1982, 42-53), there is a strong division of opinion about what constitutes cleaning in mineralogy. Traditionally in Britain the word cleaning has been used to mean the physical removal of material such as dust, smoke blackening, etc. alien to the paragenesis of a mineral specimen.

In other countries the word cleaning in mineralogy is used in a wider sense and involves, not only the physical removal of dust etc., but also the chemical removal of associated minerals. Such a constitution is better described as development, as used in the palaeontological sense. It is in this latter sense that this section on the care of minerals examines the artificial modification of a mineral paragenesis.

There are many situations where development techniques are employed, but a limited number have any positive scientific benefit. The majority are employed in an attempt to enhance the aesthetic appearance of a specimen, by the removal of what are thought to be unsightly coatings or overgrowths of associated species. Such development will always be used by the amateur. In this section an attempt has been made to direct his steps into a more enlightened and rational approach to development. Before embarking on any developmental procedure, the amateur collector must therefore consider the ethics of his action. He should remember that each mineral specimen is unique and that he, as its custodian, should ensure that it retains its full scientific potential as part of the natural heritage.

There are more arguments against the use of development than there are for it. They include:

1. The destruction of a natural association of mineral species, by the removal of one or more associates, resulting in the loss of scientific interest in that association.
2. The etched and unnatural anaemic appearance following the use of chemicals, results in the loss of scientific and often aesthetic value.
3. There can be no standard application of a development technique. No two mineral associations respond to a chemical reaction in the same way, and destruction of more of the paragenesis than is intended may follow.
4. The use of chemicals may produce chemical imbalance which may be difficult or even impossible to neutralize.
5. The removal of chemicals used in a development technique, both chemically and physically can produce additional long term risk to mineralogical material, its label and immediate storage area.

It must be recognised that, for certain classes of common minerals, development cannot be thought of as a significant threat. There should be, nevertheless, a code of practise with regard to development and a set of rules which should be strongly adhered to.

1. Always consult a competent mineralogist about:
 - (a) The ethics about what you propose to do.
 - (b) The suitability of the material you intend to develop.
 - (c) The suitability of the technique you intend to use.
2. Always use the mildest technique available.
3. Always seek to gain more than you destroy.
4. If several specimens are available, always use the least important first. If only one high quality specimen is available, then try the technique on an inconspicuous part of the specimen first.
5. Always record precisely what you have done. This data should be in the form of itemized notes which should either accompany the developed specimen or be entered in the collection register. This will enable the person subsequently responsible for the specimen to understand its atypical appearance and its possible chemical misbehaviour.

In a limited number of situations development has clear and positive scientific benefit. In such cases better quality material may be used. The development should be done, either by an expert, or by the amateur under supervision by an expert.

In this category there is usually a strongly differing degree of reaction to acid attack, by individual minerals of an association. The more resistant, and desirable remain while the less resistant and undesirable are removed in solution. Thus the beauty of crystallization of native gold embedded in calcite is revealed by development. Similarly, little would be known about the silicate minerals embedded in calcic marble from the St. Lawrence Valley of New York, USA, without development. The beauty of form and colour of benitoite from California could not be appreciated unless the natrolite, in which it is naturally embedded, had not been gelatinized and removed in acid solution.

There are development techniques common to many species. These include the removal of iron and manganese dioxides and the removal of encrustations of silica. A selection of recommended techniques is set out under the headings:

- (a) Removal of iron dioxides.
- (b) Removal of manganese dioxides.
- (c) Removal of silica encrustations.
- (d) A selected list of minerals and their recommended development.

No attempt has been made to itemize techniques, many of which have been modified to react more efficiently with select species while remaining as mild as possible.

Warning:

Many of the chemicals recommended below are extremely dangerous, either because of their short or long term toxic effects, or for other reasons. It is vital that all work with chemicals should be done in appropriate conditions, with adequate fume disposal and protective clothing. Appendix No. 1 lists the chemicals quoted below and adds the possible medical effects following exposure to them. TLV and STEL, both registered abbreviations are given, where available, as a guide to the toxicity of the listed chemicals. TLV stands for Threshold Limited Value, i.e. the recommended maximum average concentration in air of a chemical over a weekly period of 40 hours. The lower the value, the more toxic the chemical. STEL stands for Short Term Exposure Limit, i.e. the maximum recommended concentration of a chemical in air for an exposure limit period of 15 minutes, with 60 minutes between each period of exposure.

(a) Removal of hydrated iron dioxides

Perhaps the most common of all films are those caused by the yellow to brown ferric dioxides which appear on many minerals, especially silica and the silicates. Many amateur mineralogists will go to almost any length to remove them and the methods advocated are varied to the point of being haphazard. Many of these techniques are chemically far too strong and will destroy many of the associated minerals present. The development will also give, for example, an original group of iron-coated quartz crystals a distinct, unnatural and anaemic appearance. Iron-coated quartz crystals may be characteristic of the locality and it is bad curatorial practise to modify such an association.

Most techniques using mineral acids rely on the increased solubility of ferric hydroxide in acidic solutions and the ability of the anion to sequester ferric ions. Following such development, attempts to basify the acid produces ferric hydroxide which seeks out cleavages, crystal interstices, etc. from where it is almost impossible to remove it.

Following acid treatment frequent changes of water are advisable in all washing operations. Dirty water can leave deposits on crystal surfaces which are nearly as hard to remove as the original coatings. It is wise to check the tapped hot water supply used for the presence of ferruginous compounds. High concentrations of iron compounds may be produced by badly maintained boilers. It is also wise to check the cold water supply for the presence of hardness. If the supply is too hard it is advisable to use rain water or distilled water for washing, though the latter is expensive. Careful flushing, even with hard water, will remove the scums and deposits which may be present after using soap in hard water.

There are milder techniques available for the removal of iron oxide coatings which will leave the majority of the associated minerals intact and relatively unharmed. Some of these are described below. It should be pointed out that the following techniques are intended for the removal of thin films of hydrated ferric oxides, not deposits of goethite or hematite. The difficulty of removing the film increases with its degree of crystallinity.

1. The Waller Method

Films of ferric hydroxide may be dissolved in neutral solutions containing sequestering anions, thus avoiding the low pH conditions which destroy many associated minerals. Waller (1980, p. 109) has developed further a technique described by Mehra and Jackson (1958, p. 317). The Waller Method makes use of the fact that ferrous hydroxide is not only more soluble than ferric hydroxide but is more soluble over a wider pH range. This technique, is perhaps the mildest and most efficient of all.

The method involves the use of three sodium salts: Sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$), to sequester ferrous ions; sodium dithionite ($\text{Na}_2\text{S}_2\text{O}_4$) as a reducing agent; and sodium bicarbonate (NaHCO_3), as a buffer to maintain neutrality. A stock solution of sodium citrate and sodium bicarbonate is made up by dissolving 71g of sodium citrate and 8.5g of sodium bicarbonate in a litre of distilled water. As sodium dithionite is readily oxidized in solution it must be added to the formulation when required.

Technique

1. Place the specimen to be treated in a suitably sized glass or plastic container.
2. A premeasured volume of the stock solution, sufficient to cover the specimen, is poured into the vessel.
3. Add one gram of sodium dithionite to every 50 mls. of stock solution used.
4. The solution should be stirred regularly. It will remain active for about 12 hours at room temperature (c. 20°C). After that time the sodium dithionite will have completely oxidized. If any iron films remain, a fresh solution should be made up and used.

5. Following treatment the specimen should be immersed in distilled water for periods of time depending upon the nature of the material. Should it be porous or highly cleaved rinsing time should be increased accordingly.

This method is very good for removing amorphous hydrated ferric oxides on such minerals as quartz and many silicates. However there are limitations to its employment. For example, pH sensitive minerals should not be treated, especially highly soluble calcium minerals such as calcite and aragonite, because citrate sequesters calcium as well as ferrous ions.

Following the use of the above technique it is vital to carefully examine the treated material regularly over several months, and any instability recorded and dealt with by re-immersing the material in distilled water.

2. The Bridges' Method

A modification of the Waller Method also using sodium dithionite as a reducing agent was evolved by Mr. T.F. Bridges (Personal communication, 1982).

Technique

1. Place the specimen to be treated in a suitably sized vessel.
2. Add enough water to cover the specimen.
3. Add one gram of sodium dithionite per 200 mls. of water. (A level teaspoon to one litre of water). Stir to dissolve.
4. Leave for 24 hours.
5. Should the iron coatings persist discard the solution and replace with a solution of ammonium citrate $((\text{NH}_4)_3\text{C}_6\text{H}_5\text{O}_7)$ -20g per litre of water – and 2g of sodium dithionite.
6. Stir to dissolve and leave for a further 24 hours.

It may be necessary to repeat the technique several times if the coatings persist.

In both the Waller and Bridges' techniques the chemicals are expensive, but the ammonium citrate solution may be re-used and, should it become discoloured, re-charged by adding a little sodium dithionite. Both techniques should be conducted where there is adequate fume disposal and the use of lidded containers are essential, as sodium dithionite rapidly oxidizes in air.

3. The Sodium Citrate Method

This technique was evolved to remove iron "staining" from calcic marbles, but its application to carbonate minerals is just as effective.

A paste is made up by thoroughly mixing together one part of sodium dihydrogen citrate $(\text{NaH}_2\text{C}_6\text{H}_5\text{O}_7 \cdot \text{H}_2\text{O})$ with six parts of glycerine and finely powdered chalk. The paste is placed on the iron "stain" in several applications as each dries.

An alternative method, if the surface of the specimen is delicate, is to flood the iron film with a solution of one part of sodium dihydrogen citrate to 6 parts of water. This should be followed by flushing the same area of the specimen with a solution of sodium hydrogen sulphate $(\text{NaHSO}_4 \cdot \text{H}_2\text{O})$. In both cases etching of calcite will take place and the operation should be done as quickly as possible and be followed by thorough flushing in water.

4. The Oxalic Acid Method

There are several variations of this method. Of these the technique described below is perhaps the least offensive to specimen and technician.

Technique

1. The iron coated specimen is first carefully washed in luke warm water to remove any loose films and to test for any signs of structural weakness which might lead to disintegration in subsequent physically vigorous stages of the method.
2. The still wet specimen is placed in a Pyrex bowl sufficiently large that, when half-filled with liquid, the specimen is completely immersed.
3. A 5% solution of oxalic acid ($(\text{CO.OH})_2 \cdot 2\text{H}_2\text{O}$) in distilled water is poured over the specimen to completely immerse it.
4. A strip, about 30mm wide of aluminium foil (0.51mm thickness is ideal) is placed in the acid making certain that it is in contact with the specimen. Granulated zinc may be used in place of the aluminium with almost equal success.
5. The acid is brought slowly to the boil and then allowed to simmer until the film is lost. Should the acid solution become strongly discoloured, it should be discarded and a fresh quantity of acid used. Then the procedure should be repeated.

To prevent the possibility of a burst vessel, it is an advantage to use a double-boiler, where the inner acid container is heated by an outer water bath, which may be of metal. A Pyrex bowl in a saucepan of boiling water is an ideal arrangement.

An aluminium saucepan may be used instead of adding aluminium foil, but care should be taken that corrosion of the saucepan bottom has not proceeded to the point of collapse.

6. The now developed specimen is removed from the acid and placed in another vessel through which running water is passing.
7. Finally, the specimen is checked for remaining acidity by immersing it for one hour in a bowl filled with distilled water. This water is tested with litmus paper at the end of that period. If acidity is still present, the specimen is soaked for a further period in fresh distilled water, and checked until the water is neutral. No attempt should be made to basify the solution.

Should the film prove stubborn no further action should be taken. Increasing the concentration of the acid or reversion to the use of mineral acids jeopardizes the stability of the paragenesis.

5. The Tartaric Acid Method

Foshag (1954, p. 39) described a technique for removing "rust" from quartz crystals using tartaric acid ($(\text{CHOH.COOH})_2$). The "rust" covered specimen is immersed for several days. The period depends on the thickness of the coating of ferric dioxide. The strength of solution of the tartaric acid should be as low as possible and not exceed 5%.

Foshag recommended tartaric acid rather than mineral acids or oxalic acid for the following reasons: hydrochloric acid usually produces an undesirable precipitate of ferric chloride, and similarly oxalic acid often produces insoluble residues of calcium oxalates.

6. The Hydrogen Sulphide Method

This widely used method, was developed by Drosdoff and Truog (1935, p. 669), for the removal of ferruginous films from detrital minerals. It involves treatment with a concentrated aqueous solution of hydrogen sulphide (H_2S) adjusted to pH 7 with ammonium hydroxide (NH_4OH). The iron sulphides thus formed are removed by washing with dilute (0.05N) hydrochloric acid (HCl). The specimen is then washed with alcohol, carbon disulphide (CS_2) and again with alcohol to remove water and sulphur, and finally dried.

It is a complicated process best carried out under strict laboratory conditions. Apart from the dangers to the specimens by repeated handling during treatment, it is a technique kind to parageneses.

Technique

1. Place the specimen to be developed in a vessel which may be tightly stoppered.
2. Half fill the vessel with distilled water, ensuring that the specimen is covered by the water.
3. Bubble hydrogen sulphide gas through the distilled water in the vessel until saturated. Any iron films present are converted to iron sulphide.
4. Add Normal strength ammonium hydroxide. The quantity should be about 1% of the quantity of distilled water in (2), to adjust the solution to pH 7.
5. Agitate the solution vigorously.
6. Add dilute (0.05N) hydrochloric acid until the solution has become acidified (test with litmus paper) and the iron sulphides have been dissolved.
7. Flush the specimen with running water for an hour and allow it to dry.

The above chemical reaction may release sulphur in the form of pale yellow greasy-looking films or globules. This can be removed by washing the specimen first in a solution made up of one part carbon disulphide and two parts of ethyl alcohol, and then in ethyl alcohol alone to remove all traces of carbon disulphide.

There are obvious limitations to the use of this method. Not only is it an involved process, demanding the application of strictly controlled laboratory conditions, but also as associated carbonate minerals are affected.

7. The Hydrochloric Acid Method

Although widely used in the United States of America (Gordon, 1947, p. 589) and has even been recommended for use in British museums (A.E.M., 1942, p. 168), this method has been rightly condemned by various workers, for example Davidson (1942, p. 292). Even if the mineral to be developed is acid resistant, there are many associated minerals which would certainly be destroyed by immersion in any concentration of hydrochloric acid, and many more in the hot concentrated acid, which the method advocates.

To quote from Davidson's paper; ". . . the danger of these operations may not be apparent to the non-specialist A group of minerals which has undergone acid treatment in the museum laboratory is no longer truly representative of a natural occurrence, and its scientific value is less than that of a similar, but untreated specimen". Although Davidson was addressing museum curators, the point he was making is just as relevant to all mineral collectors. Their mineral collections may have research interest to scientists. The collection itself may be bequeathed to a museum or individual specimens ultimately find their way into the hands of a museum curator.

Not only does the use of hot concentrated hydrochloric acid pose a direct threat to the mineral and/or its associates, but may also pose serious longer term post development problems to the specimen (Pearl, 1973, p. 33).

In short the method should **NEVER** be used.

(b) Removal of Manganese dioxide deposits

Removing manganese oxide coatings is a far more difficult process than removing iron oxide films; the rate of success is less and the number of satisfactory techniques available are few.

The large majority of manganese dioxide coatings are of pyrolusite or psilomelane, in the form of dendrites or microcrystalline encrustations. These coatings can be removed from the surfaces of other minerals using hydrochloric acid (preferably dilute). Concentrated acid can be difficult to remove subsequently. Both pyrolusite and psilomelane are insoluble in nitric acid, a fact made use of in the development of both species.

Sinkankas (1970, p. 299) suggested the use of hydroxylamine hydrosulphate ($(\text{NH}_2\text{OH.H})_2\text{SO}_4$) but the chemical implications to the specimen of using this method have not been fully investigated. In both processes the time factor for immersion in hydrochloric acid in the first case, and hydroxylamine hydrosulphate in the second is a matter of experiment, but the shorter the time the better. Both immersions should be followed by flushing in a copious flow of water.

Manganese dioxide minerals often form an integral part of the paragenesis of a mineral. Their removal thus normally destroys the true scientific interest of the specimen. In addition, having been removed, the manganese dioxides leave a physical mark of their former presence. In the writer's view this mark diminishes even the aesthetic value of the specimen. In short the difficulty of removing manganese dioxides is a non-problem — it should never be done.

Brannock (1970, p. 45) has recommended using a saturated aqueous solution of sodium metabisulphate ($\text{Na}_2\text{S}_2\text{O}_5$) at room temperature to remove thin films of manganese dioxide. Note that the sulphur dioxide fumes evolved by this reaction are highly toxic — do it in a fume cupboard.

(c) The Removal of Silica Encrustations

Thin encrustations of silica, usually in the form of chalcedony, often coat older generations in a paragenesis, and may reduce the lustre of underlying minerals, or even mask them completely. Providing these encrustations are thin and insoluble in water or normal acids, then it is possible to remove them by the careful application of dilute solutions of hydrofluoric acid (HF).

In the same way other silicates can be removed from the surfaces of minerals. Chlorite, for example, is frequently etched away from the faces of quartz crystals. Not only will the quartz look atypical after this treatment, having lost several of its physical features, but much of the crystallographic data will be less apparent since twinning faces of quartz are often selectively chosen by chloritic overgrowths. For this and other reasons much of the scientific interest of the specimen will be lost.

Better chemical control can be achieved by using ammonium bifluoride (NH_4HF_2), which releases hydrofluoric acid when dissolved in warm water. The reaction can be inhibited on etched surfaces by the application of films of beeswax in acetone.

The use and production of hydrofluoric acid and ammonium bifluoride must be confined to strictly controlled laboratory conditions, and then only by an experienced technician.

Silica and silicate encrustations are essentially part of the paragenesis of the specimen. Their removal can only destroy the scientific value of the specimen. The unnatural appearance, and thus the loss of aesthetic value; the long term stability problems and the loss of data resulting from development must be regarded as an act of vandalism.

(d) A Selected List of Minerals and their recommended development techniques

It is impossible to provide a complete list of minerals and the techniques recommended for their development here. However an attempt has been made to select species which the collector most likely has in his care, and which he may consider require development for some special purposes. The list may allow the application of certain techniques to unlisted species of similar physical and chemical characteristics.

Amphibole Group

Members of this group are frequently embedded in calcic marbles from where they can be developed by using dilute acids. Acetic acid at concentrations not exceeding 3% is ideal. Many amphiboles are strongly cleaved and the strong effervescence induced by strong acids can open the cleavages. Neither hydrofluoric acid or solutions of ammonium bifluoride should be used as both will seriously etch members of this group.

Andalusite

Films of iron oxide can be removed by using the Waller method. No attempt should be made to remove such alteration products as mica or kyanite which would involve the use of hydrofluoric acid.

Apatite

Apatite, especially carbonate-apatite (such as francolite), is soluble in mineral acids, which should therefore not be used. Fluor-apatite or hydroxyl-apatite in calcic marbles can be developed by mechanical means by using a Vibrotool or Airpen (Appendix 2). However some success can be achieved by prolonged treatment in weak solutions of acetic or oxalic acid, taking care to coat the apatite as it is developed with a weak solution of cellulose acetate (Rawlplug Durofix thinned with acetone is adequate).

Arsenopyrite

All sulphides and sulphosalts should be handled with great care, for all should be classified as metastable to varying degrees. Their instability may result merely as a tarnish but, on the other hand, may result in complete disintegration of the specimen. Although Bertrand (1962, p.1) recommended the use of hydrochloric and sulphuric acids to "clean" arsenopyrite, the use of strong chemicals should not be countenanced.

Thin films of hydrated iron oxide on the surfaces of arsenopyrite may be removed by using either the Waller or Bridges' methods (see (a) Removal of Iron dioxide). However the writer recommends that no chemicals are used at all. The loss resulting from chemical action far outweighs any marginally rewarding "improvement".

Baryte

Films of iron oxide may be removed by any of the techniques described above, providing the films are not crystallized.

Benitoite

This barium titanium silicate is associated with natrolite in which it is usually completely embedded, and from which it can be extracted by using concentrated solutions of hydrochloric acid. The natrolite is gelatinized by the acid and can be washed away in water, thus exposing the euhedral crystals of benitoite.

Beryl

Hydrofluoric acid has been recommended (Bertrand, 1962), p. 1) for the removal of associated silicates such as clay minerals or cookeite. From experience the writer finds that using ammonium bifluoride also causes damage. Serious etching of the beryl can result using either method. The association is best left alone.

Bornite

Films of iron oxide are sometimes present on bornite. They can be removed by soaking the mineral in a 25% solution of oxalic acid for a maximum of 8 hours. A study of oxidizing bornite can prove to be interesting, the products of such natural chemistry often being of more scientific importance than the bornite itself. Bornite which has been subjected to oxalic acid development is subsequently particularly prone to rapid tarnish.

Calcite

Although there are many techniques available for the removal of calcite, there are none which may be recommended for its development at the expense of other species. Furthermore, development techniques leave their mark on the calcite, which may develop on unnatural high lustre and etched surface both of which are an offence to the eye.

The removal of slight discolouration on calcite may sometimes be effected by using sodium hypochlorite solution (NaOCl) and this can work equally well on other light coloured carbonates. Dipping the specimen in warm water before hand enhances the reaction.

Calcite easily bruises and many specimens will acquire such blemishes resulting from extraction damage in the field and from damage caused by mine explosives. Many such bruises may be effectively hidden by carefully applying dilute hydrochloric acid to the bruise with a size 00 paint brush.

Cerussite

When present as acicular or thin prismatic crystals, either in clusters or reticular aggregates, it is extremely fragile and can disintegrate into fragments even from a nearby shock. Furthermore it is readily soluble in dilute acids. From both physical and chemical standpoints therefore, cleaning and development should be avoided. If cleaning is necessary, gentle washing from a wash bottle filled with ethyl alcohol or acetone will rid the specimen of loose dust and manganese dioxide lodged in the crystal interstices. Films of manganese dioxide are impossible to remove and this should not be attempted.

Chalcanthite

Chalcanthite may be cleaned only by carefully painting or by gently flushing the surface from a wash bottle filled with ethyl alcohol (98% preferably), a measure of control against efflorescence is effected in this way. The removal of mineral associates is undesirable but should be attempted only physically.

Chalcopyrite

Crystals of chalcopyrite are often coated with black films of oxidation products such as melaconite. These may often be removed by immersing the specimen in a 2% solution of sodium cyanide (NaCN). Cyanides are of course extremely toxic and should only be used under strictly controlled laboratory conditions. — See Appendix No. 1. Equally good results, without such risk to the technician can be obtained by soaking the specimen in a 6% solution of oxalic acid for approximately 8 hours.

Should films of iron oxide be present on the chalcopyrite it should be carefully noted whether the iron oxides are due to the decay of the chalcopyrite. If this is the case then malachite may also be present and the specimen be representative of an oxidation profile. If this is so it should not be modified. If the iron oxides are due to the decay of associated pyrite or marcasite, then a justified measure of development can be achieved by using one of the techniques described above in Section (a).

Cinnabar

Some common associated minerals may be removed by the application of concentrated acids, but in so doing other rare species will certainly be lost. No attempt at any form of development should be made.

Columbite

Aqua Regia or concentrated nitric acid will remove the iridescent films which sometimes appear on crystal surfaces.

Copper, Native

Native copper is described in most text books as possessing a characteristic rose-red colour. In nature this colour is rare and, because of oxidation processes, the mineral is usually coated by black films of melaconite, green films or encrustations of such minerals as brochantite, atacamite or malachite and is commonly intimately associated with cuprite. These natural associations are considered an anathema by some amateur mineralogists and their removal is the subject of much literature in mineral club magazines. As usual many techniques for the removal of associates are of a vicious nature and some of the more drastic ones have not been considered here. One such popular method employed hydrochloric acid of varied concentrations, but this was rightly condemned by Lee (1935, p. 156) who pointed out that the acid not only removed tarnish and encrustations, but continued its action by etching the underlying copper, dimming the naturally bright surfaces of crystals. He also pointed out that the acid produced an "unnatural rose-red colour". As noted by King (1982, p. 42), this rose-red colour is quickly lost as the mineral rapidly tarnishes after treatment.

Oxidized native copper is a typical and common mineral association, whilst unoxidized native copper is uncommon. There can therefore be no case for development of any kind. Nevertheless, development is carried out for reasons stated above. The techniques described below are a selection considered to be effective while doing as little damage to the paragenesis as possible.

Techniques

1. The Sodium Hydroxide Method (Lee, 1935)

- (i) Mix one part by weight of sodium hydroxide with three parts by weight of potassium sodium tartrate ($\text{COOK.CHOH.CHOH.COONa.4H}_2\text{O}$) and dissolve in 20 parts by weight of distilled water.
- (ii) Suspend the specimen to be developed in the solution for 30-60 minutes, agitating the liquid from time to time.
- (iii) Remove the specimen and rinse thoroughly in running water and allow to dry in warm air.

2. The Cyanide Method (Pearl, 1973, p. 40)

- (i) Dissolve 1.5g of potassium cyanide (KCN) in 500 mls. of distilled water.
- (ii) Soak the specimen in the solution for as long as necessary. It is inadvisable to increase the strength of the solution. The weaker the solution the more effective it is.
- (iii) Wash the specimen in soapy water.
- (iv) Thoroughly rinse in running water and air dry.

The collector is reminded of the great personal dangers in the use of cyanides and their solutions, especially in the presence of fuming acids.

3. The Acetic Acid Method (Burns, 1941, p. 159)

- (i) Dilute glacial acetic acid with ten parts of distilled water.
- (ii) Soak the specimen in the acid solution until the oxidation products are loosened.
- (iii) The specimen should then be flushed thoroughly in running luke warm water. Brush off any loose oxidation products while under the water.
- (iv) Dry slowly in warm air.

This technique, although using acidic solutions, is mild enough to repeat if necessary.

4. The Chromate Method

This is an effective method which is speedy, but it must be followed by efficient washing to remove all traces of the solution.

Mix together 70 mls. concentrated sulphuric acid (H_2SO_4) 90 mls. glacial acetic acid and 30g sodium bichromate ($\text{Na}_2\text{Cr}_2\text{O}_7.2\text{H}_2\text{O}$).

Make up to 4.5 litres with distilled water.

- (i) Soak the specimen in the above solution for as long as necessary.
- (ii) Thoroughly flush with running water and allow to dry slowly.

The solution has a shelf life of about six months in dark cool storage. The technique, while destroying all associate minerals, does not leave native copper in such a metastable state as does the use of hydrochloric acid.

Crocoite

It should be pointed out that the most likely associates of crocoite, such as chromian cerussite and dundasite are rare minerals and will be destroyed even by the use of acetic acid. No development should be contemplated.

Dioptase

Should diopase be present in a mineral association, the use of mineral acids should not be considered in any development programme. Only acetic acid should be used.

Dolomite

Ferroan dolomite is occasionally coated by films of iron oxide. They can be removed by controlled immersion in dilute hydrochloric acid, but the association is best left alone.

Fluorite

Fluorite is usually free from the majority of so-called 'contaminants'. Associated minerals such as siderite, calcite and quartz often greatly enhance the beauty of fluorite and should be left. Occasionally, however, fluorite crystals may be coated by iron hydroxides, possibly resulting from the oxidation of associated pyrite, marcasite, etc.

Fluorite is susceptible to attack by acids, even oxalic acid but, orthophosphoric acid (H_3PO_4) meets with some success while leaving the fluorite relatively unharmed. The specimen should be completely immersed in dilute orthophosphoric acid and placed in a double-boiler. The temperature should be raised to boiling point until the coatings have been removed. This should be followed by flushing the specimen in running water. If acid conditions persist the specimen should be soaked in a dilute solution of sodium bicarbonate ($NaHCO_3$) until neutrality is achieved.

Galena

Galena readily and naturally forms a protective skin or encrustation of cerussite, after which oxidation usually ceases. If desired the cerussite can be readily removed using dilute acids, but great care must be taken to prevent the galena from being attacked also. The result is anything but satisfactory. The specimen is left with an unnatural etched surface which greatly reduces its scientific value.

Garnet

Members of the garnet family (with the exception of grossular – see below), are mostly resistant to attack by mineral acids, except hydrofluoric acid, and standard development techniques can be used. Their extraction from marbles may thus be done with ease.

Gersdorffite

Gersdorffite is often highly unstable and will rapidly disintegrate into a green mass of annabergite etc. The processes of disintegration are probably akin to those causing the decay of pyrite and marcasite. Specimens of gersdorffite should therefore be kept completely dry, only dry dusting being used to clean them. The mineral should never be washed using water. Being more robust than either pyrite or marcasite, gersdorffite can be immersed in ethyl alcohol to assist in the removal of breakdown products and to speed the drying process.

Gold

As a naturally occurring mineral, gold is remarkably stable and survives without alteration in environments which would be hostile to many other minerals. It is also an element shy of chemical combination and compounds incorporating gold are restricted to the tellurides, etc. The possibilities for the formation of coloured breakdown products are therefore slight. Sedimentary and some hydrothermal golds, however, may be found stained by iron oxides. These may be removed by employing the Waller or the Bridges' method, which are particularly effective on detrital gold.

The removal of iron coatings and associated minerals is the subject of an extensive literature and the techniques described are many.

Gold is found frequently associated with minerals typical of a gossan environment. The extraction of the gold from such a situation can involve the use of hydrofluoric acid or other strong mineral acids, and produces a completely bizarre, unnatural, and metastable result.

To preserve as much of the paragenesis as possible only three techniques (in addition to the Waller and the Bridges' methods) are described here. These three are not unduly destructive of parageneses and two have their principal use in removing obstinate oxide films on gold nuggets.

Techniques

1. Should the gold be completely enclosed in calcite, it is a relatively easy matter to develop it from its matrix by soaking the gold-bearing calcite in a 3% solution of acetic acid. If stronger solutions than this (or dilute hydrochloric acid) are used, the strong effervescence can disrupt fine gauge wires of gold.
2. Burners (1941) provided a technique for removing obstinate oxide films on gold:
 - (i) Dissolve one part by weight of calcium chloride ($\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$), two parts by weight of sodium hydrogen carbonate (NaHCO_3), and one part by weight of sodium chloride (NaCl) in 15 parts by weight of distilled water.
 - (ii) Wash the specimen in this solution using a soft brush.
3. Pearl (1973, p. 24) recommended a cleaning solution for gold:

Dissolve 31g Potassium cyanide, 31g Potassium sodium tartrate in 1 litre of distilled water.

The solution is most effective if used at temperatures between 65-80°C. Beware the handling of cyanide.

Goslarite

Goslarite is readily soluble in cold water and is commonly associated with other water soluble sulphates. The only likely contaminants are broken fragments from the same association. These may be removed by using ethyl alcohol or acetone dispensed from the jet of a plastic wash bottle.

Graphite

Graphite is unaffected by acids and any contamination present (and there are many possibilities) can often be removed by experimental immersion in a range of them, commencing with dilute acids.

Grossular

Grossular occurs in metamorphosed impure, calcareous rocks or is the product of calcium metasomatism. Thus it is often intimately associated with calcite. This calcite may even be present as internal concentric zones within the crystals of grossular. A development process employing acid cannot therefore be employed. The calcite is liable to be completely etched out of the grossular crystals and complete disintegration can result.

Gypsum

Gypsum occurs in three principal varieties: selenite, fibrous and massive gypsum (including the sub variety alabaster). All are slightly soluble in water, and more so in acids. Although the solubility rates are not high, prolonged immersion in any liquid is undesirable. Development problems associated with all varieties of gypsum are further aggravated by the perfect cleavage of the mineral, shown to perfection in the variety selenite, and to a lesser degree in fibrous gypsum (King, 1982, p. 52). The perfect cleavage on [010] readily permits the infiltration of liquids into the internal structure. Any precipitation from a liquid so entrapped remains as an unsightly film within the crystal, perfectly visible through the colourless cleavage plate. This is strikingly demonstrated if the crystals have been washed in soap solutions. Soaps tend to flocculate in the presence of gypsum. On drying this precipitate leaves an opalescent film along the cleavages.

Crystals of selenite are frequently euhedral and free from mineral associates, especially those from Mesozoic clays. Little need be done other than gentle washing in clean water. There may be a need to assist the deflocculation of the host clay, and this can be done by adding a little sodium bicarbonate to the washing water.

There are other occurrences where selenite is intimately associated with other sulphates such as celestine and carbonates such as aragonite. In these cases the association is usually aesthetically pleasing and the need for development should not arise.

Selenite may also be found in old mine adits and is then frequently associated with other sulphates, many of which are water soluble. Their removal, though relatively easy is undesirable, for it destroys not only the paragenesis but loosens the selenite crystals from the matrix. The specimen is then liable to collapse and strengthening media have to be employed, thus completely destroying any research potential the specimen may have had.

Fibrous gypsum which possesses a chatoyant effect on cut or naturally plane surfaces, has been subjected to a natural process of re-crystallization. Such material is often badly spoilt if washed in soap solutions. Fibrous gypsum has been used extensively during Victorian and earlier times as a lapidary medium, from which works of art and jewellery were created. One such centre of industry was at East Bridgford in Nottinghamshire, where gypsum was mined and worked as a cottage industry. A popular product of this activity were egg shapes of fibrous gypsum designed for ladies to hold in their hands. The fibrous character of this variety of the mineral allowed the natural oils of the hands to darken it. Many museums and privately held mineral collections possess these gypsum eggs and many are in need of cleaning.

Three useful cleaning techniques *sensu stricto* are given below:

1. A paste made up of sodium carbonate dampened with water is packed round the specimen and allowed to dry. This is followed by washing in clean water. While this is usually adequate, should the stain persist, stronger measures have to be employed. See No. 2 below:
2. Kaolin powder is made into a paste with benzene and coated thickly on the specimen and allowed to dry slowly in a closed vessel. Stains caused by handling the gypsum are effectively removed in this way.

Collectors should note that benzene is extremely dangerous (Clydesdale, 1982). See Appendix 1.

3. If the specimen has lost its original high polish, this can be restored by polishing the specimen with finely ground chalk or alumina powder made into a paste with distilled water. It should be applied with a soft cloth or tissue and rubbed gently along the fibrous grain of the gypsum.

Iron, Native

This is a rare and highly metastable mineral. The use of concentrated sulphuric acid as a development medium, recommended by some publications, is quite unthinkable. Preservation from oxidation should be the only priority. This aspect will be examined under Section 3.

Kyanite

Occasionally films of iron hydroxides may coat the crystal faces of kyanite. These may be removed by using any method as advocated under Section (a). Any concentration of hydrofluoric acid will seriously etch kyanite.

Labradorite

Apart from hydrofluoric acid and solutions of ammonium bifluoride most acids in any development process may be used. The play of colours characteristic of display specimens of the mineral is likely to be adversely affected if the mineral is left too long in acid solutions. Long immersion in acids causes problems when the need to basify the material occurs.

Magnesite

This carbonate is readily soluble in warm dilute acids, mineral acids should never be used for development purposes. Acetic or oxalic acids may be used in certain cases. As many associated minerals are chemically resistant to the use of mild chemical methods, the specimen is then best left alone.

Marcasite

This mineral is notoriously metastable, so much so that many mineral collectors will not have it in their collections.

The reaction for both marcasite and pyrite is known as pyrite rot or decay. The end product is the complete destruction of the specimen affected, the development of a white or green efflorescence and sulphuric acid.

A certain measure of success in the control of this metastability is achieved by maintaining low relative humidity in the storage area where marcasite or pyrite is kept.

Using strong mineral acids for development purposes, as recommended for example by Gordon (1947, p. 589) is therefore out of the question and should not be considered. Even the use of oxalic acid should not be contemplated. Davidson (1942, p. 292) rightly condemned the practice. It is further recommended by the advocates of acid development methods that these should be followed by the basification of the specimens and the acid using ammonium hydroxide solutions. As previously mentioned, this itself can cause serious problems, since iron hydroxide is liable to be deposited on surfaces, and in cleavages and cracks on the specimen.

Marcasite is frequently coated by films of hydrated iron oxides, ultimately to complete pseudomorphism. If the films are obviously thin, it is just possible that a measure of development could be achieved by the Waller method, for example. The degree of success achieved, however, as opposed to the great increase in the risk of the onset of instability, prompted by the development, makes the exercise valueless.

Microcline

Any mineral acid, with the exception of hydrofluoric acid may be used to remove coatings or mineral overgrowths but there can be normally no justification for such action.

Millerite

Bertrand (1962, p. 2) has suggested that overgrowths of secondary salts on millerite can be removed by using hydrochloric or sulphuric acids. Bertrand was presumably referring to the relatively large sized prisms which occur in several north American localities.

The use of acids on the acicular or capillary crystals from British or Czechoslovakian localities, which are prone to the development of green overgrowths, is not recommended. The crystals, though frequently oxidized, may not be firmly fixed to the matrix, which would itself be strongly corroded by acids, and are liable to be washed out or even completely dissolved. Of even more importance is the fact that the oxidation products on the millerite crystals are part of the paragenesis. Their presence is vital to our understanding of the genetic mechanisms.

Orthoclase (including Adularia)

Like microcline orthoclase may be developed using mineral acids other than hydrofluoric acid. Some associate minerals may be removed by immersing the specimen in a warm solution of ammonium bifluoride. In this case the orthoclase must be coated with a solution of beeswax in acetone before treatment to protect it from acid attack.

Platinum, Native

Platinum is a mineral highly resistant to chemical attack and is soluble only in hot aqua regia. Thus it is relatively simple to remove the iron oxides which commonly coat it. Platinum nuggets and grains from resistate sedimentary situations are most likely to need treatment, but the employment of the Waller Method is probably all that is necessary to remove iron films. Should it prove obstinate no harm should come to the specimen if acids are used.

Proustite

This silver salt is photosensitive and even under short periods of exposure to light in the presence of oxygen it will darken, lose its red colouration, eventually becoming completely black due to the development of silver sulphide. Most mined specimens are red when fresh and only ignorance or bad handling will cause the mineral to deteriorate. Exceptionally the mineral is found naturally blackened and this is characteristic of a particular environment and in which case the specimen should be left alone.

Should a collector obtain an old specimen which has blackened due to bad curation, proustite and its isomorph pyrargyrite may possibly be restored to their original colour by employing the cyanide method (Pearl, 1973, p. 44). Both proustite and pyrargyrite will be examined more closely under Section 5.

Technique

- (i) Prepare a solution of 1g of potassium cyanide in 500 mls. of distilled water.
- (ii) Immerse specimen in the solution and watch carefully until the black surface has been removed.
- (iii) Thoroughly flush the specimen in running water.
- (iv) Dry in a cabinet under low heat.

According to Pearl the technique is often only partially successful and a test run on a portion of the specimen of less importance should be tried first. A photographic darkroom is an ideal place in which to conduct the operation. The technician should remember the highly toxic nature of potassium cyanide – See Appendix No. 1.

Pyrargyrite

This antimony isomorph of proustite is also susceptible to deterioration in light. The same technique can be used to remove the black film of silver sulphide as described above for proustite. Also, like proustite, a blank test should be run on part of the specimen of less importance.

Good unaltered crystallized specimens of pyrargyrite and proustite are becoming of increasing rarity. Great care should be taken of those present in any collection.

Pyrite

This dimorph of marcasite has been formed under a much wider range of geological environments than has marcasite. While most marcasite found in a sedimentary environment is likely to be metastable many occurrences of pyrite have proved to be perfectly stable and show no signs of pyrite rot, even over long periods of time. There are others, from similar geological environments, however, which are strongly susceptible to decay. Therefore as in the case of marcasite, no specimens of pyrite should be assumed to have perfect stability. It is strongly recommended that the same care, as described above for marcasite, should be exercised in the preservation and cleaning of pyrite. Development should be strictly limited.

In spite of this, groups of pyrite crystals have successfully been developed out of Lower Devonian limestone, by the use of very dilute hydrochloric acid. The crystals, so developed have maintained stability for nearly three years (Dossert and Chamberlain, 1983, p. 49).

It is possible to remove films such as hydrous iron oxides by using the Waller Method. Concentrated mineral acids must not be used. Following any treatment the specimen should be kept as dry as possible and stored under temperatures $\geq 22^{\circ}\text{C}$, with relative humidity levels not exceeding 55%.

Much research is needed to safeguard pyrite and marcasite, but if the collector observes the above procedure and that described more fully under marcasite above, he will have done all he can pending the findings of current research.

Pyrolusite

Well crystallized material such as polianite may be successfully developed in solutions of nitric acid in which it is insoluble. It should be remembered that the mineral is readily soluble in hot hydrochloric acid with the evolution of chlorine. See above: Section (b). Removal of manganese dioxide deposits.

Pyromorphite

Members of this family, including campylite and mimetite are attacked by acids and alkalis and no development of any kind should be undertaken.

Pyroxenes

Like members of the Amphibole Family, pyroxenes are well cleaved and vigorous effervescence during development should not be allowed. Pyroxenes in calcic marbles can be extracted using weak solutions of acetic acid.

For other development purposes strong mineral acids are permissible, except hydrofluoric acid and solutions of ammonium bifluoride, both of which will seriously etch all members of the Pyroxene Family.

Quartz

With the exception of hydrofluoric acid and ammonium bifluoride, both of which can seriously etch quartz, most acids may be used to good effect to develop specimens coated by oxides of iron or manganese, or to remove thin encrustations of carbonates, etc.

Iron oxides are commonly present on amethystine quartz. Even if they are amorphous hydroxides, any attempt to remove them by soaking for long periods of time in concentrated acids can greatly reduce the intensity of the colour of the quartz itself. The same may apply to citrine which can be greatly harmed by strong acids.

Any technique for removing iron oxide films such as described in Section (a) above, may be employed on quartz, providing a careful examination of the mineral paragenesis has previously been made, and a technique selected mild enough to protect it.

Once quartz has been developed, the fact that it has is obvious and its scientific value is thus greatly reduced. The collector should not be prepared to accept such artificially modified material into his collection, nor be guilty of destroying his own in the same way.

Realgar

This sulphide is known for its lack of stability in light. Thus it is kept in darkened conditions, a fact which usually ensures its cleanliness.

As the mineral is readily attacked by concentrated acids, any treatment used should be confined to the use of dilute acids. If these fail, the attempt at development should be abandoned.

Rhodochrosite

Rhodochrosite is readily soluble in dilute warm mineral acids. Many of the intimately associated minerals of rhodochrosite are relatively difficult to remove by chemical means. The use of acids places the rhodochrosite at greater risk than the supposedly undesirable associates and no development of any kind should be undertaken.

Rutile

Rutile can be developed by immersion in acids, other than hydrofluoric acid. Great care should be taken to ensure the complete removal of the acid after any chemical action has ceased. Care should also be taken to protect any overgrowths of brookite or anatase which may be present.

Scapolite

Minerals of this group can be developed using most mineral acids except hydrofluoric acid. Films of iron oxides are frequent, but they can usually be removed employing the Waller Method. Oxalic acid should first be tried before applying mineral acids.

Scapolite minerals are frequently present in calcic marbles, as in the Grenville of North America. They may be readily extracted from thence as complete euhedral crystals using a 3% solution of acetic acid. Stronger concentrations of acid are liable to open cleavages, due to excessive effervescence, and can cause disintegration of the mineral. If the specimen is in the process of hydrolysis, it should be left alone.

Sillimanite

This mineral may be developed by using any mineral acid except hydrofluoric acid. Due to its common fibrous habit, care should be taken to ensure the complete removal of any acid left after treatment.

Silver, Native

Like native copper, it is difficult to draw a line between tarnish and mineralogical overgrowth. Native silver is found in a wider range of geological environments than copper, and the danger of damaging intimate associate minerals is therefore greater. Silver is deposited in four major environments:

1. Supergene
2. With silver sulphides and zeolites in a gangue of carbonates, fluorite and quartz (Kongsberg type).
3. With sulphides and arsenides of cobalt and nickel in a calcite and baryte gangue. (Cobalt type).
4. With pitchblende, and nickel and cobalt arsenides. (Jachymov type).

Silver, in all four types of environment presents problems when development is attempted. Supergene silver is likely to be delicate, adopting a filiform or arborescent habit, and is often in a friable and delicate matrix. For such material cleaning and development methods should be physically and chemically mild.

Silver deposited in the hydrothermal environments is often physically more robust, but its associates are much more liable to attack by chemicals used in development processes.

For specimens of all environments mildness of method should be the guiding rule. Normally water, or occasionally soap and water, should be the strongest chemical used on silver. There are, however, the occasions when the collector may lower his standards. The range of methods described below may then assist him to produce the result needed for a display or demonstration without unduly harming the paragenesis. The removal of films of tarnish (Ag_2S) from the surfaces of the native silver should be the sole object of the exercise.

Care should be taken in the adoption of any technique evolved for archaeological material. Electrolytic techniques using concentrated solutions of sodium hydroxide, for example, are likely to be too severe.

Techniques

1. The Sodium bicarbonate method

This is an old and well-tried technique which is reasonably kind to most parageneses where native silver is present:

- (i) Place the specimen in a Pyrex dish and cover with a solution made up of 30g of sodium hydrogen carbonate (NaHCO_3) and 30g of sodium chloride (NaCl) dissolved in 2 l. of distilled water. Experience has shown that both chemicals should be of analytical grade.
- (ii) Place strip of 0.51mm thick aluminium foil into the liquid with the specimen. Cooking foil is ideal. An alternative method is to use an aluminium saucepan, but as mentioned earlier, corrosion of the pan may take place after prolonged use.

(iii) Heat the solution but do not allow to boil.

(iv) Thoroughly wash the specimen, preferably in warm running water and allow to dry.

This method is particularly effective with the so-called "half-breeds", intimately associated native copper and silver, from the Keweenaw Peninsula of Michigan, in the United States of America.

2. The Cyanide Method

(i) Soak the specimen for short and controlled periods of time (depending on the nature of material) in a solution made up of 1g of potassium cyanide in 500 mls. of distilled water.

(ii) In between each period of immersion flush the specimen in a flow of running water, and carefully examine it for signs of deterioration.

(iii) Dip the specimen in ethyl alcohol and allow it to dry slowly at room temperature.

Pearl (1973, p. 43) pointed out that "half breeds" from Michigan are "cleaned" well by the cyanide method, but that individual specimens of copper and silver should not be cleaned in the same solution simultaneously as a greenish film would be deposited on the silver.

One of the serious failings of most cleaning or development techniques for silver is that tarnish is promoted more quickly on treated specimens.

Sphalerite

Like many sulphides, sphalerite is readily attacked by acids. Films of iron oxides are frequently present on sphalerite, but may readily be removed using the techniques described in Section (a) above, although if the technique employing oxalic acid is used the strength of the acid should not exceed 3%.

Spinel (Species not group) The mineral is resistant to most chemicals but it is wise not to use anything stronger than concentrated hydrochloric or nitric acids, for the removal of possible films of iron oxide.

Spodumene

Spodumene is resistant to many chemicals and may safely be developed by using all grades of mineral acid with the exception of hydrofluoric acid.

Stibnite

This sulphide is attacked by and is completely soluble in weak acids. It is also corroded by solutions of alkalis such as potassium hydroxide. In addition its common habit of acicular groupings of crystals makes cleaning and development physically difficult. It is also frequently coated with yellow oxidation products sometimes heavily and sometimes to pseudomorphism. Normally these oxides are an essential part of the paragenesis of the particular specimen, and should not be removed. Indeed they may prove more difficult to remove than that of the underlying, residual stibnite from which they were derived.

Should the specimen be seriously contaminated by mud or dust through unfortunate collecting circumstances or following neglect then the collector has a difficult problem to solve. It may be partially overcome by the delicate manipulation of a small soft-haired artists paint brush, aided if necessary by thin wooden splints. The careful use of a wash bottle filled with ethyl alcohol or acetone may also produce the desired results.

Sulphur

Specimens of sulphur are usually remarkable for their cleanliness and high lustre when originally collected. The common associates of sulphur, such as aragonite and celestine, though chemically less resistant are physically more robust and present the developer with a problem. Such associations should be left alone.

It is only following neglect that some measure of development should be attempted. This may take the form of the removal of contaminants that have been derived from a neighbouring specimen. Let an expert advise before attempting any work, for chemical imbalance may have already occurred. Much damage can be done to a specimen which is not yet beyond recall, should chemicals be unwisely applied to it.

Sulphur is insoluble in water and is scarcely attacked by strong acids. All chemicals should be used at the same temperature as the specimen, for sulphur is a notoriously bad conductor of heat. The use of hot water is disastrous. Sulphur is readily soluble in some organic solvents, such as carbon disulphide, and they should never be used.

Topaz

Coatings can be removed from the faces of topaz crystals quite effectively by the use of strong acids, including aqua regia.

Tourmaline

Any acid, except hydrofluoric acid or solutions of ammonium bifluoride, can be used to remove films of hydrated iron oxide from the crystal faces of tourmaline.

Tremolite

Any acid may be used for the development of tremolite except hydrofluoric acid. Great care should be taken to remove and neutralize any remaining acid after treatment, because of the fibrous or even asbestiform habit of the mineral.

Vivianite

Vivianite is highly metastable and is prone to rapid oxidation. Very few collections will possess the colourless, transparent mineral characteristic of the unaltered state. Instead they will contain specimens ranging in colour from pale greenish-blue to bluish-black as oxidation has proceeded. Vivianite is readily soluble in weak acids and rapidly darkens in water. In addition, its common associate, especially in specimens originating from Cornwall, is metastable pyrite. Vivianite should therefore remain dry, preferably in a sealed container where oxidation may be controlled. Therefore development should not be undertaken.

Wulfenite

Because of its distinct cleavage, especially when occurring in tabular crystals, this mineral is extremely delicate. In addition it is readily decomposed by acids. It may be washed clean of any fragments of broken crystals, dust, etc., by gently flushing with a slow running stream of luke-warm water, or by gently flooding the specimen with acetone, but no development should be undertaken.

Wurtzite

Wurtzite, the hexagonal phase of ZnS, is relatively stable in well organized storage, but it is often intimately associated with metastable minerals such as schalenblende and marcasite. Wurtzite is readily soluble in mineral acids, especially hydrochloric acid, and none should be used.

Much European wurtzite is present as one member of an intimate association of sulphides and the use of acids should not be contemplated. If marcasite is present as a member of this association, there should be no washing of any kind, for the association is notoriously metastable. It should remain dry at all times and no development be contemplated.

Zircon

Zircon is a highly resistant mineral and will survive most chemical development techniques. It can occur in calcic marbles, when it may be extracted out of the matrix using low concentrations of organic acid, such as 3% acetic. Some zircons possess zonal intergrowths of calcite. Once their presence has been identified the development should cease as disintegration of the zircon crystals may result.

The Last Word

As stated above on numerous occasions, great circumspection should be expressed by the collector when contemplating the use of recommended development techniques.

As stated in Section 1 (King, 1982) cleaning may be and often is necessary from the field, as a routine curatorial duty, or cleaning following neglect, but the word should be used in its strict sense and not in inverted commas as a disguise and excuse to cover the use of strong chemicals to alter an original paragenesis to something unnatural for appearances sake.

If use has been made of any of the techniques described above, the collector should, as a matter of duty, describe which technique or techniques he employed, in the form of notes to accompany the specimen he has developed. He should also make certain that a developed specimen is subjected to a rigorous and regular examination to ensure that stability is maintained.

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Appendix No. 1

List of chemicals referred to in the text, with the hazards of using them.

1. Acetic acid – CH_3OOH

Exposure: Can cause dermatitis, conjunctivitis and severe irritation of the respiratory tract. TLV: 10 ppm. STEL: 15 ppm.

2. Acetone – CH_3COCH_3

Exposure: Can cause dermatitis and severe side effects following inhalation. All operations using acetone should be conducted in a fume cupboard. TLV: 750 ppm. STEL: 1000 ppm.

3. Aluminium foil – Al.

4. Ammonium acetate – $\text{CH}_3\text{COONH}_4$

Highly toxic following ingestion.

5. Ammonium bifluoride – NH_4HF_2

Exposure: Though not so dangerous as hydrofluoric acid, severe burns can result when moistened. Avoid inhalation of dry compound. TLV: 25 ppm. Neoprene gloves and a full face shield are essential.

6. Ammonium citrate – $(\text{NH}_4)_3\text{C}_6\text{H}_5\text{O}_7$

7. Ammonium hydroxide – NH_4OH

Commonly supplied as a 35% soln. in water (S.G. 0.88)

Exposure: The vapour can cause severe irritation to all parts of the respiratory system. The solution causes severe eye and skin burns. TLV: 25 ppm. STEL: 35 ppm.

8. Aqua Regia – (3 pts./vol. HCl to 1 pt./vol. HNO_3)

Exposure: Severe burns to the skin and severe irritation of mucous membranes following inhalation. Wear neoprene gloves and full face shield. TLV: 2 ppm. STEL: 4 ppm.

9. Benzene – C_6H_6

Exposure: Has been recognized as a carcinogen which attacks the blood, bone marrow (causing leukaemia), respiratory system and central nervous system. Can cause fatal intoxication over 60 ppm. Any development involving its use should be conducted in a fume cupboard. TLV. 10 ppm. STEL: 25 ppm.

10. Calcium chloride – $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$

11. Carbon disulphide – CS_2

Exposure: Readily absorbed through the skin. Inhalation of its vapour can cause irritability, indigestion, insomnia etc., which can lead to coronary heart disease. People with diseases of the central nervous system, liver, kidneys, blood and gastro-intestinal tract are at particular risk, as are pregnant technicians. Foetal damage can occur at concentrations of $10\text{mg}/\text{m}^3$ in air. TLV: 10 ppm.

12. Carbon tetrachloride – CCl_4

Exposure: May be absorbed through inhalation and through the skin. Causes cancer of the liver and acute liver and kidney necrosis. Any development work involving its use should be done in a fume cupboard and neoprene gloves should be worn. TLV: 5 ppm. STEL: 20 ppm.

13. Ethanol (Ethyl alcohol) – $\text{C}_2\text{H}_5\text{OH}$

Exposure: Can increase toxicity of other inhaled, absorbed or ingested chemicals. Irritates mucous membranes. Severe damage may be done to the eyes with effects often delayed. TLV: 1000 ppm.

14. Hydrochloric acid – HCl

Exposure: Extremely irritant and corrosive to mucous membranes. Can cause conjunctivitis and, following inhalation, rhinitis, nasoseptic perforation and bronchitis. TLV: for HCl gas 5 ppm. 1000-2000 ppm. lethal

15. Hydrofluoric acid – HF

This is an extremely dangerous compound which attacks most compounds including glass.

Exposure: Extremely dangerous – burns are initially anaesthetic, but subsequently are severe, painful and may result in gangrene. 0.4 ml. in the eye has resulted in blindness. Inhalation of fumes can be fatal. TLV: 3 ppm. 50 ppm. and above may be lethal.

16. Hydrogen sulphide – H_2S gas.

Exposure: Can cause irritation of all parts of the respiratory system, even respiratory paralysis. Can cause conjunctivitis. The gas is extremely flammable with limits in air from 1-50%, and can ignite from light sources, ultra violet light apparatus, etc., at considerable distances from the source. TLV: 10 ppm.

17. Hydroxylamine hydrosulphate – $(\text{NH}_2\text{OH}\cdot\text{H})_2\text{SO}_4$

Exposure: Salts and solutions can burn the eyes and skin and dermatitis can result.

18. Nitric acid – HNO_3

Exposure: Can cause severe skin burns with necrosis, conjunctivitis and following inhalation, severe respiratory disorders. Neoprene gloves and a full face shield should be worn. TLV: 2 ppm. STEL: 4 ppm.

19. Orthophosphoric acid – H_3PO_4

Exposure: Can cause skin burns, and damage to the eyes followed by conjunctivitis. Can cause severe irritation of the respiratory system. Always wear rubber gloves and goggles and conduct any development work in a fume cupboard. TLV: 1.0 mg/m^3 .

20. Oxalic acid – $\text{HOOC}\cdot\text{COOH}\cdot 2\text{H}_2\text{O}$

Exposure: An extremely poisonous compound. Can cause severe chemical burns followed by gangrenous ulcerations. Can cause permanent corneal damage. Following inhalation severe irritation of the respiratory tract can lead to ulceration of the mucous membranes. TLV: 1 mg/m^3 STEL: 2 mg/m^3 .

21. Potassium cyanide – KCN

Exposure: An extremely toxic compound, which can be absorbed through the skin to cause immediate headaches, leading to paralysis, respiratory arrest, convulsions and death. Always wear rubber gloves, full face shield and conduct any technique in a fume cupboard. Never work alone. If ingested administer a 1% solution of sodium thiosulphate. Seek medical advice **immediately**. TLV: 5 mg/m^3 .

22. Potassium hydroxide – KOH

Exposure: A highly corrosive compound which can cause severe burns. Both in solid and liquid state can severely irritate skin and eyes. Always wear protective gloves and goggles.

23. Potassium sodium tartrate – $\text{COOK}\cdot(\text{CHOH})_2\text{COONa}\cdot 4\text{H}_2\text{O}$

24. Sodium chloride – NaCl

25. Sodium citrate – $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7\cdot 2\text{H}_2\text{O}$

26. Sodium cyanide – NaCN

Exposure: See above – potassium cyanide.

27. Sodium bichromate – $\text{Na}_2 \text{Cr}_2 \text{O}_7\cdot 2\text{H}_2\text{O}$

A highly dangerous compound. Exposure: Can cause sensitizing dermatitis followed by chronic ulcerations, and conjunctivitis. Inhalation can be followed by sinusitis, laryngitis and carcinoma of the lungs. Avoid all skin contact and wear rubber gloves and a face shield. TLV: 0.1 mg/m^3 .

28. Sodium dihydrogen citrate – $\text{CHNa}_2\text{HCH}_5\text{O}_7\cdot 1.5\text{H}_2\text{O}$

29. Sodium dithionite – $\text{Na}_2\text{S}_2\text{O}_4$

This is a powerful oxidizing agent. The addition of 10% of water can cause heating and spontaneous ignition. Avoid all moist flammable materials including clothing.

30. Sodium bicarbonate (Sodium hydrogen carbonate) – NaHCO_3

Exposure: Strong concentrations can be moderately toxic if ingested.

31. Sodium hydrogensulphate (Sodium bisulphate) – $\text{NaHSO}_4 \cdot \text{H}_2\text{O}$

Exposure: Corrosive. Can cause severe burns to eyes and skin. Always wear rubber gloves and a face mask.

32. Sodium hydroxide – NaOH

Exposure: Corrosive. Can cause severe skin burns by gelatinization. Can cause conjunctivitis and corneal damage to the eyes. If inhaled strongly irritates the respiratory tract. Always wear gloves and goggles. TLV: 0.02 mg/m^3 (ceiling limit).

33. Sodium hypochlorite – NaOCl

Exposure: Extreme irritant. Can cause irritation and blistering of the skin leading to eczema. Can cause permanent damage to the eyes. If vapours from its solutions are inhaled, blistering of the respiratory tract can occur.

34. Sodium metabisulphite – $\text{Na}_2\text{S}_2\text{O}_5$

35. Sulphuric acid – H_2SO_4

Concentrated sulphuric acid is an oily liquid with a great affinity for water. Great care should be exercised in its dilution by water. It is sound practise to slowly add the acid to the water and never *vice versa*.

Exposure: Can cause severe skin burns leading to dermatitis and ulceration. Conjunctivitis can result from contact with the eyes. Inhalation can cause irritation of the membranes of the nose and throat and bronchitis can be promoted.

36. Tartaric acid – $(\text{CHOH.COOH})_2$

Suggested literature on hazardous chemicals.

- | | | | |
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Appendix No. 2

Mechanical Extraction

- Tools recommended:
- i. Vibro-tool. An electrically operated engraving tool.
Manufactured by Messrs. Burgess Power Tools Limited,
Small Tools Division,
Sapcote,
Leicestershire.
 - ii. Air Pen. A pneumatically operated engraving tool.
Manufactured by Messrs. De Soutter Bros. Ltd.,
The Hyde,
Hendon
London.

Both tools are used extensively by palaeontologists for the extraction of fossils out of the matrix, where matrix and fossil are chemically similar. Their application by mineralogists is far less damaging to an association than the wholesale use of chemicals.

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