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FRONT COVER:

Pale pink bipyramidal stokesite crystal, 6.5 mm long (see Figure 12, p. 43 for details). Penryn Granite Company's quarry at Halvosso, Longdowns, Cornwall. Jim Knight Collection; collected by Richard Barstow in June 1975; photo David Green.

BACK COVER:

The appearance of a group of cream to light brown calcite crystals in various wave lengths of light: visible (top), LUV (middle) and SUV (bottom). East Face, Croft Quarry, Croft, Leics. Frank Ince specimen and photo (FI-1485; collected by Mike Smith, September 1977); specimen width 110 mm.

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EDITORIAL

Welcome to Volume 20 of the Journal of the Russell Society.

We begin this edition in the heart of the English midlands. Many of our members will have some familiarity with the South Leicestershire Diorite Complex, or SLDC; numerous Central Branch field excursions have visited this area over the years and it was, of course, one of the preferred "stomping grounds" of Society founder, the late Bob King. Frank Ince has studied a large number of specimens held in public and private collections and followed up numerous literature references to produce a comprehensive account of the minerals associated with the SLDC.

Gem-quality tourmaline occurs all too rarely in the British Isles, but it was known to occur in float boulders at Glen Buchat, in Aberdeenshire. Roy Starkey and Michael McMullen obtained permission to excavate temporary trenches which located a lithium pegmatite as the *in situ* source of the tourmaline, and also yielded Scotland's first recorded specimens of spodumene.

Our third contribution, from Alan Barnes and his co-authors, takes an in-depth look at the collection of the late Jim Knight (1927–2009). As the paper explains, Jim was a rather private individual, well-known to only a few members of the Russell Society, but there is no doubt that he was an accomplished field-collector and that he assembled a very significant collection of worldwide minerals. I found myself enjoying the descriptions of Jim's collecting experiences and his minerals, but also reflecting on what might constitute curatorial "best practice" for a large, privately owned mineral collection. Many of us spend time pondering the eventual fate of our collections, but do we make sufficient effort in terms of record keeping – labels, catalogues, datacards, field notes, lab notes, photographs – to ensure that the scientific and historical value of our specimens is properly preserved? There is much food for thought in this article!

Finally, we visit the north of England for Brian Young's account of magnetite mineralisation associated with the Great Whin Sill, in Upper Teesdale. Based mainly on field observations, Brian describes this paper as a preliminary report, with more detailed petrological and analytical studies still to come – hopefully for a "Part Two" in a future edition of the Journal.

Malcolm Southwood
Honorary Journal Editor

ERRATA

Rumsey, M.S. (2016). A review of United Kingdom herderite localities attributed to Arthur Kingsbury. *Journal of the Russell Society*, **19**, 27–34. The references to Lesceave Pot should be replaced by Lesceave Por. On page 32 the footnote should read: Lesceave Por [SW 586 274] is a little-known locality at the eastern end of Praa Sands. It is not listed on Mindat (www.mindat.org; accessed August 2016).

Betterton, J. and Grey, I.E. (2016). An occurrence of euhedral schulenbergite at the Penberthy Croft Mine, Cornwall. *Journal of the Russell Society*, **19**, 34–35. On page 36 the last sentence in the first paragraph should read: The majority of the crystals display a strong parallel growth, as can be seen in the image.

Young, B. and Pacey, A. (2016). Segnitite from Weardale, County Durham. *Journal of the Russell Society*, **19**, 39–42. On page 41 the first reference should be: Betterton, J. (2000). Famous British Mineral Localities: Penberthy Croft Mine, St Hilary, Cornwall, England. *UK Journal of Mines & Minerals*, **20**, 7–37.

A REVIEW OF THE MINERALS ASSOCIATED WITH THE IGNEOUS ROCKS OF SOUTHWEST LEICESTERSHIRE

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Southwest Leicestershire contains quarried exposures of Ordovician igneous rocks of the South Leicestershire Diorite Complex surrounded by Triassic sediments of the Mercia Mudstone Group. As quarrying has progressed, it has become apparent that these rocks contain a variety of minerals, with analcime, calcite, laumontite and palygorskite being the most well-known. This review describes the occurrences of the minerals that have been reported from this part of Leicestershire. It is evident that several phases of mineralisation have affected the South Leicestershire Diorite Complex and the surrounding Triassic rocks, and a possible paragenetic sequence is suggested.

INTRODUCTION

The part of southwest Leicestershire that is bounded by Enderby, Earl Shilton and Sapcote contains a number of quarried exposures of Ordovician igneous rocks of the South Leicestershire Diorite Complex (SLDC) surrounded by Triassic sediments of the Mercia Mudstone Group (Figure 1). As the quarries have developed it has become evident that the igneous rocks of the SLDC contain a variety of minerals; however, when compared with the igneous rocks, the sedimentary rocks of the Mercia Mudstone Group are hosts to only a limited number of minerals. In the late-19th and early-20th centuries a number of descriptions of the igneous and sedimentary rocks were published (Harrison, 1877; Hill and Bonney, 1878; Harrison, 1881; Bosworth, 1912) and these included notes of some mineral occurrences. It was somewhat later that detailed records of the occurrence of various minerals started to accumulate (Eastwood *et al*., 1923; Jones and Langley, 1931) and, since then, a large number of minerals have been reported to occur in the SLDC, together with a few minerals from the Mercia Mudstones; these occurrences are described below.

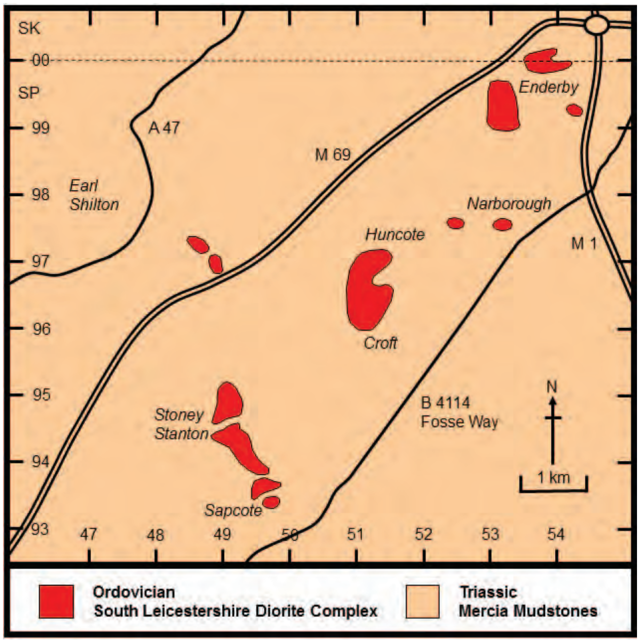

Figure 1. Geological map of part of southwest Leicestershire showing the exposures of the South Leicestershire Diorite Complex (Quaternary deposits omitted; modified from Le Bas, 1968).

LOCATIONS

All of the exposures of the SLDC shown on Figure 1 have been quarried for building stone and aggregate; some of them since Roman times (Le Bas, 1993; see also Fenn, R.W.D. *Quarrying at Croft, Part 1: The history of Croft Quarry*. www.aggregate.com/about-us/history/croft; accessed April 2016). Most of the individual quarries have been noted on maps of the area drawn by Bosworth (1912, Figure 1), Le Bas (1968, Figure 9; 1993, Figure 1), Bridge *et al*. (1998, Figure 11) and Carney (2010, Figure 1). In the past, some of these quarries have been known by a variety of different names and, for the purposes of this review, the names used are mainly those provided by Le Bas (1968; 1993); the names of these quarries (together with any alternative names and grid references noted in the literature) are given in Table 1 (see p. 4). Inevitably, many of the older, smaller quarries are disused and are variously overgrown, flooded, in-filled and landscaped or have been incorporated into more recent, larger quarries.

GEOLOGY

As can be seen from Figure 1, the pre-Quaternary geology of the area bounded by Enderby, Earl Shilton and Sapcote is superficially simple: outcrops of the SLDC of Ordovician age, surrounded by Triassic sediments. Having said this, Harrison (1877, Figure 2), Le Bas (1968), King (1973) and Worssam and Old (1988) all described some grey, green and purple, metamorphosed mudstones and shales (Figure 2, see p. 5) that were associated with the igneous rocks of the SLDC exposed in Coal Pit Lane Quarry, Enderby. It was suggested that these metamorphosed mudstones and shales could be related to the Cambrian Stockingford Shale Group (exposed in the area around Nuneaton, Warwickshire) or the slates that are adjacent to the Mountsorrel Complex (exposed in the area around Mountsorrel and Quorn, Leicestershire). Carney *et al.* (2009) concluded that the Mountsorrel Complex was intruded into metasedimentary rocks of Cambrian age and the *Geology of Britain viewer* (www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html, accessed April 2016) describes these metasedimentary rocks as the

Quarry Name	Alternative Quarry Name	NGR
	Enderby	
Warren Quarry[1,2,3,4,5]	Stone Quarry[1], Enderby Co. Pit[1], Warren Hill Quarry[1,4] or Enderby Warren Quarry[2,6,7]	SK 540 000[1,2], SK 539 002[2] SK 542 001[3], SK 538 001[4] SK 5413 0007[6]
Rawson's Pit[1]	Froanes (or Frounes) Quarry[1] or Froane's Hill[2]	SK 534 000[1,2]
Enderby Hill Quarry[1,2,4,7]		SP 533 996[1,2]
Coal Pit Lane Quarry[1,6]	Lower Enderby Quarry[1], Old Quarry, Enderby[1], Enderby Quarry[1,7] or Old Quarry[8]	SP 542 992[1], SP 5414 9912[6]
	Narborough	
Red Hill Quarry[1,2,9]	Old Narborough Quarry[1]	SP 532 975[1], SP 531 975[2]
Narborough Quarry[1,8,9]	New Pit, Narborough[1] or New Narborough Quarry[1,2]	SP 525 975[1], SP 524 975[2]
	Huncote-Croft	
Huncote Quarry[1,2,4,5,8]	Croft Hill Quarry[1] or Huncote Village Quarry[4]	SP 512 969[1], SP 5129 9650[2] SP 513 969[4]
Croft Quarry[1,2,3,4,5,7,8,9]	Village Quarry, Croft[1,4] (now a very large quarry that incorporates Huncote Quarry; operated by Aggregate Industries)	SP 512 964[1], SP 512 963[2] SP 5125 9630[2], SP 510 964[3] SP 513 964[4], SP 510 965[9]
	Earl Shilton	
Barrow Hill Quarry[1,2,7,8]		SP 487 972[1,2]
The Yennards Quarry[1]	Parish Pit or Rock Farm Quarry[1], Charity Quarry[1,8] or Yennards Quarry[2,7]	SP 489 970[1,2]
	Stoney Stanton	
Clint Hill Quarry[1,7,8,9]	Clent Hill Quarry or Stanton Bottom Pit[1]	SP 490 949[1]
Town Quarry[1]	Varnam's Pit[1]	SP 490 948[1]
Cary Hill Quarry[1,7,8,9]	Includes Wood's Pit and Parish Pit[1]	SP 490 946[1,9]
Old Quarry[1,8]		SP 493 943[1]
Lane's Hill Quarry[1,5,8]	Mill Hill[10], Top Quarry[1,8], Stanton Top Pit[1] or Stoney Cove Quarry[2,7,9] (now water-filled and the location of the UK National Diving Centre, Stoney Cove)	SP 493 942[1,4], SP 495 941[2] SP 4920 9410[9]
	Sapcote	
Granitethorpe Quarry[1,5,8,9]	Sopewell Quarry[1]	SP 495 937[1,9]
Sapcote Quarry[1,5,7,8,9]	Includes Lovett's Pit, Parish Pit, Old Quarry and Windmill Quarry[1,4]	SP 497 934[1], SP 496 934[4]
Calver Hill Quarry[1,7,8,9]	Cauver (or Canver) Hill Quarry[1]	SP 497 932[1], SP 496 931[9]

References: [1] Le Bas (1968); [2] Worssam and Old (1988); [3] Manning (2010); [4] King (1968); [5] King (1973); [6] Carney *et al*. (2009); [7] Carney (2010); [8] Bosworth (1912); [9] Bridge *et al*. (1998), [10] Le Bas (1993).

Table 1. The locations, names, alternative names and national grid references (NGR) of the quarries that have exploited the SLDC.

Stockingford Shale Group – Mudstone. Sedimentary Bedrock formed approximately 479 to 528 million years ago in the Ordovician and Cambrian Periods.

Thus there seems to be general agreement that the slates, previously exposed in Coal Pit Lane Quarry, can also be correlated with the rocks of the Stockingford Shale Group, in which case, they are Cambrian to Ordovician in age; but older than the igneous rocks of the SLDC (see below).

South Leicestershire Diorite Complex (SLDC)

The geology and petrology of the SLDC have been discussed many times over the last 135 years (Hill and Bonney, 1878; Harrison, 1881; Bosworth, 1912; Le Bas, 1968; Le Bas, 1972; Le Bas, 1982; Worssam and Old, 1988; Pearson and Jeffrey, 1997; Bridge *et al*., 1998; Carney and Pharaoh, 1999; Carney *et al*., 2009; Carney, 2010; Manning, 2010) and only a brief description will be given here. The rocks of the SLDC have been variously referred to as syenites (Hill and Bonney, 1878; Harrison, 1881), microdiorites (Jones, 1933) or diorites, tonalities and microtonalites (Le Bas, 1968). They are now described as quartz-diorites and tonalites (Worssam and Old, 1988; Bridge *et al*., 1998; Carney *et al*., 2009; Carney, 2010). Pearson and Jeffrey (1997) described the petrology of the igneous rocks exposed at Croft Quarry and they noted that

> ...the primary mineralogy of the diorites consists of euhedral plagioclase, augite and hornblende set in a granophyric ground mass of quartz and alkali feldspar. This mineralogy has been extensively overprinted by sericite, carbonate, chlorite, actinolite, epidote, prehnite, pumpellyite, analcime and laumontite.

Figure 2. Contact metamorphosed, green, fine-grained Cambrian mudstone showing disrupted bedding and brecciation that occurs in close association with the cream to brown medium-grained Ordovician microtonalite. Coal Pit Lane Quarry, Enderby, Leics. Leicester Arts and Museums Service specimen; specimen 150 x 110 mm; Frank Ince photograph, reproduced with permission.

It is evident that there is a large-scale variation in the composition of the SLDC, both laterally (Le Bas, 1968; Allsop and Arthur, 1983) and vertically (Carney, 2010). There is also a smaller-scale variation in composition of the SLDC: Carney (2010) noted that diorite xenoliths

> ...are ubiquitous in all parts of the host quartz-diorite that were accessible for examination,

some of these xenoliths are hosts to a number of minerals.

In his discussion of the age of the SLDC, Carney (2010) stated that a

> ...U-Pb date of 449±18 Ma was obtained by merging the data for zircons separated from plutonic rocks exposed at Enderby…with values for zircons from granodiorites of the closely related Mountsorrel Complex…This age confirms that…[they]…were emplaced during an intrusive event of Ordovician (late Caradoc) age, contemporary with the subduction-related, Caledonian magmatism of central Wales and the Lake District.

Similar igneous rocks have been proved in boreholes and geophysically both locally (Le Bas, 1968; Allsop and Arthur, 1983) and at various sites in the East Midlands and eastern England (Le Bas, 1972; Francis, 1992; Carney *et al*., 2004; Carney *et al*., 2009); however, the structure and dimensions of the intrusion(s) in central and eastern England have yet to be well-defined.

Mercia Mudstone Group

The Triassic rocks of the Mercia Mudstone Group and their relationship to the exposures of the SLDC have also been described in some detail (Bosworth, 1912; Worssam and Old, 1988; Le Bas, 1993; Bridge *et al*., 1998; Carney *et al*., 2009). Figure 1 gives a rather simplistic impression of the Triassic sequence and Table 2 contains some details of the rocks of the Mercia Mudstone Group (as shown on the *Geology of Britain viewer*: www.bgs.ac.uk/discoveringGeology/geologyOfBritain/viewer.html, accessed April 2016). These sandstones, siltstones and mudstones were deposited under desert conditions, with occasional lacustrine intervals, and are predominantly

Structural Unit	Rock type[1]	Age (Ma)
Branscombe Mudstone Formation	Sst–Mst	200–217
Arden Sandstone Formation	Sst–Mst	217–229
Cotgrave Sandstone Member	Sst	217–229
Edwalton Member	Sst–Slt–Mst	217–229
Gunthorpe Member	Slt–Mst	229–246

[1] Sst, sandstone; Slt, siltstone; Mst, mudstone

Table 2. The rocks of the Mercia Mudstone Group in the area adjacent to exposures of the SDLC (data from the BGS website; see text).

red-brown with occasional greenish-grey bands. The regional bedding of the mudstones, siltstones and sandstones is almost horizontal; although, catenary bedding is evident where these sediments fill wadis in the Triassic land surface at the Ordovician–Triassic unconformity; see Figure 3 and also figures 13 and 15 in Bosworth (1912).

MINERALS

During the preparation of this article specimens in various collections were examined: The R.J. King Collection at the National Museum of Wales, Cardiff (NMW); Leicester Arts and Museums Service, New Walk Museum, Leicester (LAMS); Geology Department, University of Leicester (GDUL); Natural History Museum, London (NHM); Oxford University Museum of Natural History, Oxford (OUMNH) and the private collections of Neil Hubbard, John Jones, Nigel Moreton, Roy Starkey and that of the author. A number of specimens from these collections are described below, the NMW: R.J. King Collection (Kxxx, NMW83.41G.Myyy) and R.J. King Reserve Collection (Kxxx.yyy); the LAMS Collection (LEICS Gxxx.yyy.zzz); the NHM (BM.xxx or BM.xxx,zzz); the Neil Hubbard Collection (NH-xxx); the Roy Starkey collection (RS xxx-yyy); the author's collection (FI-xxx).

A variety of techniques, including wet chemistry, optical and X-ray (XRD) methods, have provided data that supports the identifications of the individual minerals described below (a table of data will be provided on request). The minerals and localities noted in italics are those where further work is required to confirm the occurrence of a particular mineral. The materials in lower case and enclosed by inverted commas are those that are no longer considered to be valid mineral species (Bayliss, 2000; Back, 2014) or have an ill-defined chemical composition.

ANALCIME, $NaAlSi_2O_6 \cdot H_2O$

Croft Quarry, Croft

Jones and Langley (1931) described a zeolite-filled fissure that was found in the igneous intrusion at Croft. It took the form of a cavity

> ...18 inches long by 5 inches wide [460 mm x 130 mm] apparently filled with "calcite or quartz"…On closer examination the mineral showed perfect trapezohedra of analcime and cube-like rhombohedra of chabazite [however, see the Calcite-2 section]. The analcime crystals attained a diameter of 0.4 inches [10 mm]: they comprised the bulk of the specimen.

Francis Jones donated two specimens to the collections at the NHM (BM.1930,1046 and BM.1930,1047, that were presumably related to this occurrence) which have colourless to dark pink analcime crystals (to 9 mm; analcime-2, see below). BM.1930,1047 (Figure 4) also has some colourless to cream rhombs of calcite that were originally thought to be chabazite (see the Calcite-2 section).

King (1968; 1973) concluded that post-emplacement albitisation and analcitisation had taken place (see also Pearson and Jeffrey, 1997). The analcitisation resulted in analcime occurring in highly drusy fissure veins (up to 370 mm wide) in belts of rotten rock that rose vertically out of the quarry floor, splitting and bifurcating across the igneous mass in great sweeping anticlinal areas. Cavities were relatively common and some of them were quite large

Figure 3. An aerial view of Croft Quarry looking northeast, showing the unconformity between the grey Ordovician quartz-diorite and the wadis filled with red-brown Triassic Mercia Mudstones. Photograph reproduced courtesy of the British Geological Survey; Permit Number [CP16/040] British Geological Survey © NERC 2016. All rights reserved.

(Figure 5). The belts of rotten rock could attain a thickness of 12 m and were known as "rammel" (a local term for junk). King (1968) also described the manual 'quarrying' of the analcime-containing "rammel", noting that the loose material was

> ...shovelled from the face and sold as footpath gravel, due to the property of setting into a hard mass after being thoroughly saturated with water.

The paragenesis of analcime deposition was described by King (1973) and he indicated that there were two distinct generations of analcime:

Analcime-1

The first generation analcime (GDUL XRD 469) formed very small crystals, never exceeding 1.2 mm across (average 0.7 mm), that were colourless, transparent, perfect trapezohedra; though they may be tinted green, pink or orange by underlying epidote-2 or hematite-1 and also pink or orange by inclusions of hematite-2. This generation of analcime was also associated with quartz-2, as small white analcime-1 crystals (to 1 mm) forming 'collars' just below the pyramidal faces (Figure 6) or minute, pale brown analcime-1 crystals sprinkled on hexagonal prisms of colourless quartz-2 giving them a "frosted" appearance (see BM.1959,614).

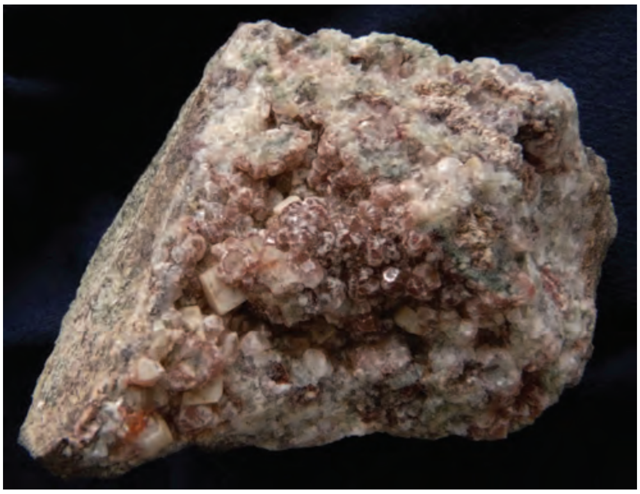

Figure 4. Pink analcime crystals (to 3 mm) with very pale yellow to cream 'rhombs' of calcite (to 6 mm; calcite-2, originally thought to be chabazite). Croft Quarry, Croft, Leics. NHM specimen (BM.1930,1047; donated by Francis Jones, November 1930); specimen width 75 mm; Frank Ince photograph, ©NHM reproduced with permission.

Figure 5. Bob King (on the left) and Julian Cleeton (Quarry Manager, Croft Quarry; on the right) investigating a large, newly-exposed cavity in 1978. John Jones photograph, reproduced with permission.

Analcime-2

The second generation analcime was the major depositional event and it tended to obscure any earlier event(s) as the analcime-2 crystals were numerous and larger, up to 13 mm across (see Figure 7). King (1973) noted that

> ...the majority of the crystals are simple trapezohedra, {211}, though mutual interference is common. Other forms present include the octahedron, {111}, which is seen occasionally modifying the trapezohedron. The colour varies from colourless, through [orange and] pale red to lobster-red…the lustre is vitreous…even when the material has been subjected to long periods of weathering. Specimens can be difficult to preserve due to

Figure 6. Hexagonal prisms of colourless quartz (to 12 x 6 mm; quartz-1) with "collars" of small white analcime-1 crystals just below the pyramidal faces. Croft Quarry, Croft, Leics. NMW specimen (K1429-1957, NMW 83.41G.M.6601, collected by Bob King, 1957); specimen width 130 mm.

Figure 7. Colourless to pale brown analcime-2 (to 17 mm) with minor marcasite. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0234); specimen width 100 mm.

their great friability; the crystals remain as loose individuals without any great strength of mutual cementation.

Pearson and Jeffrey (1997) provided another description of the material from Croft noting that

> ...analcime also occurs as veins and cavity infills. The earliest phase of analcime deposition [analcime-1] is represented by small colourless trapezohedra (1 mm to 5 mm across) along the vein and cavity walls. Later analcime [analcime-2] is represented by much larger crystals (up to 90 mm across); these crystals, which are associated with calcite, occur as simple trapezohedra… Most of the analcime is translucent or white, although some crystals have orange tips or are lobster red, while others are coated in hematite. Chalcopyrite occurs as tiny inclusions within analcime.

The largest crystal of analcime-2 in the author's collection is 30 mm across (FI-0751), collected by the late Trevor Bridges in 1977. Pearson and Jeffrey (1997) also suggested that the analcime was produced by the action of water on feldspars:

plagioclase (albite) + water → analcime + laumontite + quartz

Various specimens show the relationship between the two generations of analcime (see Figure 8). Both analcime-1 and analcime-2 may enclose, or be coated with, variable amounts of hematite (hematite-2 and hematite-3 respectively) resulting in orange to pink to red crystals; they may also be coated with more substantial amounts of earthy or nodular red-brown to almost black hematite-4 (Figure 9). Analcime-2 can also be associated with calcite and various sulphides (marcasite, chalcopyrite or galena). An interesting specimen in the Neil Hubbard Collection shows a marked stoss-side development of a very pale green microcrystalline mineral (that has yet to be identified) on well-crystallised analcime-2 (to 17 mm) with some calcite-3 (Figure 10).

Tschernich (1992) mentioned specimens from Croft Quarry in the collections of the British Museum (presumably the NHM, London) on which small colourless analcime crystals occurred with calcite. Wilson *et al*. (2003) listed Croft Quarry as one of the UK occurrences of analcime. Tindle (2008) appears to have based his description of the occurrence of analcime at Croft Quarry on the work of Pearson and Jeffrey (1997) and Manning (2010), included analcime amongst the minerals that occur in the quarry.

Analcime has replaced a prismatic mineral, producing pseudomorphs and/or epimorphs with a cross section that can have the shape of a parallelogram; although, in some examples, it appears almost as a square. Pseudomorphs and/or epimorphs after a monoclinic mineral could have these characteristics and, given that it occurs in the quarry, it is most probable that the original mineral was laumontite. The pseudomorphs and/or epimorphs after laumontite are formed of small analcime crystals (< 5 mm); consequently, it appears that they were produced during deposition of analcime-1. Where the replacement of the prismatic mineral is complete, the pseudomorphs and/or epimorphs are almost totally filled with small crystals of analcime-1 (Figure 11); however, the replacement of the prismatic mineral is not always complete and this has resulted in epimorphs that have a U-shaped habit where one of the original prism faces is missing (Figure 12). The replacement of laumontite

Figure 8. Colourless to white analcime-2 (to 6 mm) on very small, pale orange to brown analcime-1. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-2417; collected by Phil Jackman 22 July 1995); specimen width 90 mm.

Figure 9. Analcime-2 (to 15 mm) on analcime-1 coated with dark red-brown hematite-4. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-1854); specimen width 40 mm.

Figure 10. Colourless to white analcime-2 (to 16 mm) with a marked stoss-side development of a very pale green microcrystalline mineral. Croft Quarry, Croft, Leics. Neil Hubbard specimen (NH-666); specimen width 85 mm.

by analcime has been described in the literature. In his review of some British pseudomorphs, Miers (1897) included

> Analcime after Laumontite, from Kilmalcolm, Renfrewshire; in the British Museum.

Two specimens in the NHM collections correspond to this report

> BM.91896 does look to be a true pseudomorph rather than an epimorph. Quite different from the Croft specimens; whereas BM.95513 has less obvious laumontite crystal shape remaining and the analcime has seemingly grown on top and around the remains of the laumontite in a crustiform mass, it's probably more equivalent to the Croft specimens [Mike Rumsey, *personal communication*].

Figure 11. Pseudomorphs/epimorphs of analcime-1 after prisms of laumontite (to 45 mm; some with hollow interiors) and analcime-2 coated with dark red-brown hematite-4 with minor white calcite and (not visible) a cube of pale yellow fluorite-3. Croft Quarry, Croft, Leics. Neil Hubbard specimen (NH-210); specimen width 50 mm.

Figure 12. U-shaped epimorphs of colourless to pink analcime-1 after laumontite (to 30 mm) and colourless to pink analcime-2 (to 10 mm) with small white to cream scalenohedral calcite crystals (to 1 mm; calcite-5?). Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0080; collected by John Cooper 17 October 1992); specimen width 65 mm.

Warren Quarry, Enderby

King (1968) described the process of analcitisation at Warren Quarry as occurring

> ...in the form of arcuate zones, bifurcating from a central vein situated at the foot of the incline on the lower level. These are known locally as the "dark zones";

he also pointed out that the mineralisation was similar to the occurrence at Croft Quarry (see above). Tschernich (1992) noted that

> ...white trapezohedra [of analcime] with reddish laumontite are found at Enderby, Leicestershire (Robert Ray, *pers. comm.*);

it is most probable that this occurrence refers to Warren Quarry. Tindle (2008) repeated Tschernich's description of analcime at Enderby.

BARYTE, $BaSO_4$

Croft Quarry, Croft

Baryte occurs as very thin, white to pink, curved tabular crystals (up to 5 mm long) that form rounded aggregates (up to 8 mm across; Figure 13) and irregular 'cockscomb' groups; with a pale yellow fluorescence under both shortwave ultra violet light (SUV) and long wave ultra violet light (LUV). The baryte has crystallised on analcime (that may have a coating of reddish-brown hematite) and is later in the paragenetic sequence than both generations of analcime (and hematite).

CALCITE, $CaCO_3$

Croft Quarry, Croft

Calcite occurs in a number of different associations and a bewildering array of habits. The crystals are usually colourless to white with occasional yellowish, pinkish or purplish tints. From a paragenetic perspective the deposition of calcite is complicated and it is evident that there are several generations.

Figure 13. An aggregate of white, thin tabular curved baryte crystals (8 mm across) on analcime (analcime-1?) coated with hematite-4. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0947); collected April 1995); field of view 20 mm.

Calcite-1

Cavities in veins of pink to red laumontite have been filled with white calcite (calcite-1) that shows a yellow to red fluorescence under both SUV and LUV. Pearson and Jeffrey (1997) noted that the laumontite was "intergrown with calcite rhombs"; however, such specimens have not been seen in the course of this investigation. The white calcite may be removed by treatment with a suitable dilute acid to reveal the underlying laumontite (see the Laumontite section). Pearson and Jeffrey (1997) described their fluid inclusion microthermometry studies using the calcite associated with the laumontite; in their discussion of the homogenisation temperatures (T_h), they noted that

> ...the inclusions within the early calcites associated with laumontite are in the range of 79°C to 244°C, with salinities ranging from 0.2 to 15.9 wt% NaCl equiv… which is interpreted as a mixing trend between fluids of different salinities.

Calcite-2

There appear to be two distinct generations of calcite associated with analcime and the first of these has been designated as calcite-2. The zeolite-filled cavity described by Jones and Langley (1931; see the Analcime section) was

> ...apparently filled with "calcite or quartz"…On closer examination the mineral showed perfect trapezohedra of analcime and cube-like rhombohedra of chabazite.

King (1973) noted that a specimen in the collections of the NHM (Figure 4, BM.1930,1047) was presumably related to this occurrence (see also K289-1930, NMW 83.41G.M.6599). Following his examination of Jones' specimens from Croft, King (1968; 1973) questioned the occurrence of chabazite ($(Ca_2(Al_4Si_8O_{24})\cdot 13H_2O$, chabazite-Ca), indicating that the crystals were essentially positive rhombohedra $\{10\bar{1}1\}$ with a rare modification involving the negative rhombohedron $\{20\bar{2}1\}$ and that they displayed a well-pronounced rhombohedral cleavage; using chemical and staining techniques this material was shown to be calcite (Figure 14). King (1973) noted that

> ...it is not difficult to see how Jones and Langley made this mistake, for the angles of the rhomb appear to be anomalously obtuse and the opaque white colouration is also deceptive.

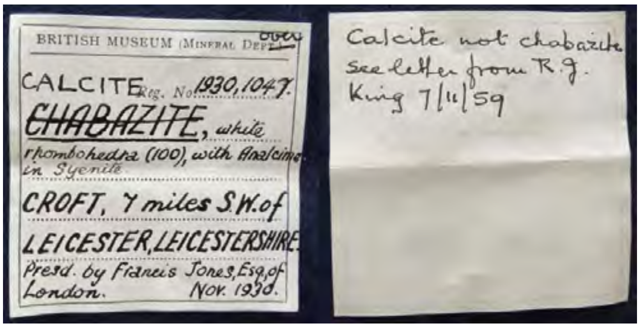

Figure 14. The obverse and reverse of the label for BM.1930,1047 (see Figure 4) indicating that the chabazite reported by Jones and Langley (1931) had been identified as calcite by Bob King in 1959. Frank Ince photographs, ©NHM reproduced with permission.

Figure 15. A group of rhombs of cream to pale yellowish-grey calcite (calcite-2); largest rhomb 18 x 16 x 11 mm. Croft Quarry, Croft, Leics. Neil Hubbard specimen (NH-47).

Figure 16. A pseudo-cubic crystal of cream calcite (17 mm on edge; calcite-3) with minor marcasite on pink analcime-1. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0116; collected 1987); specimen width 65 mm.

Figure 17. Pseudo-octahedral cream to pale brown calcite crystals (to 35 mm on edge; calcite-3) and globular calcite crystals (to 18 mm; also calcite-3) with both habits containing included microcrystals of marcasite and associated with white to cream analcime-2. Croft Quarry, Croft, Leics. Neil Hubbard specimen (NH-42); specimen width 95 mm.

Despite the reappraisal of the occurrence of chabazite (King, 1968; 1973), it was still included in a recent review of the geology and mineralogy of Croft Quarry (Manning, 2010); interestingly, that review also included the occurrence of rhombic calcite in the quarry. On BM.1930,1047 and K289-1930 the cream to yellowish-cream rhombs of calcite (calcite-2) are associated with pink analcime. King (1973) also described the occurrence of specimens of cloudy white and translucent calcite forming positive rhombohedra $\{10\bar{1}1\}$ modified by a bevel face $\{11\bar{2}0\}$ and stated that they attained a maximum size of 12 mm. The specimen shown in Figure 15 and a specimen in the author's collection (FI-1794) both exhibit well-formed rhombs that are similar to those described above, and the calcite-2 displays a bright orange-red fluorescence under both SUV and LUV.

Figure 18. A plate of cream calcite (20 mm thick; calcite-3) partly enclosing some "stalactites" of orange analcime (possibly analcime-1 pseudomorphs after laumontite) with galena and marcasite on the reverse side. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0844; collected 1993); specimen width 65 mm.

Figure 19. A group of complex crystals of calcite-3 (partly coated with or including pale red to brown hematite-4 or containing a clay-hematite layer on the surface or internally) associated with analcime, white "prisms" of calcite (possibly epimorphs after *aragonite*, i.e., calcite-5), fluorite-1 and fluorite-2 (the pale pinkish-yellow crystals above and to the right of the largest white "prism"). Croft Quarry, Croft, Leics. Frank Ince specimen (FI-1698; collected by Bill Swindell, October 1982); specimen width 75 mm.

Calcite-3

The second generation of calcite associated with analcime has been designated as calcite-3. Crystals up to 100 mm are quite common; although much larger crystals (up to 240 mm across) have been recovered (John Jones, *personal communication*). Some of the larger crystals contain colourless, transparent portions of calcite variety Iceland Spar; cleavage rhombs (up to 35 x 20 x 18 mm) were collected by Phil Jackman in 1996. The crystals of calcite-3 occur in a bewildering array of habits (modified scalenohedra and rhombs, "cubes" and "octahedra"; see figures 16, 17 and 18) and the crystals are usually cloudy white with occasional yellowish, pinkish or purplish tints. Some crystals are pale red to brown as they are coated with hematite; others may have a clay-hematite layer on the surface or internally (Figure 19). This generation of calcite sometimes displays a yellow, or dull red, fluorescence under LUV, and a yellow, or brighter red, fluorescence under SUV (Figure 20, see p. 12). It may be associated with analcime-2 and sulphide deposition (marcasite, chalcopyrite or galena). Calcite-3 also occurs in a lenticular habit: as pale orange crystals (to 35 x 8 mm) or smaller mid to dark reddish-brown, hematite-coated crystals (to 10 x 2 mm) associated with analcime-2 on analcime-1.

Pearson and Jeffrey (1997) described their fluid inclusion microthermometry studies using the calcite crystals associated with the later analcime. In their discussion of the homogenisation temperatures (T_h) they concluded that

> ...the data for the late calcites associated with analcime show a different pattern to that of the earlier calcite [with laumontite], with low and high salinity inclusions (0.4 to 16.7 wt% equiv.), but generally lower temperatures (41°C to 165°C). The lower salinity group of late calcite inclusions, which is more tightly clustered, may represent meteoric waters, whereas the higher salinity group shows a more scattered sub-horizontal trend, which is again consistent with variable mixing of two fluids.

Calcite-4

Specimens with two generations of smaller calcite crystals have been recovered (Figure 21, see p. 12). Both generations have a modified scalenohedral habit with crystals that possess a number of additional crystal faces. The later generation (calcite-4) occurs as opaque cream-coloured crystals (to 5 mm), with a dull red-orange fluorescence under both SUV and LUV. Calcite-4 partly coats an earlier generation of calcite (calcite-3) which occurs as translucent cream to pale yellow crystals (to 6 mm) associated with very small chalcopyrite crystals on analcime and displays a dull red fluorescence under both SUV and LUV.

Calcite-5 and calcite epimorphs

Calcite, as very small, white to cream, scalenohedra and/or rhombs (0.5–1 mm), with an orange-red to red fluorescence under SUV and a less marked orange-red to red fluorescence under LUV, is relatively common as crusts on earlier minerals (mainly analcime and calcite). This generation of calcite has been designated as calcite-5; it has a different habit from calcites-1–4 and appears to be later in the paragenesis.

Very small calcite crystals (up to 0.5 mm) with the habit of calcite-5 form epimorphs after a prismatic mineral (or minerals, see below) that have been traditionally labelled as "calcite epimorphs after laumontite". A specimen in the Neil Hubbard Collection (Figure 22) is composed of epimorphs with cavities that have an approximately rectangular cross section and this might be consistent with the original mineral having monoclinic symmetry; consequently, these specimens could be calcite epimorphs after laumontite. Other specimens exhibit a complex habit comprising a number of prisms (Figure 23). This second group of epimorphs have also traditionally been labelled as "calcite epimorphs after laumontite"; however, rather than the expected monoclinic symmetry, some of these epimorphs have a well-defined hexagonal appearance (Figure 24). In this group of epimorphs, it seems more likely that the original mineral was aragonite (Neil Hubbard, *personal communication*), with some of the crystals displaying remnants of the pseudohexagonal trillings formed by repeated contact twinning on {110}.

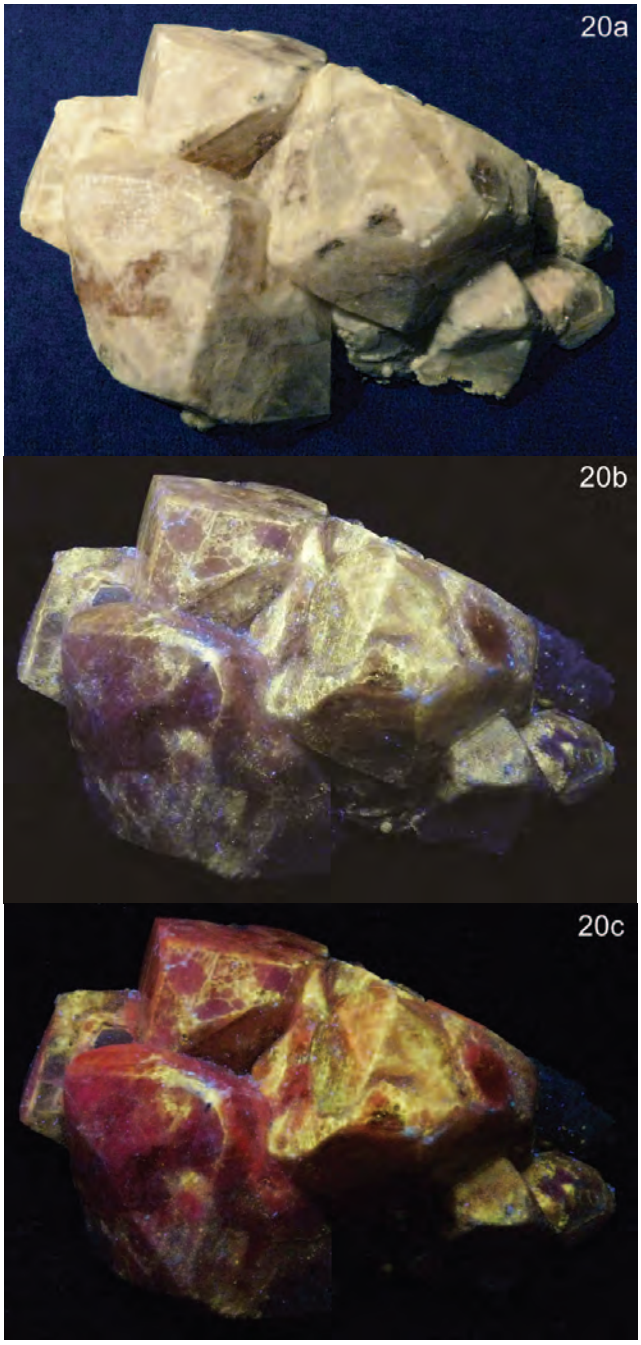

Figure 20. The appearance of a group of cream to light brown calcite crystals (calcite-3) in various wave lengths of light: 20a. visible, 20b. LUV and 20c. SUV. East Face, Croft Quarry, Croft, Leics. Frank Ince specimen (FI-1485; collected by Mike Smith, September 1977); specimen width 110 mm.

Figure 21. Translucent pale yellow modified scalenohedra of calcite-3 (to 6 mm) with some chalcopyrite, partly coated with cream modified scalenohedra of calcite-4 (to 5 mm) on an analcime-rich matrix. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0123; collected July 1992); specimen width 105 mm.

Figure 22. An interlocking mass of calcite epimorphs after prisms of laumontite?, a number of which have cavities with a rectangular cross section; the prisms are composed of very small cream scalenohedral crystals of calcite-5. Croft Quarry, Croft, Leics. Neil Hubbard specimen; specimen width 40 mm.

Enderby Hill Quarry, Enderby

King (1973) recorded the occurrence of microcrystalline calcite (rather than dolomite) in the "plaster-board" habit of palygorskite (see the Palygorskite section) on the east face of the quarry. This calcite is the last calcite to be included in the paragenetic sequence (calcite-7).

Granitethorpe Quarry, Sapcote

Eastwood *et al*. (1923) mentioned that joint-planes in the diorite were sometimes coated with green-stained calcite or opal (see the Quartz section) and that some of the joints were slickensided and contained a film of calcite.

Figure 23. A radiating group of calcite epimorphs after prisms of *aragonite?* on analcime-2; the prisms are composed of very small cream scalenohedral crystals of calcite-5. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0994); specimen width 20 mm.

Figure 24. Calcite epimorphs after prisms of *aragonite?* (to 20 mm) on colourless analcime-1; the prisms are composed of rounded rhombs of white calcite-5 (note the pseudohexagonal appearance and the definition of the twinning planes in of one of the epimorphs). Croft Quarry, Croft, Leics. Neil Hubbard specimen (NH-260; collected by Phil Jackman 7 August 1993); specimen width 75 mm.

Lane's Hill Quarry, Stoney Stanton

King (1973) noted the presence of calcite on a specimen from the Wale Collection (LEICS G587.1961.233). This specimen was recovered in 1940 from a vein on the north face of the bottom level of Lane's Hill Quarry, and showed three generations of Fe-rich dolomite[1] followed by calcite deposition. In the paragenetic context this generation of calcite has been designated as calcite-6 (as its deposition presumably predates that of calcite-7); however, its relationship with/to the sequence of calcite deposition at Croft and the Enderby quarries (calcites-1–5) is unclear.

Sapcote Quarry, Sapcote

Eastwood *et al*. (1923) recorded the occurrence of veins of calcite in "rammel" bands and King (1973) suggested that this probably refers to an occurrence at Windmill Quarry, Sapcote (see Table 1).

Warren Quarry, Enderby

Evans and King (1962), King (1973) and Tien (1973) recorded the occurrence of both fine-grained and more coarsely crystallised calcite with palygorskite and dolomite at Warren Quarry. The calcite (presumably calcite-7) and dolomite appeared to line the walls of joints and veins in the diorite that were filled with an intergrowth of calcite and fibrous palygorskite.

CERUSSITE, $PbCO_3$

Croft Quarry

A specimen collected by Phil Jackman in 1995 (now FI-2437) has very small acicular and prismatic crystals of colourless to cream cerussite, some with a bright yellow fluorescence under LUV (less-marked under SUV), on dark grey cubo-octahedral galena crystals associated with analcime-2. A photograph posted by Steve Rust on the Croft Quarry page of mindat.org also shows some very small white to pale yellow acicular crystals of cerussite 'on corroded galena and limonite replaced pyrite' (www.mindat.org/photo-163230.html; accessed April 2016).

CHALCOPYRITE, $CuFeS_2$

Croft Quarry

Pearson and Jeffrey (1997; see also Tindle, 2008) noted that chalcopyrite occurred as tiny inclusions within analcime and also as minor disseminations in the host diorite and Manning (2010) included chalcopyrite amongst the minerals that occur at Croft Quarry. In his review of the occurrences of chalcopyrite in Leicestershire, King (1998) stated that

[1] Fe-rich dolomite: King (1973) used the term 'ferroan dolomite' to describe some iron-containing dolomite specimens. Bayliss *et al*. (2005) have recommended that the name 'ferroan dolomite' should be discontinued; consequently, such material from the exposures of the SLDC will be described as Fe-rich dolomite (however, see Bridges *et al*. (2014) for a discussion of the issues related to the composition and naming of the dolomite group minerals).

> ...chalcopyrite has been found…as minute (c.1.8 mm) single tetrahedral crystals sparingly dispersed on an early generation of analcime, associated with similar-sized crystals of marcasite. The majority of the occurrence was on No. 8 Level. Many crystals show varying degrees of oxidation, and may then be confused with similarly-oxidised marcasite.

In some cases, the presence of green secondary copper minerals can be an aid to the identification of the chalcopyrite.

In the mid-1990s specimens were found that comprised groups of small yellow chalcopyrite crystals (up to 1 mm) with a purple-brown iridescence that were associated with fluorite-3, calcite-3? and both analcime-1 and analcime-2. On other specimens the chalcopyrite also occurred as small tetrahedral crystals, usually a golden yellow colour, some with a deep purplish-blue iridescence, associated with white microcrystalline calcite (calcite-5?) and cream to pink calcite (calcite-3?) on colourless or orange analcime (Figure 25).

Figure 25. Aggregates of small tetrahedral chalcopyrite crystals (to 2 mm) with some minute globules of malachite, and (out of focus) cubes of colourless fluorite-3 on cream calcite-3 with pink analcime-2. Croft Quarry, Croft, Leics. Roy Starkey specimen (RES 0521-045); field of view 15 mm.

CHLORITE GROUP, $[(Mg,Fe)_5Al](AlSi_3)O_{10}(OH)_8$ (clinochlore–chamosite)

Lane's Hill Quarry, Stoney Stanton

King (1973) described a specimen containing chlorite that was recovered in 1940 from a vein on the north face of the bottom level of Lane's Hill Quarry (LEICS G587.1961.233; a specimen from the Wale Collection). This specimen contained well-crystallised, dark green microcrystals of chlorite (possibly clinochlore) that occurred with three generations of Fe-rich dolomite and later calcite (calcite-6).

DATOLITE, $CaBSiO_4(OH)$

Croft Quarry, Croft

In a field trip report for a visit in June 1974, Bob King noted that

> ...datolite had been considered a rare species…for many years, but the material discovered must surely compare favourably with Cornish and Scottish localities [R.J. King, Russell Society Newsletter, **No. 2**, p. 16].

Unfortunately, despite extensive searches of a number of collections, no specimens related to this report have been found. As noted below, a specimen labelled as datolite in the King Reserve Collection (K57-C1) has been shown to be prehnite (see the Prehnite section); consequently, the occurrence of datolite remains to be confirmed.

DJURLEITE, $Cu_{31}S_{16}$

Lane's Hill Quarry, Stoney Stanton

King (1973) described a small specimen (18 mm x 16 mm x 12 mm) containing some copper mineralisation that was found on the dumps of waste rock at Lane's Hill Quarry by Mr R.P.W. Mayes in 1963. The copper mineralisation was initially identified as bornite, Cu_5FeS_4, and took the form of a small, black (with a bronze-colouration) metallic mass (6 mm in diameter) that was embedded in coarsely crystalline brown Fe-rich dolomite with minor anhedral quartz. Subsequent examination suggested that it might be chalcocite, Cu_2S, and it also showed well-developed fringes of a soot-like mineral that appeared to be secondary chalcocite, Cu_2S; however, further analysis at the NHM confirmed that the black to bronze-coloured mineral was djurleite. At that time (1964–5) this appeared to be the first record of djurleite in the UK. A diligent search of the dumps (by Bob King and Mr Mayes) provided other specimens of the Fe-rich dolomite vein (up to 175 mm wide) that enclosed pea- to golf ball-sized masses coated with thin films and encrustations of vivid green malachite (King, 1973); unfortunately, these larger specimens of djurleite were not located in the course of this investigation.

DOLOMITE, $CaMg(CO_3)_2$

Both dolomite (*sensu stricto*) and Fe-rich dolomite, $Ca(Mg,Fe)(CO_3)_2$, (see footnote on p. 13) are associated with the quarried exposures of the SLDC. It is worth noting that King (1973) concluded that, apart from the siderite-containing nodules in the Coal Measures,

> ...many of the Leicestershire occurrences of siderite [$FeCO_3$] described in the literature have been discredited

and have been shown to be Fe-rich dolomite.

Croft Quarry, Croft

King (1973) recorded that dolomite was present in veins, up to 35 mm wide, running through the Triassic breccia and into open joints in the Ordovician quartz-diorite. Elongated cavities that were parallel to the walls of the vein sometimes contained well-developed, very small, white to pinkish, rhombic dolomite crystals; calcite (calcite-7) was the only associated mineral. Manning (2010) included dolomite amongst the minerals that occur at Croft Quarry.

Lane's Hill Quarry, Stoney Stanton

King (1973) described a specimen containing Fe-rich dolomite that was recovered in 1940 from a vein on the north face of the bottom level of Lane's Hill Quarry (LEICS G578.1961.233; a specimen from the Wale Collection). This specimen contained three generations of mid-brown Fe-rich dolomite with later pink calcite (calcite-6) and well-crystallised, dark green microcrystals of chlorite. This vein also enclosed small masses of djurleite (see the Djurleite section) that were associated with thin films and encrustations of vivid green malachite (King, 1973). King (1973) also described a large vein of Fe-rich dolomite at Lane's Hill Quarry (investigated by Mr R.P.W. Mayes, who referred to it as "siderite") that contained large transparent, colourless quartz crystals (quartz-3). Specimens were donated to the LAMS Collection (LEICS G198.1963.1-2) and, although they are labelled "Sapcote", King (1973) thought that they must have "originated from the former Lane's Hill Quarry" and that they showed

> ...a complex paragenetic sequence of mineralizing events, commencing with: 1. Ferroan dolomite-pyrite (the latter is now highly oxidized, and largely goethite); 2. Ferroan dolomite-quartz; 3. Ferroan dolomite. The final deposition of the species takes euhedral form with crystals showing rhomb faces up to 6 mm. in length. The colour ranges from greyish-brown…to greyish-orange.

Warren Quarry, Enderby

Evans and King (1962), King (1973) and Tien (1973) recorded the occurrence of dolomite and palygorskite together with both fine-grained and crystalline calcite (calcite-7). The dolomite and calcite appeared to line the walls of joints and veins in the diorite that were filled with an intergrowth of fine-grained calcite and fibrous palygorskite. King (1973) also noted that the southern face of the quarry contained a section of a broad Triassic wadi cut into the diorite; the lower part of the wadi being filled by a dolomite-cemented breccia, above which was a bed of dolomite (up to 162 mm thick).

EPIDOTE, $Ca_2Al_2(Fe^{3+},Al)Si_3O_{12}(OH)$

Epidote is an accessory mineral in the SLDC and there appear to be two distinct generations, designated here as epidote-1 (associated with diorite xenoliths in the SLDC) and epidote-2 (associated with the early phases of mineralisation and pegmatites in the SLDC); however, only a limited number of occurrences will be described.

Calver Hill Quarry, Sapcote

Hill and Bonney (1878) noted the occurrence of epidote.

Croft Quarry, Croft

In his discussion of the relationship of the deposition of epidote to other minerals, King (1973) noted that

> ...in the vein mineralisation [epidote-2] precedes zeolitisation, and there is usually a lining of typically green epidote on both flanks of the veins, associated with a little hematite. This has, in the past, caused minor confusion, as the underlying green colour tends to tint the overlying younger white or colourless minerals [analcime and calcite] with shades of green.

On a number of specimens yellowish-green to green epidote-2 is associated with small flakes and fractured crystals of molybdenite.

Granitethorpe Quarry, Sapcote

Harrison (1881) described the exposures of the SLDC (referring to them as "syenite") at Sopewell Quarry (see Table 1), noting that "epidote too occurs, and may be known by its apple-green tint", together with pyrite and "some large crystals of pink feldspar"; it seems likely that this is an occurrence of epidote-2 in a pegmatite. Even though the quarry was flooded, King (1973) recorded that

> ...it is still possible to find minor amounts of epidote [epidote-1]…in the form of nests of granules and crystals completely enclosed within the tonalite, presumably representing an original xenolith. The deposition of the epidote preceded that of the associated pyrite.

Lane's Hill Quarry, Stoney Stanton

King (1973) reported that epidote (epidote-2) occurred in the granite pegmatite veins that appeared to be relatively common at one time. Eastwood *et al.* (1923) may have been referring to a similar occurrence of epidote-2 in the Top Quarry (see Table 1), noting that

> ...this rock is very coarse grained, and a hand-specimen shows large pink crystals of feldspar and green radiating aggregates of epidote.

Sapcote Quarry, Sapcote

Hill and Bonney (1878) noted that "Feldspar, epidote, and hornblende, [are] coarsely crystallized together"; it is likely that this is another occurrence of epidote-2 in a pegmatite.

FELDSPAR GROUP

A typical description of the igneous rocks of the SLDC is that given by Pearson and Jeffrey (1997), who noted that (at Croft Quarry)

> ...the primary mineralogy of the diorites consists of euhedral plagioclase, augite, and hornblende set in a granophyric ground mass of quartz and alkali feldspar.

Whilst the minerals of the feldspar group can be seen in thin sections, it is unusual for them to be found as macroscopic, euhedral crystals.

Coal Pit Lane Quarry, Enderby

At a quarry to the southeast of Enderby (presumably Coal Pit Lane Quarry), Hill and Bonney (1878) noted that the SLDC (that they referred to as "syenite") had

> ...a compact groundmass, with numerous small glittering feldspar crystals, many of them plagioclase.

Croft Quarry, Croft

Carney and Pharaoh (1999) noted the occurrence of a

> ...massive, pale grey, inequigranular medium- to coarse-grained tonalite. This is characterised by common large crystals of white euhedral plagioclase, up to 6 mm long.

Some very small cream to light brown (partly hematite-coated) feldspar-like crystals (to 1 mm) are embedded in a matrix of altered quartz-diorite and associated with hematite-covered quartz and chlorite?, together with analcime, baryte and calcite (see FI-0946).

Granitethorpe Quarry, Sapcote

Harrison (1881) described the exposures of the SLDC (referring to them as “syenite”) at Sopewell Quarry (see Table 1) and mentioned the occurrence of “some large crystals of pink feldspar” associated with pyrite and apple-green epidote. It is likely that this is an occurrence of feldspar in a pegmatite.

Lane’s Hill Quarry, Stoney Stanton

In their description of the exposues in Top Quarry (see Table 1), Eastwood *et al*. (1923) indicated that

> ...this rock is very coarse grained, and a hand-specimen shows large pink crystals of feldspar and green radiating aggregates of epidote;

This is probably an occurrence of feldspar in a pegmatite. They also mentioned that in a thin section

> ...the most prominent [feldspar] consists of large crystals, up to 0.8 ins [20 mm]…of a microperthite of albite, probably with orthoclase.

Sapcote Quarry, Sapcote

Hill and Bonney (1878) noted that “Feldspar, epidote, and hornblende, [are] coarsely crystallized together”. It is likely that this is another occurrence of feldspar in a pegmatite.

FLUORITE, CaF_2

Croft Quarry, Croft

In a report written in 2006 (following the evaluation of Croft Quarry as a Regionally Important Geological Site), it was recorded that

> ...topaz and fluorite form part of an early hydrothermal phase of alteration of the quartz-diorite [Gill Weightman, *personal communication*]

and Manning (2010) included fluorite amongst the minerals that have been recorded from Croft Quarry; however, neither author provided a description. It appears that the occurrence of fluorite was first recognised in the late 1980s; although, since then, it has been found on material that was collected in the early 1980s. It is evident that there are three generations of fluorite each of which has a different habit.

Fluorite-1

The first generation of fluorite (designated as fluorite-1) occurs as very small (<1 mm), lustrous, colourless dodecahedra (XRD: NHM 7019F, April 1988; Neil Hubbard, *personal communication*). On specimen FI-1698 (Figure 26) these crystals have a dull yellowish fluorescence under both SUV and LUV. This generation of fluorite is associated with a later generation of colourless to pale yellow fluorite (fluorite-2; see below), chalcopyrite, analcime and at least two generations of calcite: calcite-3 (some with a red surface coating of hematite), and calcite-5 (possibly as pseudomorphs after aragonite).

Fluorite-2

Aggregates of colourless to pale yellow (Figure 26) or pale greenish-blue (Figure 27), globular, isotropic masses (to 5 mm), with a markedly-pitted surface or a coating of extremely small crystals constitute a second generation of fluorite. The colourless to pale yellow crystals display a lilac to purple fluorescence under LUV and a dull yellow fluorescence under SUV; the pale greenish-blue crystals display a bright lilac to purple fluorescence under LUV that is less marked under SUV. This generation of fluorite is associated with analcimes-1–2, calcite-3 (some with a red surface coating of hematite), calcite-5, fluorite-1 and chalcopyrite.

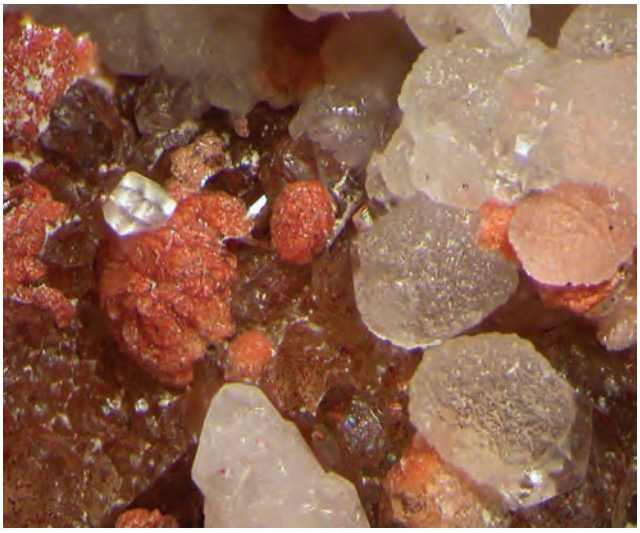

Figure 26. A minute (0.3 mm) lustrous, colourless, dodecahedral fluorite crystal (fluorite-1) on red calcite (calcite-3?) and another crystal of fluorite-1 partly enclosed by pale yellow fluorite-2 (bottom right), together with white calcite (calcite-5) on colourless and pink analcime. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-1698; collected by Bill Swindell in 1982); field of view 4 mm.

Figure 27. Globular aggregates of minute pale greenish-blue crystals of fluorite-2 associated with white calcite (calcite-5?), pale orange analcime and minor chalcopyrite. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0082); field of view 10 mm.

Fluorite-3

"Simple", isotropic cubes (up to 7 mm on edge) that are colourless to pale yellow (Figure 28) have been designated as a third generation of fluorite. These crystals display a dull yellowish or lilac fluorescence under LUV and a yellowish fluorescence under SUV. Some of the cubes have slightly pitted crystal faces and may be elongated along one axis. A number of specimens have been examined and, in each case, this generation of fluorite was the last mineral to be deposited. Fluorite-3 may be variously associated with analcimes-1–2, calcite-3 (some with a red surface coating of hematite), calcites-4–5 and chalcopyrite; on other specimens, fluorite-3 is associated with groups of small "tetrahedral" chalcopyrite crystals, analcime-1, calcite-3 and calcite-5.

No specimens have been seen where any of the three generations of fluorite have been enclosed by later minerals; indicating that the fluorite crystallisation is very late in the paragenesis.

Figure 28. Pale yellow cubes of fluorite-3 (to 5 mm), with some 'pitting' of the crystal faces, on analcime-2. Croft Quarry, Croft, Leics. Steve Rust specimen and photograph, reproduced with permission.

GALENA, PbS

Croft Quarry, Croft

Galena occurs as small, dull grey cubes (to 2 mm on edge) with analcime, marcasite, calcite-3 and, occasionally, cerussite. It also occurs as groups of more lustrous, grey cubo-octahedral crystals (to 2 mm) that may be associated with chalcopyrite, analcime and calcite (Figure 29). Photographs posted by Steve Rust on the Croft Quarry page of mindat.org show "corroded galena and limonite replaced pyrite" on analcime, together with some very small white to pale yellow acicular crystals of cerussite (www.mindat.org/photo-163230.html; accessed April 2016) and an oxidised galena crystal on analcime (www.mindat.org/photo-8846.html; accessed April 2016).

Figure 29. Small lustrous to dull grey cubo-octahedral crystals of galena with white calcite (calcite-5?) and colourless to pale pink analcime-2. Croft Quarry, Croft, Leics. Neil Hubbard specimen (NH-693); field of view 15 mm.

GOETHITE, α-FeO(OH)

Croft Quarry, Croft

King (1973) noted that microscopic spheroids of goethite (singly or in groups) occurred on quartz in association with calcite. Manning (2010) included goethite amongst the minerals that occur at Croft Quarry. On the Croft Quarry page of mindat.org, Steve Rust noted that "rusty spots of goethite replaced pyrite" were associated with a small cubo-octahedral galena crystal (with some cerussite alteration) on analcime (www.mindat.org/photo-8846.html; accessed April 2016).

Lane's Hill Quarry, Stoney Stanton

The pyrite that occurred with the Fe-rich dolomite has been oxidised and is now largely goethite (King, 1973).

HEMATITE, α-Fe_2O_3

Croft Quarry, Croft

There appear to be at least four generations of hematite deposition. King (1973) noted that an early generation of hematite (hematite-1) could give rise to a pink tint in the overlying analcime-1. Analcime-1 can be orange to red as a result of included hematite (hematite-2) and analcime-2 can also be orange to red as a result of included hematite (hematite-3). A later generation of hematite (hematite-4) occurs as very small balls of a dark red coating on analcime (Figure 9), as dark red-brown earthy coatings on analcime and analcime epimorphs after laumontite (Figure 11). Hematite-4 is associated with calcite-3 and it may be mixed with a clay mineral, as a layer on the surface or internally in the calcite (see Figure 19); it also occurs as a coating on analcime that is associated with baryte (Figure 13). Manning (2010) included hematite amongst the minerals that occur at Croft Quarry.

HOLLANDITE, $Ba(Mn^{4+},Mn^{2+})_8O_{16}$

Croft Quarry, Croft

In their comments on the manganese and palygorskite mineralisation that occurred on joint faces in the quartz-diorite and the Triassic basal breccia, Pearson and Jeffrey (1997) reported hollandite as a minor component of the manganese ‘wad’ that was associated with palygorskite and dolomite; they noted that the ‘wad’ was mainly pyrolusite.

HORNBLENDE SERIES, $(Ca,Na)_2(Mg,Fe^{2+},Fe^{3+},Al)_5(Al,Si)_8O_{22}(OH)_2$

Hornblende series minerals are commonly observed in thin sections of the diorite (Pearson and Jeffrey, 1997) but rarely as macroscopic, euhedral crystals.

Coal Pit Lane Quarry, Enderby

At a quarry to the southeast of Enderby (presumably Coal Pit Lane Quarry), Hill and Bonney (1878) indicated that

> ...here and there are irregular dull green patches, sometimes half an inch [12 mm] or so in diameter, the smaller of which rather resemble decomposed hornblende; the larger, nodes [*sic*] in which much of this mineral is present.

It is likely that this is an occurrence of hornblende in a pegmatite.

Sapcote Quarry, Sapcote

Hill and Bonney (1878) noted the occurrence of “Feldspar, epidote, and hornblende, coarsely crystallized together”. It is likely that this is another occurrence of hornblende in a pegmatite.

ILLITE-BRAMMALITE series, $(K,Na)_{0.65}Al_2\square Al_{0.65}Si_{3.35}O_{10}(OH)_2$

Illite, $K_{0.65}Al_2\square Al_{0.65}Si_{3.35}O_{10}(OH)_2$, and brammallite, $Na_{0.65}Al_2\square Al_{0.65}Si_{3.35}O_{10}(OH)_2$, are the end-member names of a series of incompletely-investigated members of the interlayer-deficient, dioctahedral mica group (Back, 2014).

Croft Quarry, Croft

A specimen listed in the on-line database of the collections of the Oxford University Museum of Natural History (OUMNH 28872; donated by John Cooper) is described as

> Illite or brammallite? (white spherular aggregates) on analcime…Croft quarry, Croft, near Leicester, Leicestershire, England…Originally catalogued as: Illite - white spherular aggregates on analcime, is this Na-rich variety brammallite?

A similar-looking specimen (Figure 30) has small cream to very pale greenish-cream spherules (to 1 mm) of *illite-brammallite* that display a dull yellow fluorescence under LUV which is much less marked under SUV. These spherules form an incomplete crust on colourless to white analcime-2, associated with one of the later generations of calcite as small cream scalenohedral crystals (to 2 mm), possibly calcite-4. Further analysis will be required before it can be confirmed whether this material is illite or brammallite.

KAOLINITE, $Al_2Si_2O_5(OH)_4$

Croft Quarry, Croft

King (1968) noted that the feldspars adjacent to the mineralised veins in the pink quartz-diorite showed varying degrees of decomposition leading to their sericitisation and eventually kaolinisation; whereas the feldspars in the grey diorite were unaltered. A similar occurrence of kaolinite was noted by Pearson and Jeffrey (1997) in their description of the prehnite–pumpellyite wall-rock alteration surrounding the zeolite-containing veins. A very pale green clay? mineral, that has been tentatively identified as kaolinite, occurred with magnetite and molybdenite on altered quartz-diorite (see the Magnetite section).

Stoney Stanton

Two specimens in the collections of the LAMS (LEICS G1235.1951.49 and LEICS G578.1961.49) are labelled “Kaolin. Stoney Stanton, S. Leics.”. King (1973) noted that they

> ...are typical of down-washed and ground water remobilised palygorskite

(see the Palygorskite section); consequently, this occurrence of kaolinite remains to be confirmed.

LAUMONTITE, $CaAl_2Si_4O_{12}\cdot 4H_2O$

The chemical formula of laumontite given above is that used by Back (2014).

Croft Quarry, Croft

King (1968) recorded the occurrence of laumontite. King (1973) described its occurrence in more detail noting that

> ...splendid groups do occur…commonly in the form of rosettes and groups of long equant cross-sectioned divergent prisms, associated with colourless crystalline calcite…the colour range [white to red; see below] is identical to that of Huncote, and it is often difficult [to] differentiate unlabelled material from the two localities. The freshly quarried material from Croft probably possesses the higher lustre of the two [see Figure 31].

He also noted that laumontite displayed a faint pink fluorescence under both SUV and LUV (although, some of the laumontite specimens in the author’s collection also display a dull yellowish fluorescence under both SUV and LUV). Pearson and Jeffrey (1997) stated that

> ...laumontite in-fills veins and cavities as prismatic laths that form rosettes in association with microcrystalline calcite. It also occurs as equant prisms up to 18 cm [*sic*; see below] long (King, 1973) inter-grown with calcite rhombs [calcite-1?]. Although very little laumontite remains because of quarrying activity, where it does occur it generally precedes the formation of analcime.

This section of their article referred to any of the occurrences of laumontite in the SLDC. The maximum length of the laumontite crystals given by King (1973) is 38 mm (see Huncote Quarry, below). Interestingly, whilst the dimensions of the laumontite from Croft Quarry are not given, King (1973, Figure 36) shows an image of K1085-47 (NMW 83.41G.M6856) and the prisms of laumontite on the original specimen are about 45 mm long; consequently, 18 cm prisms of laumontite seem most unlikely. Dyer and Wilson (1988) included an image of red laumontite in their description of zeolites and Wilson *et al*. (2003) listed Croft Quarry as one of the occurrences of laumontite in the British Isles.

A specimen collected in 1985 was recovered from a vein of pink laumontite with minor colourless to red analcime lining cavities filled with white calcite-1. Removal of the calcite using dilute acid revealed laumontite (Figure 32) as an interlocking mass of pink to white, almost square, prisms (to 6 x 6 x 25 mm) some with oblique terminations $(\bar{2}01)$, see Dana and Ford (1932). Other specimens collected in 1983 contain pink prismatic crystals up to 30 mm long. Despite anecdotal reports of the instability of laumontite from Croft Quarry (see the 'Leonhardite' section), these specimens appear to be reasonably stable; as are other specimens collected from the surrounding area.

Analcime-1 has replaced and/or formed epimorphs after a prismatic mineral, most probably laumontite (see the Analcime section and figures 11, 12 and 18). Calcite-5 has formed epimorphs after a prismatic mineral; the cavities in these epimorphs have a rectangular cross section, indicating that the original mineral might have been laumontite (see the Calcite-5 section and Figure 22).

Enderby

Tschernich (1992), reporting a personal communication from Robert Ray, mentioned that reddish laumontite had been found with white trapezohedra of analcime at Enderby, Leicestershire; it is most probable that this occurrence refers to Warren Quarry, Enderby. Tindle (2008) repeated Tschernich's description of laumontite at Enderby.

Figure 30. Small cream to very pale greenish-cream spherules (to 1 mm) of *illite-brammallite* partly coating colourless to white analcime-2 and associated with one of the later generations of calcite as small cream scalenohedral crystals (to 2 mm), possibly calcite-4. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0905; collected by John Cooper, 12 November 1994); specimen width 65 mm.

Figure 32. Prisms of white to pink laumontite (to 25 x 6 x 6 mm), some with oblique terminations, and minor colourless to pink crystals of analcime on altered quartz-diorite (this specimen has had the white calcite-1 that enclosed the laumontite removed using dilute hydrochloric acid). Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0233; collected April 1985); specimen width 85 mm.

Figure 31. Prisms of white to cream laumontite (to 15 mm), some with oblique terminations, partly coated with minute crystals of pink to brown analcime? on altered quartz-diorite. Croft Quarry, Croft, Leics. NHM specimen (BM 1964,R10262; Russell Collection); specimen length 100 mm; Frank Ince photograph, ©NHM reproduced with permission.

Figure 33. A cavity (115 x 35 mm) lined with rough prisms of pinkish-buff laumontite (to 18 mm) with a minor surface encrustation of prehnite? on altered quartz-diorite. Huncote Quarry, Huncote, Leics. NHM specimen (BM.1932,1318; donated by S.H. Langley, 22 October 1932); specimen length 135 mm; Frank Ince photograph, ©NHM reproduced with permission.

Huncote Quarry, Huncote

King (1968) noted that laumontite was probably the most common zeolite at Huncote Quarry. King (1973) described the occurrence in more detail indicating that

> ...magnificent specimens of laumontite…occur as veins, up to 7 mm wide, and occasionally as thin films on joint surfaces. The material is always crystalline, forming rosettes of subhedral radiate plates, up to 38 mm in length, the average being 18 mm. There is a great deal of mutual interference between individual crystals, and no terminating faces have been observed, with the possible exception of one, (001). The material is stained by iron oxides and the colour varies between white and English-red…the most common being pastel-red [see Figure 33, p. 19].

Wilson *et al*. (2003) included Huncote Quarry in their list of the occurrences of laumontite in the British Isles. Manning (2010) noted that laumontite was amongst the minerals that occur at Huncote Quarry.

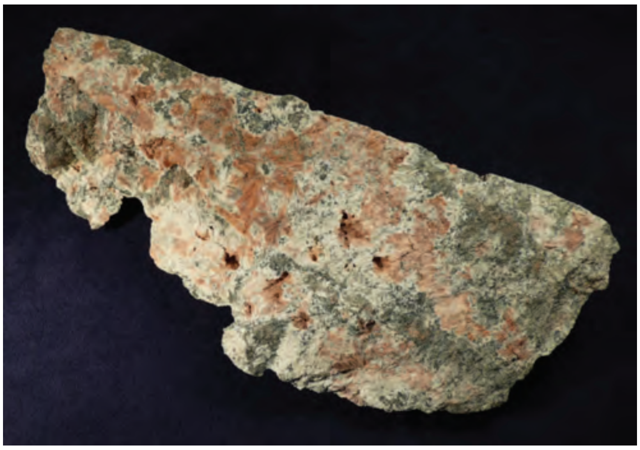

Figure 34. White powdery 'leonhardite' replacing prisms of pink to red laumontite on altered quartz-diorite. Level 8, West Face, Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0278, NK 336-1975, K75-5; collected by Bob King, 6 June 1975); specimen length 220 mm.

Figure 35. Masses of distinctly magnetic, black magnetite, with some small crystals having an octahedral habit (to 4 mm on edge), associated with aggregates of lustrous grey sub-hexagonal plates of molybdenite (to 3 mm) and a very pale green clay? mineral (possibly kaolinite) on altered quartz-diorite. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0296; collected by Bill Swindell, 1980s); field of view 15 mm.

'Leonhardite', $Ca_4[Al_8Si_{16}O_{48}]{\cdot}{\approx}14H_2O$

In their recommendations for the nomenclature of zeolite minerals, Coombs *et al*. (1997) stated that

> ...leonhardite is discredited as the name of a separate species. It is an H_2O-poor variety of laumontite.

Croft Quarry

King (1973) described a white, sometimes powdery, alteration product of laumontite, with a cream-coloured fluorescence under SUV, that occurred at Croft Quarry and he identified it as 'leonhardite' (see Figure 34). Interestingly, he indicated that laumontite from Croft and Huncote quarries is remarkably resistant to this form of alteration.

'Limonite', $FeO(OH){\cdot}nH_2O$?

Whilst 'limonite' is no longer a recognised mineral species (Bayliss, 2000), there are a few records of its occurrence in association with the SLDC.

Croft Quarry, Croft

A photograph posted by Steve Rust on the Croft Quarry page of mindat.org shows "limonite replaced pyrite" associated with oxidised galena and some very small white to pale yellow acicular crystals of cerussite (www.mindat.org/photo-163230.html; accessed April 2016).

Warren Quarry, Enderby

King (1973) recorded brown films and dendrites of 'limonite' on palygorskite.

MAGNETITE, Fe_3O_4

Croft Quarry, Croft

In a letter to Bob King (6 August 1985, in the King Archives), Neil Hubbard indicated that John Faithfull had found magnetite on the lowest level the previous year. He went on to describe the occurrence when it was examined in 1985 as

> ...a thin flat layer which is horizontal and extends for about a foot, at one end the magnetite seem [*sic*] is in fairly clean tonalite…but away from this the magnetite occurs as euhedral crystals up to about 8 mm in a hard whitish clay-like mineral (much of this now appears to be altered tonalite)…On washing the specimens, some of them were found to have molybdenite with the magnetite, there is also a very small amount of pyrite.

In his reply to this letter (6 August 1985, in the King Archives) Bob King implied that magnetite had been found in 1931; however, neither the identity of the finder nor a description of the material were mentioned. A specimen collected by Bill Swindell in the 1980s is shown in Figure 35. The magnetite and molybdenite are thought to be early in the paragenesis.

MALACHITE, $Cu_2(CO_3)(OH)_2$

Croft Quarry, Croft

Very small spherules and encrustations of pale to mid-green malachite are associated with oxidised chalcopyrite (see Figure 25); indeed, King (1998) noted that the presence of green oxidation products can be useful in distinguishing chalcopyrite from marcasite.

Lane's Hill Quarry, Stoney Stanton

In his description of some oxidised copper minerals, King (1973) noted that

> ...malachite occurred intimately associated with djurleïte [*sic*] in a large vein of ferroan dolomite [Fe-rich dolomite]. Present usually as thin films and encrustations, it occasionally occurred as minute single crystals, 0.5 to 1.1 mm in length. These were very striking, being vivid green in colour.

MANGANITE, MnO(OH)

Croft Quarry, Croft

During the removal of the overburden from an extension of the quarry towards Huncote in 1987, a thick layer of manganese mineralisation was revealed at the unconformity between the Ordovician quartz-diorite and the Triassic sediments (see the Pyrolusite section). Analysis of a sample of this material showed that it contained manganite (*circa* 23%) and pyrolusite (*circa* 77%) (XRD: NMW X-2343 and X-2344; Tom Cotterell, *personal communication*).

MARCASITE, FeS_2

Croft Quarry, Croft

Marcasite occurs as groups and single crystals of very small, light brass-yellow tabular crystals (up to 1 mm) that frequently show signs of oxidation. King (1998) noted that the partly oxidised marcasite might be confused with chalcopyrite; although the chalcopyrite (usually as small "tetrahedral" crystals) may be associated with very small spherules of green oxidation products. The marcasite is associated with analcime-2, calcite-3, chalcopyrite and galena.

MICA GROUP

Croft Quarry, Croft

A photograph posted by Steve Rust on the Croft Quarry page of mindat.org shows a small

> ...partly altered white mica crystal on analcime with calcite. These mica crystals are commonly nucleated around crystals of chalcopyrite and pyrite [www.mindat.org/photo-163231.html; accessed April 2016].

Pearson and Jeffrey (1997) noted that the prehnite-pumpellyite wall-rock alteration haloes that surround the zeolite-containing veins in the quartz-diorite contained minor sericite, (a variety of muscovite, $KAl_2\square AlSi_3O_{10}(OH)_2$), associated with prehnite, Fe-rich pumpellyite, chlorite, quartz and analcime, and also minor kaolinite and smectite.

MOLYBDENITE, MoS_2

Croft Quarry, Croft

King (1968) recorded the occurrence of molybdenite in veins associated with analcime, rhombic calcite, laumontite and prehnite, and Manning (2010) included it amongst the minerals that occur in the quarry. King (1973) described specimens as consisting of

> ...a thin granite-pegmatite vein running through the 'pinked' tonalite. The only minerals present are the essential components of the pegmatite and molybdenite… [which]…forms small foliated masses and nests of very thin plates, up to 3 mm in diameter. They stand…at right angles to the walls of the vein. The plates are often strongly malformed and curved round quartz and feldspar crystals;

however, he questioned the association of molybdenite with the zeolites.

In a field trip report for a visit in June 1975, Roger Harker noted that

> ...the need to find molybdenite *in situ* in this geological situation has always been highly desirable. Its relationship with the zeolites [analcime and laumontite] has never been understood. On this occasion its relationship was well displayed, several problems thus being resolved, but creating many more as a result. Molybdenite seemed to be everywhere" [R.S. Harker, *Russell Society Newsletter*, **No. 3**, p. 7].

This report implies that molybdenite does occur with the zeolites and there are a few specimens where very small flakes of molybdenite are surrounded by analcime (analcime-1?) and/or calcite (calcite-1?) (Neil Hubbard, *personal communication*). Carney and Pharaoh (1999) also noted that the

> ...occurrence of molybdenite in association with these secondary minerals [albite and analcime] is unusual and not understood fully.

The molybdenite is likely to be early in the paragenesis; consequently, its association with analcime remains to be explained.

In 1985 small amounts of molybdenite, associated with magnetite and pyrite, were collected *in situ* from the lowest level (Neil Hubbard, *personal communication*; see Magnetite section). A specimen collected in the 1980s contains aggregates of lustrous, mid-grey hexagonal plates (to 3 mm), small black octahedral crystals of magnetite and a very pale green clay mineral (possibly kaolinite) on altered quartz-diorite (Figure 35). The molybdenite and magnetite are thought to be early in the paragenesis.

PALYGORSKITE, $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4H_2O$

Croft Quarry, Croft

Pearson and Jeffrey (1997) noted that palygorskite occurred within the basal conglomerates of a Triassic wadi in the Caledonian basement and along joints in the quartz-diorite immediately below the unconformity. It was intimately associated with dolomite, and with manganese 'wad' (enriched with Cu, Pb and Ba) which consisted of pyrolusite with minor hollandite. Tindle (2008) also noted the occurrence of palygorskite at Croft Quarry.

Enderby Hill Quarry, Enderby

King (1973) described the ocurrence of palygorskite stating that it

> ...could be found at the top of the eastern face of Enderby Hill Quarry…[and]…was of the "plaster board" type,

though its associate was calcite [calcite-7] rather than dolomite [see Warren Quarry, below]…The sheet was multi-leaved, up to 10 leaves being visible, the total thickness being 3.2 mm…It was stained to varying degrees by iron oxides, which took the form of dendrites, and occasionally films.

Stoney Stanton

King (1973) recorded that he had found two additional specimens

> ...in the collections of the Leicester City Museum, labelled "LEICS G1235.1951.49 and LEICS G578.1961.49. Kaolin. Stoney Stanton, S. Leics." are typical of down-washed and groundwater remobilised palygorskite.

These specimens are much thicker (30 mm) than many of the specimens of palygorskite (mostly 3-5 mm thick). It is not known from which of the Stoney Stanton quarries these specimens originated.

Warren Quarry, Enderby

The occurrence of palygorskite at Warren Quarry (together with that from Bardon Hill and Old Cliffe Hill quarries) was described by Evans and King (1962); it was also noted by King (1968) and Tindle (2008). Both King (1973) and Tien (1973) described the occurrence, appearance and properties of the palygorskite in more detail.

In his description of the occurrence of palygorskite, King (1973) noted that

> ...it presents a striking deposit, the whole quarry face just below the Triassic unconformity having the appearance of being "white-washed". The major feature of the southern face of the eastern extension of this quarry, is a long transverse section of a Pre Triassic wadi cutting the tonalite. The lower part of the wadi is filled by a strongly dolomite-cemented breccia, above which there is a bed of dolomite, up to 162 mm. thick…Within the wadi the basal beds, including the dolomite, are full of felted masses of pure white palygorskite in the form of (a) disseminations within the dolomite and especially in the dolomite cement of the breccia; and (b) sheets resembling the "mountain leather" of other localities. The highest concentration is in the lower 0.5 m. of the wadi, but it does not extend higher than 1.8 m. into the overlying beds. Where there are open joints below the wadi, and to a certain degree elsewhere below the unconformity, typical vein-like intergrowths of dolomite and white palygorskite extend down into the tonalite. The average depth of penetration is 10.7 m., but it has been observed in the lower levels of the quarry, 52 m. below, though the sheets are thin and nowhere reach the base of the quarry workings. As a rule the mineral is pure white, but it is occasionally stained by ferromanganese solutions, which may form dendritic "stars" on its surface. See: K1109-1953 [Figure 36].

King (1973) also pointed out that there are notable specimens that are formed from palygorskite heavily impregnated with dolomite and that they resemble plaster board (LEICS G35.1955, LEICS G259.1961.1 and BM.1955,101); the dimensions of LEICS G35.1955 are quite remarkable being 520 x 400 x 5 mm. Whilst the material in the NMH Collection was originally catalogued as 'attapulgite', subsequent XRD analysis (NHM 6561) showed that it was palygorskite; 'attapulgite' is no longer a recognised mineral species (Bayliss, 2000).

Tien (1973) also described the occurrence of the palygorskite and he provided a variety of analytical data stating that

> ...palygorskite occurs as 3-10 mm long bundles of fibres, 0.03-0.1 µm wide. X-ray diffraction data indicate that the mineral may occur in the monoclinic form. The structural formula for the half-unit cell is $Si_8(Al_{1.89}Fe^{3+}_{0.05}Ti_{0.01}Mg_{1.99})O_{20}(OH)_2(OH_2)_4\,3{\cdot}61\,H_2O.Ca_{0.07}$ [*sic*; an odd formula]. Data obtained from differential thermal and infrared analysis are comparable with those for palygorskite from the literature, but the six-sided transverse cross-section of the fibres as revealed by electron microscopy is unexpected.

Evans and King (1962) suggested that the palygorskite was

> ...deposited from downward-moving waters which were in direct connexion [*sic*] with the lakes and rivers in which the basal sediments of the area were deposited and not from post-Triassic ascending hydrothermal solutions,

a mechanism that was supported by King (1973) and Tien (1973). Pearson and Jeffrey (1997) noted that the formation of palygorskite is favoured by alkaline conditions (pH > 8-10) and, whilst they agreed with Evans and King (1962) that palygorskite was precipitated at the unconformity following deposition from downward-moving Mg-rich alkaline meteoric waters, they also suggested that some of the palygorskite might have been formed from the reaction of dolomite with smectite.

PREHNITE, $Ca_2Al_2Si_3O_{10}(OH)_2$

It appears that the occurrence of prehnite in Leicestershire was first reported by Jones (1933) in his description of the hydrothermal alteration of the igneous rocks and he noted that

> ...the Croft-Huncote rock is of especial interest… albitization is advanced: analcite [analcime] and laumontite have been developed as vein minerals, and prehnite occurs within the wall rock.

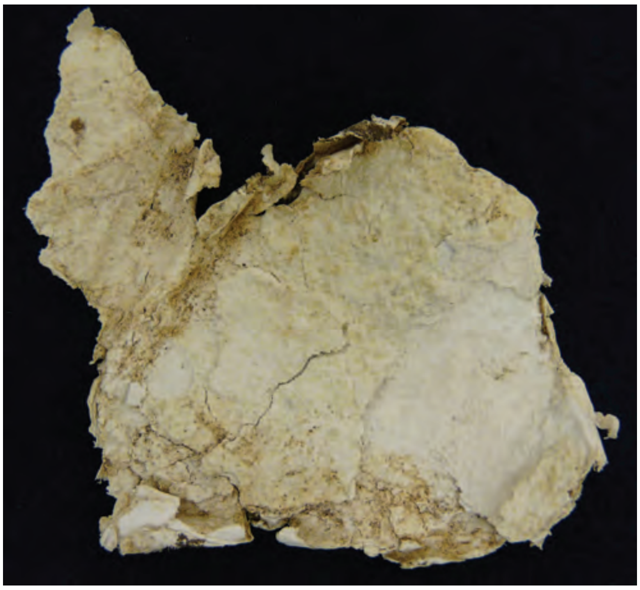

Figure 36. A cream to greenish-grey felted sheet of palygorskite mixed with dolomite. Warren Quarry, Enderby, Leics. NMW specimen (K1109-1953, NMW 83.41G.M.6784; collected by Bob King, 1953); specimen width 75 mm.

Given that fluorite-2 may look similar to some habits of prehnite, it is possible that some previously-identified prehnite is actually fluorite-2 (Neil Hubbard, *personal communication*).

Croft Quarry, Croft

King (1968) mentioned the occurrence of prehnite and King (1973) described it in more detail indicating that

> ...this Croft material, associated principally with analcime (the deposition of which it precedes) and minor calcite, occurs as disseminations and pale-green masses…up to 30 mm. in diameter. Where the vein matter is cavernous, typical botryoidal surfaces have formed, the diameter of each spheroid being an average of 7 mm. The surface of the spheroids is crystalline and when broken open shows a divergent radiate grouping of plates. Rarely, sub parallel groupings of tabular forms appear on the surfaces. Subhedral forms are present, but they are unrecognizable. See: K57 and K58-143 [see Figure 37, K58-143(i)].

A closely-related prehnite specimen is in the collection of Roy Starkey (RES-2092-052; NK305-1958; K58-143(ii)) and the labels establish that it and, presumably, K58-143(i) were collected from the 2nd Level on the east face. King (1973) also described a specimen (LEICS G75.30.4) noting that

> ...apart from being a very fine specimen of analcime, [it] also shows a minor development of crystalline calcite and very pale green prehnite;

unfortunately, this specimen was not located during this study.

Another specimen of prehnite has been identified during the course of this investigation; although, it was originally thought to be datolite, $CaBSiO_4(OH)$. The occurrence of both prehnite and datolite had been noted by King (1968), King (1973) and Manning (2010). King (1973) described a specimen (K57-C1) noting that the material was

> ...a rare associate of the zeolite assemblage…[and]…was found as a small mass (4.2 mm in diameter) showing an internal divergent crystalline radiate group, greenish-grey in colour…[and]…was intimately associated with analcime on badly "rotted" tonalite. See K57-C1. The identification of this specimen was kindly made by Dr. M.H. Hey during a personal visit by the writer to the Natural History Museum of London in 1958.

Figure 37. A cavity lined with pale green botryoidal prehnite on altered quartz-diorite. Croft Quarry, Croft, Leics. NMW specimen (K58-143(i), NMW 83.41G.M.9529, collected by Bob King, 1958); specimen 56 x 40 mm; Tom Cotterell photograph.

Following an examination of the prehnite and datolite specimens in the King collections at the National Museum of Wales (by Tom Cotterell), K57-C1 has been reinvestigated and the material analysed was shown to be prehnite (XRD: NMW X-2925; Tom Cotterell, *personal communication*).

In their description of the prehnite-pumpellyite wall-rock alteration haloes that surround the zeolite-containing veins in the quartz-diorite, Pearson and Jeffrey (1997) noted that the haloes contain intergrown radiating sheaves of prehnite and Fe-rich pumpellyite together with chlorite, quartz and analcime, and also minor sericite, kaolinite and smectite. Tindle (2008) used this description as the basis of his summary of the occurrence of prehnite from Croft Quarry and Manning (2010) included prehnite amongst the minerals that occur in the quarry.

Huncote Quarry, Huncote

King (1968) noted that the mineralisation was similar to that of Croft Quarry (described above); implying that prehnite also occurred there. King (1973) described a specimen in the NHM Collection (BM.1932,1319) labelled as

> Analcime, rough white crystals with laumontite in Syenite. Huncote Quarry, 6 miles S.W. of Leicester. Presd. By S.H. Langley, Esq. B.Sc. of Aylestone, Leicester. October 22, 1932;

however, he concluded that the specimen

> ...showed spheroidal masses of a pale greenish-white mineral which is much more likely to be prehnite.

PUMPELLYITE-(Fe^{2+}), $Ca_2Fe^{2+}(Al,Fe^{3+})_2(SiO_4)(Si_2O_7)(OH)_2{\cdot}H_2O$

Croft Quarry, Croft

Pearson and Jeffrey (1997) noted that the prehnite-pumpellyite wall-rock alteration haloes that surround the zeolite-containing veins in the quartz-diorite contained pumpellyite-(Fe^{2+}), associated with prehnite, chlorite, quartz and analcime, and also minor sericite, kaolinite and smectite.

PYRITE, FeS_2

There appear to be at least four generations of pyrite deposition: designated here as pyrite-1 (associated with diorite xenoliths in the SLDC), pyrite-2 (associated with the early phases of the mineralisation and pegmatites in the SLDC), pyrite-3 (associated with analcime and calcite) and pyrite-4 (associated with the mineralisation in Lane's Hill Quarry).

Croft Quarry, Croft

In his descriptions of the occurrences of pyrite in the county, King (1973) noted that it

> ...is rare in the masses of igneous rock which occur in South Leicestershire

and, perhaps surprisingly, Croft Quarry was not among the locations he described. Small amounts of pyrite-2 were found in 1985 and they were associated with magnetite and molybdenite (see the Magnetite section). Pyrite (pyrite-3) occurs as groups of small, dull brown cubes (to 1 mm) with colourless to white calcite (calcite-3?), minor chalcopyrite and marcasite on colourless to pink analcime (Figure 38). Manning (2010) included pyrite amongst the minerals that occur at Croft Quarry.

Granitethorpe Quarry, Sapcote

Harrison (1881) described the exposures of the SLDC (that he referred to as "syenite") at Sopewell Quarry (see Table 1) and noted that he had

> ...found some good crystals of iron pyrites, a mineral of a shining yellow colour…which I have not found elsewhere in these South Leicestershire pits,

associated with "apple-green" epidote and "some large crystals of pink feldspar"; it seems likely that this is an occurrence of pyrite-2, associated with a pegmatite. King (1973) summarised Harrison's description and added that he had also

> ...found pyrite forming aggregations of strongly striated intergrown pyritohedra. These formed the cores of nodular masses consisting of pyrite [pyrite-1], quartz [quartz-1] and epidote [epidote-1], completely enclosed within the formerly quarried tonalite and were presumably xenoliths.

Lane's Hill Quarry, Stoney Stanton

King (1973) noted that the Fe-rich dolomite that almost certainly originated from Lane's Hill Quarry contained some pyrite (pyrite-4); however, it had been oxidised and is now largely goethite (see LEICS G199.1963.1-2).

PYROLUSITE, MnO_2

Croft Quarry, Croft

In their comments on the manganese and palygorskite–dolomite mineralisation that occurred in joints in the Ordovician quartz-diorite and the Triassic basal breccia, Pearson and Jeffrey (1997) reported that pyrolusite was the major component of the manganese 'wad' (with minor hollandite) and was associated with palygorskite and dolomite. Tindle (2008) used this description as the basis of his summary of the occurrence of pyrolusite and Manning (2010) included pyrolusite amongst the minerals that occur in the quarry.

In a field trip report for a visit in July 1987, the author described a thick layer of manganese mineralisation exposed at the unconformity between the Ordovician quartz-diorite and the Triassic sediments on the eastern side of an extension towards Huncote Quarry (F. Ince, *Russell Society Newsletter*, **No. 17**, p. 4). This deposit was up to 50 mm thick and contained a few cavities lined with interlocking sheaves of lustrous to dull, black laths and acicular crystals (up to 7.5 mm; Figure 39). Analyses of a sample of this material showed that it was mainly pyrolusite (*circa* 77%) with some manganite (*circa* 23%) (XRD: NMW X-2343 and X-2344; Tom Cotterell, *personal communication*).

QUARTZ, SiO_2

There appear to be at least three generations of quartz deposition: designated here as quartz-1 (associated with

Figure 38. Two groups of small, brown interpenetrating cubes of pyrite-3 (to 2 mm) with colourless to white calcite-3 on colourless to pink analcime. Croft Quarry, Croft, Leics. Frank Ince specimen (FI-2436; collected by Phil Jackman, 1995); field of view 8 mm.

Figure 39. A cavity in a crystalline mass of manganese oxides lined with interlocking sheaves of lustrous to dull, black laths and acicular crystals of pyrolusite-manganite (to 4 mm). Croft Quarry, Croft, Leics. Frank Ince specimen (FI-0449; collected July 1987); specimen width 75 mm.

diorite xenoliths in the SLDC), quartz-2 (associated with an early phase of the mineralisation of the SLDC) and quartz-3 (associated with the mineralised veins in Lane's Hill Quarry).

Croft Quarry, Croft

King (1968) noted that quartz (quartz-2) was associated with analcime and

> ...it was often well crystallised and showing left-hand faces. It may be rarely amethystine.

King (1973) described

> ...some very attractive mineralogical material. In 1957, a wide vertical quartz-analcime vein was exposed at the base of the western face of the quarry. At a height of 2.3 m. from the quarry floor the vein contained a large lens-shaped cavity, 134 mm. wide and 420 mm. in diameter. Its walls were lined by a film of epidote with a little hematite, upon which was deposited a comb structure of thousands of small quartz crystals. The large majority of [the] crystals wore "collars" of minute crystals of analcime in complex twinning units, just below their pyramids…Upon examination these quartz crystals are seen as colourless prisms up to 12 mm. in length and up to

5 mm. in cross section. At the point of attachment they are usually tinted by the underlying epidote and hematite. Of 52 crystals examined, 43 showed the development of the left trigonal pyramid $\{2\bar{1}\bar{1}1\}$, and rarely the left trigonal trapezohedron $\{6\bar{1}\bar{1}1\}$.

The specimen shown in Figure 6 is representative of this material with white analcime (analcime-1) crystals (up to 1 mm) forming “collars” just below the pyramidal faces of the colourless hexagonal prisms of quartz-2. Other specimens (*e.g*. BM.1959,614), from the same occurrence, have similar hexagonal prisms of colourless quartz-2 but with a “frosted” appearance produced by a partial coating of minute, pale brown analcime crystals (analcime-1).

King (1973) also noted that quartz, in association with calcite, was invested with single or groups of microscopic spheroids of goethite. Manning (2010) included quartz amongst the minerals that occur in the quarry. Pearson and Jeffrey (1997) described their fluid inclusion microthermometry studies that used the quartz crystals (associated with pumpellyite and prehnite) found in the altered wall rock and the small crystals that occurred in the calcite-zeolite veins. These studies showed that

...the inclusions in the quartz crystals…have the highest homogenisation temperatures [T_h 93–320°C] and are of low salinity [0.2–5.9 wt% NaCl equivalent], and probably represent meteoric fluids.

Granitethorpe Quarry, Sapcote

King (1973) described the occurrence of quartz in nodular masses consisting of pyrite [pyrite-1], quartz [quartz-1] and epidote [epidote-1], completely enclosed within the formerly quarried tonalite, and presumably xenoliths.

Lane’s Hill Quarry, Stoney Stanton

In his description of the occurrences of quartz, King (1973) noted that Lane’s Hill Quarry

...has produced transparent colourless [quartz-3] crystals of great beauty from time to time. They were restricted in their occurrence to a large vein of ferroan dolomite [Fe-rich dolomite]. In a personal communication, Mr R.P.W. Mayes stated: “…within the siderite (ferroan dolomite), fully embedded were large quartz crystals (3 cm. to 12 cm. in length, and up to 4 cm. in diam.) doubly terminated as if allowed free growth”. He [Mr Mayes] donated a specimen…to the collections of the Leicester City Museum.

A small specimen (LEICS G198.1963) includes colourless to white well-terminated hexagonal quartz crystals (to 20 mm) with brown Fe-rich dolomite; unfortunately, the whereabouts of any specimens with large quartz crystals from this locality remains a mystery.

QUARTZ VARIETY OPAL, $SiO_2 \cdot nH_2O$

Granitethorpe Quarry, Sapcote

Eastwood *et al*. (1923) mentioned that joint-planes in the diorite were sometimes coated with green-stained calcite or opal. King (1973) noted that

...the quarry is now water-filled and confirmation has not been established. There is the possibility that this ‘opal’ may be prehnite.

This occurrence of quartz variety opal remains to be confirmed.

TITANITE, $CaTiOSiO_4$

The Yennards Quarry, Earl Shilton

Titanite has been tentatively identified on a very small specimen collected in the mid-1970s (Neil Hubbard, *personal communication*). It occurs as a pale yellow tabular crystal (up to 1 mm long) associated with acicular yellow epidote and a hemispherical mass of dark green chlorite on a black mineral (possibly magnetite or hematite) in a cavity lined with pink feldspar crystals (probably orthoclase). Given the paucity of material, the presumed titanite has not been analysed; consequently, its occurrence remains to be confirmed.

TOPAZ, $Al_2SiO_4(F,OH)_2$

Croft Quarry, Croft

In a report written in 2006 (following the evaluation of Croft Quarry as a Regionally Important Geological Site), it was recorded that

...topaz and fluorite form part of an early hydrothermal phase of alteration of the quartz-diorite [Gill Weightman, *personal communication*].

Further investigation of this record has failed to verify the occurrence of topaz at Croft Quarry or any of the other exposures of the SLDC (Gill Weightman, *personal communication*). Given the occurrence of topaz in the closely-related Mountsorrel Granodiorite (King, 1959), its presence in exposures of the SLDC might have been anticipated; however, the occurrence of topaz in the SLDC remains to be confirmed.

VOLBORTHITE, $Cu^{2+}_3V_2O_7(OH)_2 \cdot 2H_2O$

Enderby Quarry, Enderby

A specimen in the collections of the NHM is described in the on-line database as

BM.1988,278. Volborthite, dark-green crystalline coating on grey scalenohedral calcite crystals on matrix. Enderby Quarry, Enderby, Leicestershire, Donated by Mr R.W. Thomas, 1/11/1988. XRD 6947F.

It is not known from which of the Enderby quarries this specimen originated (R.W. Thomas, *personal communication*); however, it seems likely that it might have been Warren Quarry.

Inspection of BM.1988,278 (Figure 40, see p. 26) revealed some interesting features and its provenance has to be questioned. The habits of the volborthite and calcite are similar to that seen on specimens from Newhurst Quarry, Shepshed, Leicestershire (Green *et al*., 2008); the occurrence and collection of the specimens from Newhurst Quarry has been confirmed (Peter Lord, *personal communication*). The habit of the calcite on BM.1988,278 (sharp scalenohedra, rather than scalenohedra with marked modifying faces) is unusual for the exposures of the SLDC. The matrix of BM.1988,278 (dark grey-green groundmass with phenocrysts of pink feldspar) is atypical for the exposures of the SLDC and is almost identical to that of the exposure of the North Charnwood Diorite occurring at Newhurst Quarry. A label that accompanied BM.1988,278 indicated that it was obtained by the NHM from "The Stone Corner", 42a High St, Hastings, Sussex; however, further investigations have not provided any new information (David Binns, *personal communication*). The provenance of BM.1988,278 is still being investigated and remains to be clarified.

OTHER FEATURES

HALITE PSEUDOMORPHS

Croft

Pseudomorphs after halite, formed from fine-grained Triassic sediments, are fairly common in many of the exposures of the Mercia Mudstones in Leicestershire (Bosworth, 1912; King, 1973; Ince, 2005; Ince, 2011). Records of such specimens in the area covered by this review are scarce; although, a specimen from Croft is included in the collections of the NHM (BM.1934,832; see Figure 41).

DISCUSSION

It is evident that the SLDC, and the surrounding Triassic rocks, have been affected by several phases of mineralisation and a possible paragenetic sequence is given in Table 3. Phases 1–8 occurred during or relatively soon after the emplacement of the SLDC, whereas phases 9–10 took place during or after Triassic times. A brief description of these phases is given below:

1. Epidote-1, pyrite-1 and quartz-1 are associated with diorite xenoliths in the SLDC.
2. One of the earliest mineralisation events is the deposition of epidote-2, pyrite-2, hematite-1, feldspar, hornblende, chlorite, *titanite*, quartz-2, pumpellyite and sericite. This probably occurred as part of the wall rock alteration during pegmatite formation and the introduction of mineralised veins. Although field evidence is less well-defined, it is likely that the deposition of magnetite, molybdenite and pyrite-2 also took place during this phase, and this process might well have been associated with kaolinite formation.
3. The first phase of zeolite formation was the deposition of laumontite and this was followed by calcite-1 filling the majority of the cavities in the well-crystallised laumontite. Prehnite and, if the occurrence can be verified, *datolite* may also have been deposited at this time.
4. The first phase of analcime deposition (analcime-1) was accompanied by hematite-2 formation (as inclusions) and also the development of pseudomorphs and/or epimorphs of analcime-1 after laumontite.
5. The main phase of analcime and calcite mineralisation (analcime-2 and calcites-2–3) appears to be quite complex. The specimens described by Jones and Langley (1931) comprise analcime-2 with rhombs of calcite-2. Other specimens have a much more varied composition: analcime-2 (sometimes with included hematite-3) and calcite-3 (in various habits: modified scalenohedra and rhombs, "cubes" and "octahedra") both of which can be intimately associated with marcasite. Calcite-3 may also be associated with, or contain, hematite-4 (sometimes as a mixture with a clay mineral). It is evident that, in addition to marcasite, other sulphides are also associated with analcime-2 and calcite-3, chalcopyrite, galena and pyrite-3.
6. A later generation of calcite (calcite-4, as small white to cream modified scalenohedra) has crystallised on top of calcite-3 (as yellowish modified scalenohedra) and chalcopyrite. Calcite-4 also appears to be associated with the deposition of *illite-brammalite*. At some stage it is proposed that aragonite was formed (see Phase 7, below) and it could be that it was during this phase of mineralisation.

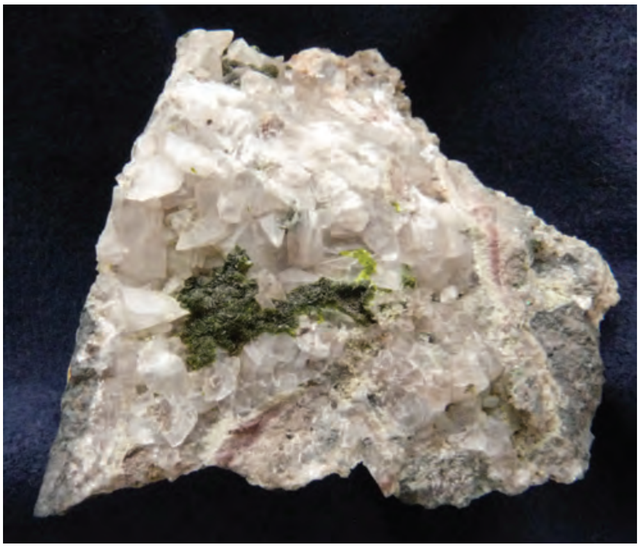

Figure 40. Dark green platy crystals of volborthite partly coating a vugh lined with colourless to grey well-formed scalenohedral calcite crystals on a dark green and pink matrix. Enderby Quarry, Enderby, Leics. NHM specimen (BM.1988,1278; donated by R.W. Thomas, 1 November 1988); specimen width 50 mm; Frank Ince photograph, ©NHM reproduced with permission.

Figure 41. Mudstone pseudomorphs after halite. Croft, Leics. NHM specimen (BM.1934,832; presented by Miss M.S. Johnston, July 1934); specimen width 40 mm; Frank Ince photograph, ©NHM reproduced with permission.

7. The last of the well-crystallised habits of calcite (calcite-5, as very small white rhombs and scalenohedra) occurs as patches on a number of specimens; however, the majority of calcite-5 occurs as epimorphs after at least two distinct minerals. It is suggested that the specimens that contain cavities with an approximately rectangular cross section are epimorphs after laumontite, whereas those with a hexagonal appearance are epimorphs after aragonite.
8. Baryte and the various habits of fluorite (fluorite-1: dodecahedra, fluorite-2: microcrystalline, and fluorite-3: cubes) do not appear to be overgrown by other minerals and are, consequently, amongst the last minerals to be deposited within veins and cavities in the SDLC.
9. In a much later phase of mineralisation, a few minerals crystallised from solutions that percolated down through the Triassic sediments and were deposited close to the unconformity between the SLDC and the Mercia Mudstones (Evans and King, 1962). This process resulted in the formation of palygorskite, calcite-7 (both as crystals and as a fine-grained mixture with fibrous palygorskite) and dolomite.
10. Bearing in mind the extensive supergene mineralisation in other parts of Leicestershire (Hubbard *et al*., 2005; Ince, 2005; Ince, 2007), the occurrences of secondary minerals related to oxidation processes that could have affected the SLDC are scarce. Apart from the significant occurrence of pyrolusite–manganite–hollandite at the unconformity between the SLDC and the Mercia Mudstones, only small amounts of malachite, cerussite, goethite pseudomorphs after pyrite and/or marcasite, and 'limonite', have been reported. The possible occurrence of volborthite at Enderby Quarry is still being investigated.

?? Apart from the occurrence of feldspar and epidote (which may be related to Phase 2 noted above), the mineralisation in the veins exposed in Lane's Hill Quarry (Fe-dolomites-1–3, pyrite-4, quartz-3, chlorite, djurleite, calcite-6 and, subsequently, malachite and goethite) is quite distinct from that seen in the other exposures of the SDLC and it has not been assigned to any of the phases mentioned above. It seems reasonable to suggest that these mineralised veins were formed in pre-Triassic times; hence the designation of the calcite as calcite-6 (as it would have been formed before calcite-7 and any supergene minerals).

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Phase	Minerals
1	Epidote-1, pyrite-1, quartz-1
2	Epidote-2, pyrite-2, hematite-1, feldspar, hornblende, chlorite, *titanite*, quartz-2, pumpellyite, sericite?, magnetite, molybdenite, kaolinite?, *topaz*?
3	Laumontite, calcite-1 (rhombs and massive), prehnite, *datolite*?
4	Analcime-1 and analcime-1 ps. and/or epi. laumontite, hematite-2
5	Analcime-2, hematite-3, marcasite, calcite-2 (rhombs), calcite-3 (various habits: modified scalenohedra and rhombs, 'cubes' and 'octahedra'), hematite-4 (+ clay), chalcopyrite, galena, pyrite-3
6	Calcite-4 (modified scalenohedra), *illite-brammalite, aragonite*?
7	Calcite-5 (small rhombs and scalenohedra) and calcite-5 epi. laumontite and/or *aragonite*?
8	Baryte; fluorite-1 (dodecahedra), fluorite-2 (microcrystalline), fluorite-3 (cubes)
9	Palygorskite, calcite-7, dolomite, 'limonite'
10	Pyrolusite–manganite–hollandite; malachite, cerussite, goethite ps. pyrite and/or marcasite, *volborthite*?
??	Lanes Hill Quarry (paragenetic assignment uncertain): Feldspar (albite/orthoclase), epidote-2 (possibly related to Phase 2), Fe-dolomite-1–3, pyrite-4, quartz-3, chlorite, djurleite, calcite-6, malachite, goethite

Table 3. A possible paragenetic sequence for the mineralisation of the SLDC and the Mercia Mudstones.

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SPODUMENE FROM THE PEATFOLD PEGMATITE, GLEN BUCHAT[1], ABERDEENSHIRE – THE FIRST SCOTTISH OCCURRENCE

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The presence of macroscopic, subhedral crystals of spodumene ($LiAlSi_2O_6$) associated with a lithium pegmatite at Peatfold, Glen Buchat is reported. Fieldwork, involving the trenching of an area of float boulders, has confirmed the occurrence of a lithium pegmatite at shallow depth, bearing gem quality tourmaline. Detailed measurement, photography and sampling of the pegmatite has yielded a considerable dataset for future analysis. This preliminary note provides the first record of spodumene from Scotland.

PREVIOUS RECORDS OF SPODUMENE IN BRITAIN

Spodumene is a relatively uncommon lithium-aluminium silicate which occurs in lithium-rich granitic pegmatites and aplites (Linnen *et al*., 2012). In the United Kingdom, spodumene has been reported from the Meldon aplite by Drysdale (1985, 1991), based upon material in the Kingsbury collection at the Natural History Museum, London (BM 1968,105). However, there appears to be some doubt about the validity of the occurrence. Von Knorring and Condliffe (1984) comment that

> ...Kingsbury (1966) recorded a remarkable list of minerals new to Meldon, amongst them…spodumene… [Note: This citation is incorrect and should read "Kingsbury (1964)"]

but, perhaps significantly, do not report observing the occurrence of the mineral in material collected and examined by themselves. Tindle (2008, p. 478) also cites Kingsbury's record (1964) but notes that "…further confirmation is desirable". In Ireland, spodumene occurs in a belt of lithium pegmatites associated with the Leinster batholith, and at a variety of other localities listed by Tindle (2008, p. 478). Spodumene is not listed in the *Glossary of Scottish Mineral Species* (Macpherson and Livingstone, 1981), and the occurrence of the mineral in Scotland was judged by them to "…be highly doubtful".

Figure 1. Bi-coloured red and green prismatic crystals of tourmaline, in a matrix of sericite (fine grained muscovite), Peatfold Pegmatite, Glen Buchat, Aberdeenshire. Field of view is 75 mm wide. Roy Starkey specimen (RES 0852-003) and photo.

LOCATION

The occurrence of gem-quality tourmaline (Figure 1) in a lithium pegmatite at Glen Buchat, is thought to have been first discovered by the late Gordon Sutherland. He brought the occurrence to the notice of the Royal Scottish Museum (now National Museum of Scotland), and a description of the occurrence was published in the *Journal of Gemmology* (Jackson, 1982).

Over the years, various interested parties have visited the locality (figures 2 and 3) to study the material, but no systematic investigation had been undertaken in order to

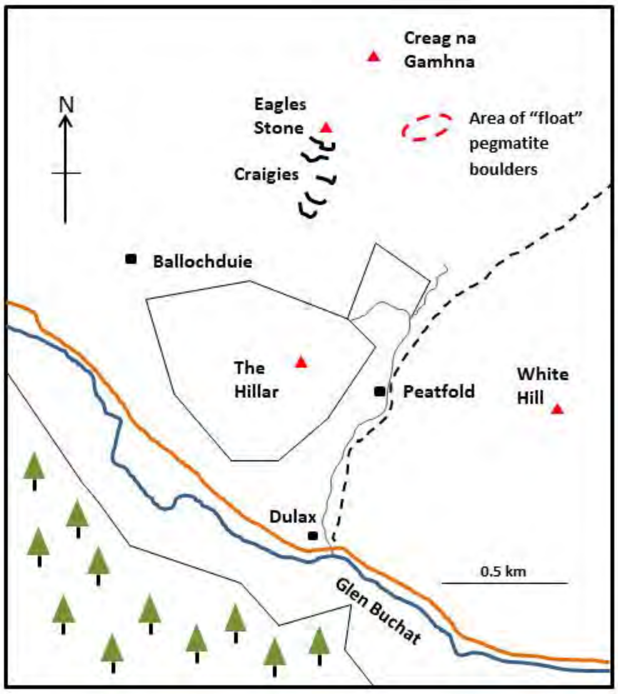

Figure 2. Sketch map showing the location of the Peatfold pegmatite.

[1] The Ordnance Survey gazetteer gives Glen Buchat for the valley, but Glenbuchat for Glenbuchat Lodge and Mill of Glenbuchat, the latter spelling also being adopted by the North Glenbuchat Estate.

assess the extent or precise nature of the mineralisation, nor, importantly, had any pegmatite been seen *in situ*.

In early 2014, an approach was made to Glenbuchat Estate for permission to undertake limited excavations in an attempt to establish the true nature of the occurrence, and whether or not pegmatitic material could be located *in situ* under the superficial deposits which blanket the moorland.

Agreement was reached with the Estate for two days of excavation followed by rehabilitation of the ground, and the work to be carried out at the beginning of April 2014. This initial excavation yielded much new "float" material and enabled the synthesis of a probable structure for the zoned pegmatite body, but failed to locate any pegmatite *in situ*, despite trenching to approximately 2 m depth at various points across the likely area of subcrop. In an effort to reach a definite conclusion regarding the occurrence, the Estate was approached with a view to undertaking a second two-day dig in April 2015. Permission was kindly granted and a larger excavator deployed, enabling more material to be removed and larger buried boulders to be dealt with easily. Pegmatite was located *in situ* at a depth of approximately 1 m at National Grid Reference NJ 35577 19722.

Figure 3. Area of 'float' pegmatite boulders on moorland approximately 1 km north-north-east of Peatfold Cottage (just visible in the centre distance - circled).

Figure 4. Lens of fractured and altered, white to pink spodumene *in situ*, in the trench after washing and scrubbing to remove mud, clay, etc. The hammer head is 15 cm in length.

GEOLOGY

The 1:50,000 scale geological map S75E, for Glen Buchat (BGS, 1998), shows the area running from Dulax up past Peatfold and onto the moor above Creag na Gamhna, as quartz-biotite-norite, with a small indication of a post-orogenic (Upper Silurian to Lower Devonian) pegmatite, striking ESE–WNW. Exposure is very poor on the low-lying moorland, with only limited exposure along the ridge-line and adjacent to several estate tracks. The area of float boulders, on which the presumed presence of the pegmatite has been mapped by previous workers, is about 200 × 50 m, with a broadly ovoid aspect ratio, and a long axis trending roughly WSW–ENE (as shown on Figure 2).

DESCRIPTION

The Peatfold pegmatite, as exposed in the headwall of a trench excavated at NJ 35577 19722 shows a distinctly zoned structure, broadly symmetrical around a central core of bright purple mica, probably lepidolite.

In summary, the lithologies observed are (from west to east):

- pink feldspar pegmatite, containing very pale blue, fractured crystals of blue tourmaline up to 10 mm, muscovite flakes to 10 mm, numerous black/brown 'spots', and blocky crystals of feldspar to 10–15 mm.
- quartz, muscovite, blue tourmaline, pink feldspar, with (white) platy albite (var. cleavelandite).
- a small lens of waxy, pale green, muscovite var. 'sericite', pink feldspar, quartz, red staining, metallic grains, striated impressions in quartz now filled by muscovite var. 'sericite', minor colourless to very pale pink tourmaline to 10 mm, resinous, brown tetragonal crystals (2 mm).
- mica zone - near 100% mica, probably lepidolite, with minor quartz, albite (var. cleavelandite), a few brown grains, sprays of pink tourmaline to 70 mm, and small patches of green muscovite.
- spodumene lens (Figure 4), showing striated, white to pinkish, blocky to bladed, fractured intergrown crystals of spodumene, associated with much pale blue to colourless, grey or pink tourmaline up to 20 × 5 mm, and patches to 30 × 20 mm, resinous brown grains, and tiny (<1 mm) elongate black blades.
- muscovite with pink feldspar and tourmaline, albite, pale blue tourmaline in quartz, black grains, associated with pink feldspar with strings of quartz as seen at the western margin of the pegmatite (above).
- plumose muscovite, quartz, pale blue to dark blue tourmaline, pink feldspar and cream feldspar.

The spodumene lens (Figure 4) measured approximately 45 × 28 cm and was exposed in the east wall of the trench, just below a patch of milky quartz. Much of the spodumene exhibits considerable alteration, which is not uncommon for the species, and has been described and discussed by e.g. London and Burt (1982) in relation to zoned lithium pegmatites from the White Picacho District, Arizona.

This alteration hampered initial attempts to confirm the identity of the mineral, which morphologically looked like spodumene – striated monoclinic crystals (Figure 5), with a pearly cleavage, and occurred in a lithium-bearing assemblage which seemed a likely environment for the occurrence of the mineral.

Initial investigation of the suspected spodumene at the Hunterian Museum failed to produce a satisfactory X-ray pattern, but the presence of the mineral was considered highly probable (J. Faithfull, *personal communication*). Examination of the pink-coloured material, and some of the white material by X-ray diffraction analysis (XRD) at the National Museum of Wales, indicates that it has been replaced by a mixture of kaolinite and illite (XRD No. NMW X-3449); and kaolinite, quartz and a mica (possibly phlogopite) – (XRD No. NMW X-3473) T. Cotterell, *personal communication*.

Subsequent examination by XRD at the National Museum of Wales, Cardiff, of carefully selected grains of the pale-coloured material, which retained a fairly fresh surface lustre (Figure 6) yielded a satisfactorily distinct diffractogram (Figure 7) to confirm the presence of spodumene in the Peatfold pegmatite (XRD No. NMW X-3472).

DISCUSSION

The occurrence of spodumene in the Peatfold Pegmatite, Glen Buchat is thought to be the first substantiated report of the mineral from Scotland. Work is continuing to characterise other, as yet unidentified, phases within the bulk material samples. A detailed, illustrated description of the mineralogy across the width of the pegmatite body is in preparation.

Figure 5. Spodumene - subhedral crystal with pinkish tinge, and exhibiting monoclinic symmetry, partially replaced by kaolinite, illite, quartz and a mica (possibly phlogopite). 70 × 50 × 10 mm. Roy Starkey specimen (RES 2446-001) and photo.

SPECIMENS

Suites of representative material have been deposited in the Oxford University Museum of Natural History; The Hunterian Museum, Glasgow; the Natural History Museum, London; National Museum of Wales, Cardiff and National Museum of Scotland, Edinburgh.

ACKNOWLEDGEMENTS

Glenbuchat Estate kindly granted permission for fieldwork, and for us to publish this paper; Brian Mackie of Donside Slating provided a Hanix H75C excavator and skilfully excavated, and reinstated the site after the dig; Dr John Faithfull of The Hunterian, University of Glasgow, and Tom Cotterell of the National Museum of Wales, Cardiff are thanked for assistance with X-ray diffraction confirmation of the spodumene. Paul Carr and Malcolm Southwood provided helpful comments which improved the manuscript. Please note that the locality is on private estate property and lies within sensitive moorland on a working grouse moor. All access is controlled and monitored, and under no circumstances should the site be visited without prior permission from the Estate.

Figure 6. Fragment of relatively fresh, lustrous white spodumene, confirmed by XRD analysis. 45 × 30 × 20 mm. Roy Starkey specimen (RES 2446-002) and photo.

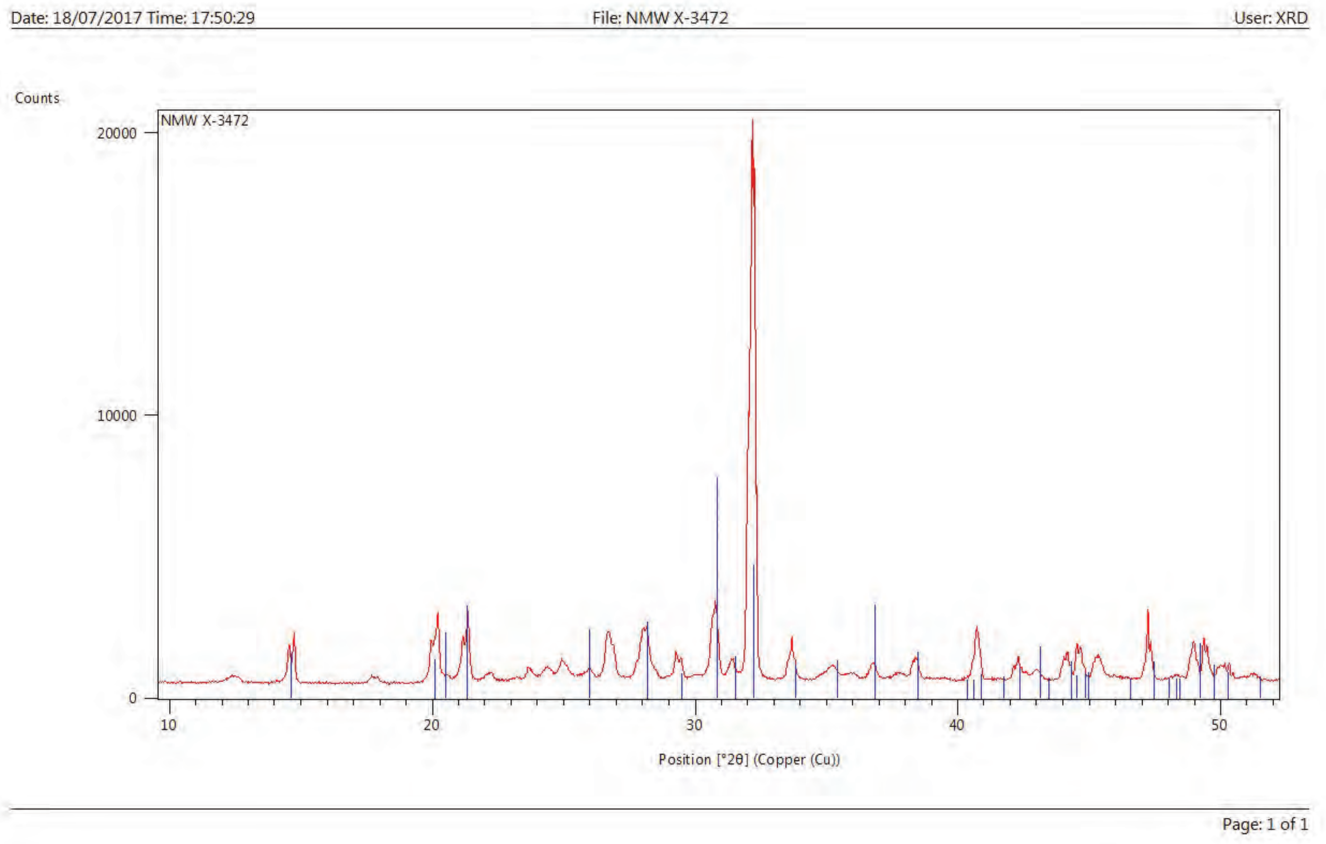

Figure 7. X-ray diffractogram confirming the identity of the spodumene, courtesy of T. Cotterell, National Museum of Wales, Cardiff. Red line is diffraction pattern for Peatfold sample; blue bars indicate positions of spodumene diffraction peaks.

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JIM KNIGHT AND HIS MINERAL COLLECTION

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James Rodney 'Jim' Knight (1927–2009) was one of the foremost British mineral collectors of the last fifty years, but his relatively private personality meant that he was known to few of his contemporaries. Jim assembled a remarkable collection, with a particular focus on rare species, from the 1950s until his death in 2009. A biographical sketch and description of the Knight Collection are provided as a record of Jim's life and mineralogical legacy.

BIOGRAPHY

Born in 1927, Jim Knight was the eldest son of Harold and Rebecca Knight (née Corbett); he was one of two children and had a brother, John. His principal interests as a child were in the sciences, with a particular fascination for chemistry. After leaving Burnage Grammar School, he joined ICI Paints at Blakeley in north Manchester, where he progressed up the career ladder to become head of the paints division, a position he held until retirement. An inquisitive mind led him into various scientific pursuits including electronics; ham radio, using the call letters G3JRK (in spite of a childhood illness that had left him deaf in one ear); and mineralogy (Figure 1).

Living close to Manchester airport, in a house beneath one of the flight paths, Jim became an avid plane spotter and would regularly drive to the airport to spot one he hadn't seen before. This was also his *modus operandi* in mineral collecting: he was always keen to add a species he hadn't got to his collection. Minerals were not Jim's only passion; a keen philatelist and numismatist, he assembled an outstanding collection of stamps from Barbados, and had a collection of rare gold coins. None of this was at all obvious on first acquaintance; Jim's semi-detached house, which he inherited after his mother's death, was modest, the garden unkempt, the rooms piled with books and bric-a-brac, the carpets worn in holes, and the furniture threadbare. Tim Greenland recalls visiting on one occasion to find the stairs, and the narrow walkways from kitchen to sitting room and bathroom to bedrooms, littered with disembodied Geiger counters.

Figure 1. Jim Knight collecting celestite in the mid-1960s at Ecton Mine in Staffordshire.

Jim cared deeply for his parents and topped up their pension from his salary, often at the expense of his own interests. The Knight family were not affluent, and had little to spend on non-essential goods, but they always made people welcome. Everything in the house was well-used, but Jim's mother was house-proud and kept the place clean and tidy. None of this 'cleaning malarkey' mattered a jot to Jim after his mother's death: he was content to live the way he wanted; convention could go hang! Although he was reluctant to do any cleaning, Jim was welcoming to visitors. An accomplished cook, he would prepare excellent meals, spaghetti Bolognese being one of his great specialities.

It seems to have been an interest in chemistry that led Jim to begin collecting minerals in the 1950s; he continued with dedication and passion for the rest of his life. His knowledge of minerals, their chemistry, associations and localities, was extensive. In 1964 he joined a small group of local collectors organised by Richard Braithwaite. Along with Jim, David Hardman was a regular attendee; Terry Seward, Mick Cooper, Ralph Sutcliffe, Ike Wilson, George Ryback, Don Hyde, Tim Greenland, and Peter Thomson would attend when they were able. Meetings were held at members' houses on a rotational basis until the group dissolved in the mid-1970s. This was not due to lack of interest; career progression had taken too many of the members away from the Manchester area.

Figure 2. Members of the Manchester group on a collecting trip to Deep Navigation Colliery at Treharris in 1964. Present in the photograph are (from left to right): Tim Greenland, Richard Braithwaite, the shift boss, Graeham Saville and George Ryback. Photo Jim Knight.

A passion for the outdoors, coupled with an enthusiasm for minerals, resulted in frequent field trips to Cornwall and Devon, south Wales, the north Pennines, the Caldbeck Fells, southern Scotland, and a few foreign localities. One of the favoured Scottish destinations was on the Solway coast near Dalbeattie. It was here that Jim and his friend Richard Braithwaite collected a suite of uranium minerals formed by the supergene alteration of primary U–Cu–As–Bi–Co mineralisation. Some of the minerals were new to Britain; they are described in Braithwaite and Knight (1990).

Deep Navigation Colliery at Treharris was one of the Welsh localities the group visited (Figure 2). After being shown underground by a foreman, it was decided to partake of lunch in the public house which was frequented by the miners. When the miners came in the foreman cried out: "Ere ... it's them b******s what finds pins and needles down the pit!". The 'pins and needles' were millerite crystals for which the locality is famous.

Localities in Weardale (Figure 3) and the Caldbeck Fells were among Jim's favourites and the Manchester group made many field trips, often visiting several locations on the same day. Jim collected at all of the famous localities in the Caldbeck Fells, but Carrock Mine, with its rare tellurides and unusual (for the north of England) high-temperature mineralisation was his particular favourite.

The Cornish mineral dealer and collector Richard Barstow (1947–1982) (Starkey, 2010) was a great friend. Barstow, who did not drive, made several visits to see Jim in Manchester; the two would embark on field trips around northern England in Jim's car, collecting as they went. The arrangement was reciprocal, and Jim collected with Barstow in Cornwall. It was on a trip with Tim Greenland that posnjakite was found at Drakewalls Mine (Knight and Barstow, 1970). Blue stains could be seen and it was Greenland, the lightest of the three, who was 'volunteered' to be lowered on a rope to collect whatever he could from the lip of a huge stope. Anything that slipped into the void took a few seconds before a resounding 'badaboom' rose from the depths. Alteration at the site was extensive: roots had penetrated the top of the stope, the ground was loose,

Figure 3. Jim Knight (left) with Tim Greenland at Heights Mine, Westgate, Weardale in 1964.

and the vein had been 'beaten away to the ferny braes'. Greenland was more than a little relieved when his friends decided that enough was enough and hoisted him back to *terra firma*.

Barstow and Jim were involved in the discovery of the spectacular specimens of botallackite that were attributed to Botallack Mine, St Just. The best specimens were collected on the 24-fathom level of the recently dewatered Levant Mine, but Barstow thought it unwise to reveal their true provenance. This must have pricked Jim's conscience and he set the record straight many years later in a short article describing his personal involvement in collecting the specimens (Knight, 2002). In his last published article, which appeared less than six months before his death, Jim returned to the theme of Cornish copper hydroxychlorides, with a blend of mineralogy, history and field collecting experiences that reflected his diverse range of skills and interests (Knight, 2009).

Apart from a small circle of collector friends, and a few dealers, most British collectors seem to have been unaware of Jim. This is surprising, as he was a prolific letter writer and well known to many important names in mineralogy including Joe Mandarino, Tony Nikischer, Michael Fleischer, and Charlie Key. Of all Jim's mineralogical collaborations, that with Richard Braithwaite was the longest; the pair having co-authored a number of papers. As well as their description of the minerals from the Solway coast near Dalbeattie, they noted the occurrence of serpierite at Ecton Mine in Staffordshire (Braithwaite and Knight, 1968) and were involved in research on numerous new or unusual species.

Jim's interest in rare minerals led him into regular contact with the American mineral dealer Tony Nikischer, president of the Excalibur Mineral Co. He purchased specimens from Excalibur Minerals over a period of thirty years. Nikischer had a keen interest in philately and the two would occasionally trade stamps. Jim was a generous trading partner and Nikischer would buy any Barbados cover he could find in America and send it to Jim knowing that it would find a good home in his collection. One of Nikischer's early gifts was reciprocated by a fine collection of US airmails including some very valuable issues in which Jim 'had no interest'. This generosity was evident to the authors. During a visit to his house, Jim asked Alan Barnes if there was any parsonsite in his collection. Replying in the negative, four rich specimens were produced. They were given without any question that money should be exchanged, Jim was simply glad that they would find a home with another enthusiastic species collector.

The parsonsite had been collected at La Faye Mine, Grury, France, by Tim Greenland, who had moved from Manchester to France in 1968. With Tim's guidance, the Manchester group made several trips to French uranium mines. After one trip to La Faye Mine, the boot of the car had "hardly a spare square inch of space in it" such was the number of specimens collected. Arriving in Dover, the car was flagged down by Customs and Excise officials due to the 'amount of radiation emanating from the vehicle'. According to Jim, a brief discussion was sufficient to settle the matter and the relieved collectors continued their homeward journey; one wonders what might happen if the trip were to be repeated today.

One of Tim's tasks in preparation for the French trips was to find good quality restaurants with authentic country dishes and fine red wine. Red wine was one of Jim's favourite tipples. On one trip he was left at a small country hotel where a wonderful dish of mushrooms in cream with roast local chicken and good local wine was served. While Jim indulged himself, Tim travelled to Lyon on business. On his return he was met by a nervous waitress who said:

> Your friend ordered a bottle of wine with his lunch, and when I asked him if he meant a half bottle, he replied: "No, I mean a full bottle; and if I like it I shall have a second bottle too!". He is out in the fields sleeping; could you bring him back to his room? We don't dare to.

On a visit by David Green in 2006, the conversation turned to Dry Gill Mine, which Jim had visited with Richard Barstow. He produced two specimens with prismatic crystals of a bright orange colour, an unusual habit for the locality. One was sufficiently good to be reproduced as the front cover image of the *Journal of the Russell Society*, and Jim was kind enough to donate it to the Manchester Museum (Figure 4).

Jim's knowledge of minerals and their genesis was only apparent to those who knew him well. He did not flaunt his learning, but would give an opinion if consulted, or if a particular specimen attracted his attention. One of us

Figure 4. Orange hexagonal mimetite crystals up to 4 mm long from Dry Gill Mine, Caldbeck Fells, Cumbria. One of the few Jim Knight specimens in a public collection. Manchester Museum specimen (MANCH: N19206); photo David Green.

(Alan Barnes) fondly remembers the Bakewell Show in 2004, an event that Jim had attended every year since its inception. While examining a specimen of charoite, tinaksite and aegirine from the Charo River in Russia, there was a presence at one side. Out of the corner of an eye Jim's distinctive green jacket and 'yogi trapper' hat was visible: "Come this way", he said; and took the specimen outdoors to make a proper inspection under his loupe. "Have a close look. What do you see?" There was something in the region where Jim was pointing; but what? "You should get that specimen", he said, "it's got ekanite on it". Subsequent conversations returned to the subject of magnification. Jim was forthright: "How can you call yourself a rare mineral collector if you haven't got a bloody microscope?". Needless to say, it wasn't long before a microscope took pride of place on the bench.

Jim's chemical knowledge was most obvious when it came to performing tests on minerals. He would open a cabinet containing a range of chemicals and use them to perform 'spot tests', viewing any chemical changes under the microscope. A couple of drops of this and a couple of drops of that and, as if by magic, he would have a good idea of the composition of an unknown species.

Although he was serious about minerals, Jim had a sense of humour. In a note to the mineral dealer, Tony Nikischer (who wrote Jim's obituary on Mindat) Richard Braithwaite recounted a trip to the Lake District with Richard Barstow (who himself was not averse to the odd practical joke). Camping in the Caldbeck Fells, Jim quietly placed a partially used butane canister on the embers of the dying camp fire. After a short while it shot vertically upwards on a column of fire. Barstow's face was a picture!

Jim suffered a stroke in 2007; it caused lasting physical impairment but did not dampen his enthusiasm for minerals, which he continued to collect until his death. Tony Nikischer recalls that as soon as Jim had received an order, he would write to say that the parcel had arrived. The last parcel was sent just two days before Jim passed away of heart failure on 14th May, 2009; Nikischer suspected that 'something was wrong' when the message from Jim saying that the parcel had arrived did not appear.

By the time of his death, the diversity of Jim's collection was remarkable: there were 3670 recorded specimens, representing perhaps 1800 species. There was always something different to see on visits to his home, often unusually rare, or beautiful, or a combination of the two. Jim is missed by those who were lucky enough to know him for his stories, dry wit and most of all his mineralogical knowledge. It is hoped that this short biographical sketch provides an insight into the life of a rather private collector for those who did not have the pleasure of his acquaintance.

COLLECTION RECORDS

Most of the scientific value of any collection is in the data associated with the specimens; a record of each specimen, including acquisition details, locality and provenance, is key. Jim's cataloguing system was simple but effective. He used an accession number beginning at one and increasing numerically as new specimens were added. As there were very few specimens in the collection without an accession number (the authors are aware of less than 50), it is reasonable to assume that it contained less than 4000.

Most of Jim's specimens were catalogued in a register, which was begun in the early 1960s, and used a four column format to record the acquisition number, species name, varietal name and locality (Figure 5, see p. 38). The cabinet and drawer number were added later; cabinets were labelled A–L and drawers numerically. The first 2450 catalogue entries are handwritten in copperplate script; subsequent entries are in block capitals (Figure 6, see p. 39), initially neat, but deteriorating towards the end of the register. As the catalogue progressed, the five column format was replaced by three more detailed columns listing the accession number, species name and locality: key pieces of data for any mineral collection. The last catalogued specimen is number 3142 (entered in 2002), and the last accession number the authors are aware of is 3673; therefore, there are about 530 specimens with accession numbers and labels, but no catalogue records. It may be that the last pages of the register have been lost, or that Jim was leaving the specimens until a sufficient number had accumulated to make cataloguing worthwhile. Inspection of the catalogue gives the definite impression that entries were added in batches.

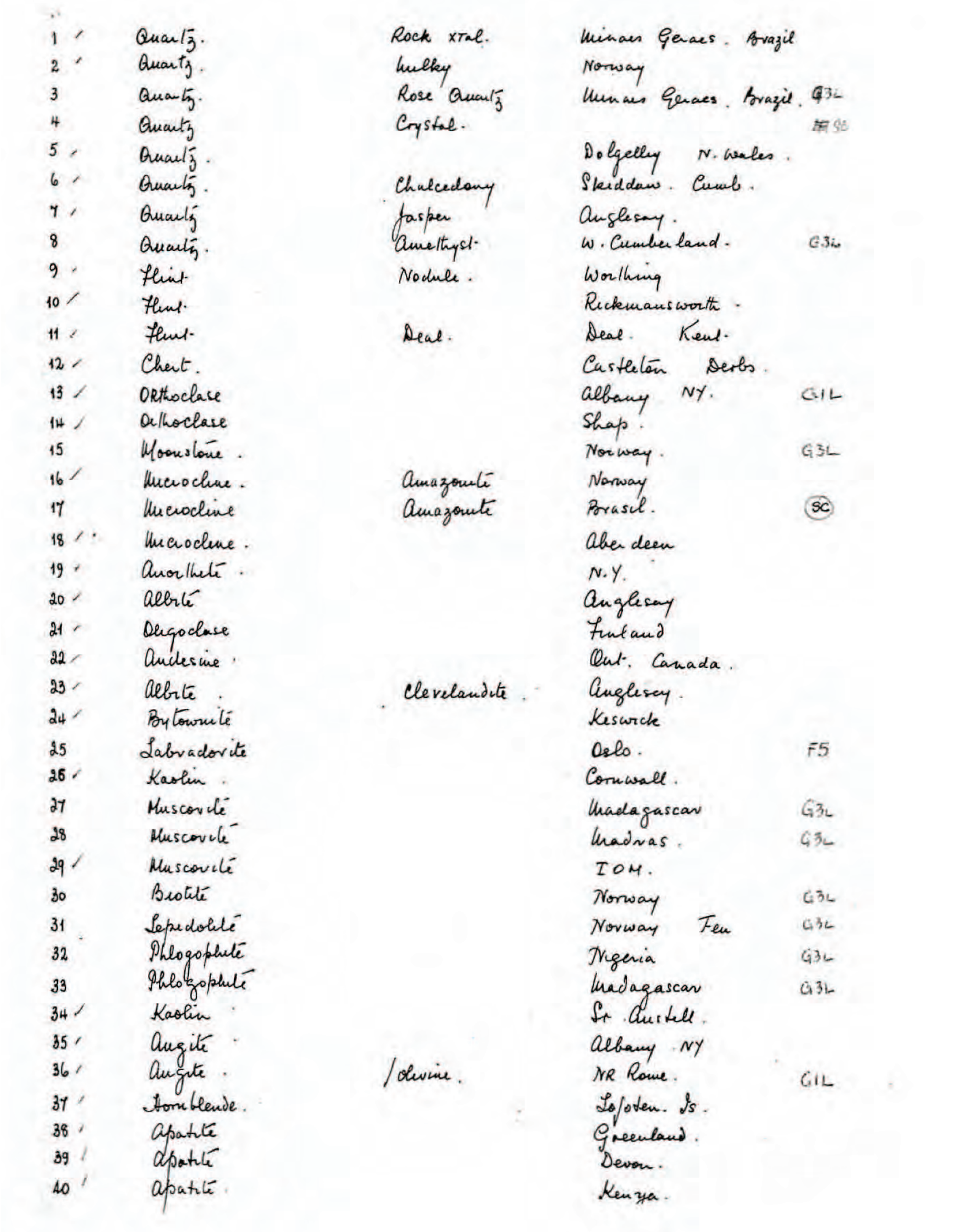
The way that the first few hundred specimens are catalogued, in batches of similar species, suggests that they were acquired before the catalogue was started and Jim was catching up on a backlog. This supposition is supported by a few isolated file cards, the earliest of which records:

> Good Linarite, but also displaying perhaps better Caledonite with traces of Anglesite.

This card describes specimen 465, which was self-collected in May 1961 (Figure 7, see p. 40). The fact that Jim was sufficiently advanced as a collector to recognise linarite, caledonite and anglesite in 1961 (when he was aged about 34) suggests he had been collecting for some time.

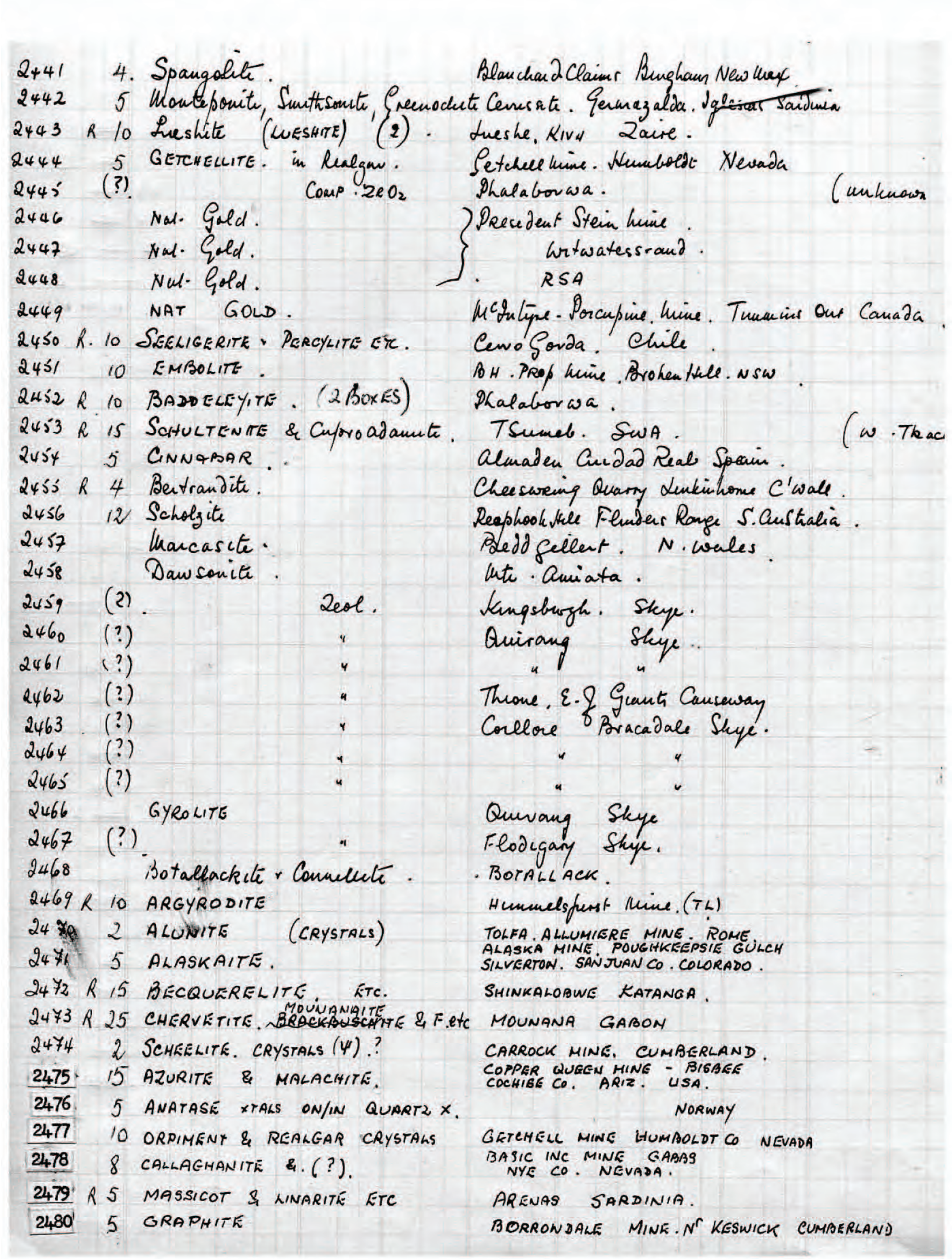
In the early part of the register, between specimen numbers 1 and 611, most localities lack detail; the entries commonly include just a country, state or province. There are exceptions, mostly those entries describing self-collected specimens, for which a vein or mine is usually noted. From specimen number 612 onward the localities become more precise, although many entries still lack useful detail. As with most collections, some of the early location records are problematic. A baryte specimen (No. 51) from "N. Cheshire", is very unlikely. A fluorite from "Leadhills" (No. 71) is equally improbable. Jim left the early catalogue records as they were, although he would have known that some were erroneous in later years. Corrections were made on later specimen labels (Figure 8, see p. 40).

Jim went to considerable lengths to ensure that if a specimen became separated from its label, it would be easy to identify and replace in his collection. Most early specimens have an accession number neatly inscribed in white paint on the matrix. Later specimens have a small piece of paper with a printed number glued onto them.



1	Quartz.	Rock xtal.	Minas Geraes. Brazil	
2	Quartz.	Milky	Norway	
3	Quartz.	Rose Quartz	Minas Geraes. Brazil.	G3L
4	Quartz	Crystal.		[illegible]
5	Quartz.		Dolgelly N. Wales.	
6	Quartz.	Chalcedony	Skiddaw. Cumb.	
7	Quartz	Jasper	Anglesey.	
8	Quartz.	Amethyst	W. Cumberland.	G3L
9	Flint	Nodule.	Worthing	
10	Flint.		Rickmansworth.	
11	Flint.	Deal.	Deal. Kent.	
12	Chert.		Castleton Derbs.	
13	Orthoclase		Albany NY.	G1L
14	Orthoclase		Shap.	
15	Moonstone.		Norway.	G3L
16	Microcline.	Amazonite	Norway	
17	Microcline	Amazonite	Brasil.	SC
18	Microcline.		Aberdeen	
19	Anorthite.		N.Y.	
20	Albite		Anglesey	
21	Oligoclase		Finland	
22	Andesine		Ont. Canada.	
23	Albite.	Cleavelandite.	Anglesey.	
24	Bytownite		Keswick	
25	Labradorite		Oslo.	F5
26	Kaolin.		Cornwall.	
27	Muscovite		Madagascar	G3L
28	Muscovite		Madras.	G3L
29	Muscovite		TOM.	
30	Biotite		Norway	G3L
31	Lepidolite		Norway Feu	G3L
32	Phlogophite		Nigeria	G3L
33	Phlogophite		Madagascar	G3L
34	Kaolin		St Austell.	
35	Augite		Albany NY	
36	Augite.	Olivine.	NR Rome.	G1L
37	Hornblende.		Lofoten. Is.	
38	Apatite		Greenland.	
39	Apatite		Devon.	
40	Apatite		Kenya.	

Figure 5. The first page of Jim's collection register, listing accession number, species name, varietal name, locality and storage location (the last column, which was added later, records data for less than half of the specimens, it is presumed the others had been discarded). The first four columns are written in Jim's characteristic early copperplate handwriting.



2441		4.	Spangolite.	Blanchard Claims Bingham New Mex
2442		5	Montesponite, Smithsonite, Greenockite Cerussite.	Germazalda. ~~Iglesias~~ Sardinia
2443	R	10	Lueshite (LUESHITE) (2).	Lueshe. KIVU Zaire.
2444		5	GETCHELLITE. in Realgar.	Getchell Mine. Humboldt Nevada
2445		(?).	Comp. ZrO_2	Phalaborwa. (unknown
2446			Nat. Gold.	President Stein Mine.
2447			Nat. Gold.	Witwatersrand.
2448			Nat. Gold.	RSA
2449			NAT GOLD.	McIntyre-Porcupine Mine. Timmins Ont Canada
2450	R.	10	SEELIGERITE + PERCYLITE ETC.	Cerro Gorda. Chile.
2451		10	EMBOLITE.	BH. PROP Mine. Broken Hill. NSW
2452	R	10	BADDELEYITE. (2 BOXES)	Phalaborwa.
2453	R	15	Schultenite & Cuproadamite.	Tsumeb. SWA. (w. Trac
2454		5	CINNABAR.	Almaden Ciudad Real Spain.
2455	R	4	Bertrandite.	Cheesewring Quarry Linkinhorne C'wall.
2456		12	Scholzite	Reaphook Hill Flinders Range S. Australia.
2457			Marcasite.	Bedd Gellert. N. Wales
2458			Dawsonite.	Mte. Amiata.
2459		(?).	Zeol.	Kingsburgh. Skye.
2460		(?)	"	Quirang Skye.
2461		(?)	"	" "
2462		(?)	"	Throne, E. of Giants Causeway
2463		(?)	"	Coillore Bracadale Skye.
2464		(?)	"	" "
2465		(?)	"	" "
2466			GYROLITE	Quiraing Skye
2467		(?)	"	Flodigarry Skye.
2468			Botallackite + Connellite.	BOTALLACK.
2469	R	10	ARGYRODITE	Himmelsfurst Mine. (TL)
2470		2	ALUNITE (CRYSTALS)	TOLFA. ALLUMIERE MINE. ROME
2471		5	ALASKAITE.	ALASKA MINE. POUGHKEEPSIE GULCH SILVERTON. SAN JUAN CO. COLORADO.
2472	R	15	BECQUERELITE. ETC.	SHINKALOBWE KATANGA.
2473	R	25	CHERVETITE. MOUNANAITE ~~BRACKEBUSCHITE~~ & F.etc	MOUNANA GABON
2474		2	SCHEELITE. CRYSTALS (4)?	CARROCK MINE. CUMBERLAND.
2475		15	AZURITE & MALACHITE.	COPPER QUEEN MINE - BISBEE COCHISE CO. ARIZ. USA.
2476		5	ANATASE XTALS ON/IN QUARTZ X.	NORWAY
2477		10	ORPIMENT & REALGAR CRYSTALS	GETCHELL MINE HUMBOLDT CO NEVADA
2478		8	CALLAGHANITE & (?).	BASIC INC MINE GABBS NYE CO. NEVADA.
2479	R	5	MASSICOT & LINARITE ETC	ARENAS SARDINIA.
2480		5	GRAPHITE	BORROWDALE MINE. Nr KESWICK CUMBERLAND

Figure 6. The page of the collection register on which Jim's handwriting style changes from copperplate to block capitals. All of the following pages and all of Jim's printed labels are written in block capitals. The change appears to have happened in about 1974. This is one of the few pages in the catalogue that records the prices paid for specimens (in a column to the left of the species name) and Jim's impression of their rarity as a sporadic entry to the right of the accession number.

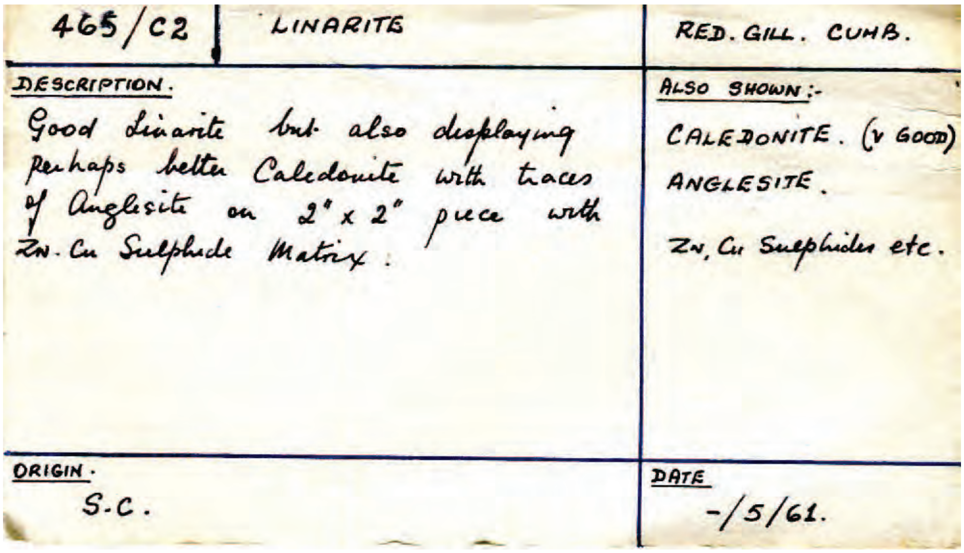


Figure 7. An early file card from an incomplete set describing one of the Knight Collection specimens with problematic provenance. The specimen label for No. 465 lists the locality as Red Gill Mine, but the bottom of the box notes it as Wanlockhead (which seems more likely, on the basis of appearance, although the differences are subtle; cf. Bridges *et al*., 2008); the catalogue entry reads “Red Gill. ? (WANLOCK HEAD)”. It seems that Jim was catching up on a backlog and could not remember where the specimen had been collected. The card has the earliest date recorded for a field trip: May 1961.

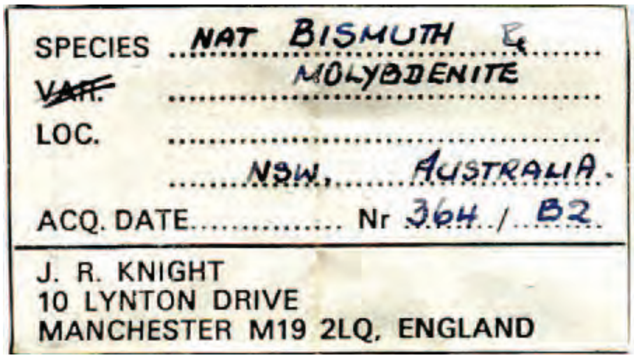


Figure 8. Printed label for specimen 364. It is listed as “Br. Hill.” [Broken Hill] in the collection register, but this is almost certainly in error (cf. Birch *et al*., 1982): Kingsgate in New South Wales is the probable locality, as Jim must have realised when he wrote the label. The label was added a long time after the specimen was catalogued, it is certainly post-1974, when Jim’s handwriting style changed to block capitals.

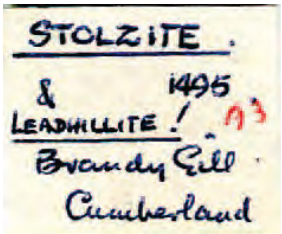


Figure 9. Handwritten label on a small square of card (37 mm on edge) for specimen 1495, from Brandy Gill in the Caldbeck Fells, Cumbria. The date of collection is unknown, but specimen 1492 is dated 1974, so it was probably one of many that were catalogued around that time. The red lettering, which is almost certainly later than the label, indicates the storage location: cabinet A, drawer 3.

In the 1000–2000 number range, a paper number is commonly glued over a pre-existing painted number. Specimens that are very small or otherwise problematic (perhaps due to deliquescence or efflorescence) have their number glued onto their box or container.

Early labels (distinguished by their copperplate handwriting) commonly record just the species name and specimen number; the locality details are written on the bottom of specimen boxes. Over time, brief locality details begin to be included on the labels (Figure 9). Printed labels, which have Jim’s address and placeholders for the information he considered important, are a later addition. They list the mineral name and accession number, often include more locality information than is present in the collection catalogue, and may include the date of acquisition and storage location (Figure 10). A chemical formula is usually present for unusual or newly discovered mineral species. Specimens from type localities commonly have the abbreviation L.T. (or occasionally *Locus Typus*), a convention more usually associated with zoology. The printed labels are almost always written in block capitals, even if they describe early specimens, for which the catalogue records and box inscriptions are in neat copperplate. They are clearly a later addition to the early specimens (dot-matrix printers were not available until 1968 and not in common use until the late 1970s).

In addition to the collection catalogue, the principal species present on each specimen are recorded in a card index. If several examples of a particular species had been acquired, the accession numbers are written in numerical sequence. The species name, chemical classification number

Figure 10. A selection of the printed labels with Jim's address, which were used to retrospectively label most of the early specimens in his collection and for all of the later specimens. The top label for the rare titanium tellurite winstanleyite, from the type locality in Arizona (Williams, 1979), seems to have been written in April 2007 or shortly thereafter, and is in the rather shaky block capitals that are typical of Jim in later life. Winstanleyite is one of the last species to be included in Jim's species index (the last specimen in the index is No. 3513). The earlier labels are in a more confident hand. The rare copper zinc tellurite quetzalcoatlite (Williams, 1973), named in honour of the Toltec and Aztec god of the sea, was acquired in April 1991. Jim's specimen of alstonite from the cotype locality is undated, but nearby specimens date from 1971 or 1972, so it is safe to assume it is an 'old-time' specimen that significantly predates the rediscovery of the locality in the late 1980s (Green *et al*., 2000).

and formula are recorded at the top of the file card, followed by a numerical list including details of other important minerals, the storage location and brief locality details (Figure 11, see p. 42). The card index was begun at a time when computer databases were not generally available and provides a valuable cross-reference to the collection register. It must have taken significant effort to keep it up to date, and reinforces the impression that Jim's was fundamentally a species collection. The last entry in the species index is for specimen 3513 and seems to have been added in 2007, shortly before Jim suffered a stroke.

Many of Jim's specimens were stored in custom-made boxes. The boxes, which came as a kit, were assembled in a series of painstaking operations and finished using a glass panel that was cut to size and glued into the lid. Other members of the Manchester group, notably Mick Cooper[1], housed their collections in similar boxes. Jim used many different sizes, but had a tendency to 'fit a quart into a pint pot'. The smallest box measures 44 × 30 ×38 mm, and most of the larger sizes are simple multiples thereof, so that they pack neatly into storage. In sorting through the collection, more than twenty different sizes were encountered, including deep, shallow and extra-shallow versions of most of the larger sizes. Plastic micromount and Jousi boxes feature extensively in the later part of the collection, but the folding card trays that are typical of most late twentieth century collections are scarce. Most boxes have an accession number glued or written on their lids and base. Labels bearing the species name, acquisition number, brief locality details, storage area and, for new minerals, the chemical formula, are occasionally glued onto the underside of boxes, but most are in the boxes with the specimens they describe.

In spite of his attention to detail, it was rare for Jim to retain labels from previous collectors or dealers. A few nineteenth century labels survive with specimens, as do a handful from the London dealers Gregory, Bottley (and later Lloyd), whose shop was one of Jim's favourite haunts in the 1960s and 1970s. From specimen number 3300 (after the collection register had been abandoned) dealer labels, notably those from Excalibur Minerals, are stapled to the back of Jim's labels.

Even if dealer labels were kept, the prices paid for specimens were almost always removed. The motivation is unclear. The removal of prices from labels may have been a way to disguise the sums paid at a time when money was scarce, or a security measure in case the house was burgled. The few labels that survive with prices paid (almost all post-2002, after the register had been abandoned), show that some were 'expensive': one of the last specimens to be added, (No. 3660), a tiny chip of tsumgallite from the Tsumeb Mine in Namibia, cost 480 euros. In spite of a general lack of pecuniary data, Jim noted the prices paid for specimens catalogued between about 1975 and 1983 (specimens 2441 to 2689 see Figure 6) in an extra column in the collection register. A fine specimen of chervetite (No. 2473) from Mounana Mine in Gabon cost £25; two fine hutchinsonite specimens (Nos 2483 and 2596) from Quiruvilca Mine in Peru cost £50 and £40, respectively; and a fine hand specimen of cerussite (No. 2604) from Touissit, Morocco cost £30.

[1] Jim always spoke very highly of Mick and made a major contribution to his obituary (Green *et al*., 2009).

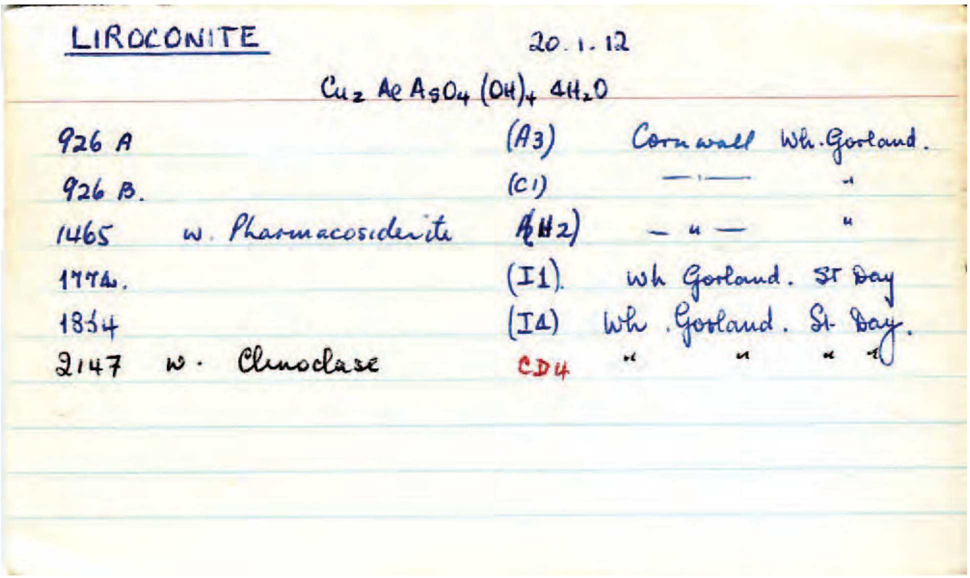


Figure 11. One of the file cards used to record species present in the collection. Most of the liroconite specimens came from Richard Barstow.

A second column is sporadically present to the left-hand side of the price paid. In homage to Philip Rashleigh (who used a similar system in his own catalogue), it gives Jim's impression of the 'rarity and importance of the specimen' using the code R for rare; RR for very rare; and RRR for extremely rare. Most specimens do not merit any designation at all; the chervetite described in the foregoing paragraph has a single R; the two hutchinsonite specimens are RR; only two specimens merit the exceptional designation RRR: demesmaekerite (No. 2561) from the type locality, Musonoi Mine in the Democratic Republic of Congo, and stokesite (No. 2500) from Halvosso Quarry in Cornwall.

THE COLLECTION

The Knight Collection was broad-ranging and eclectic, with a focus on rare species and unusual chemistry. In any analysis there is a tendency to impose personal biases; a collector of British minerals, for example, is likely to emphasise British material. Jim's collection included a significant number of specimens from Cornwall, the north of England and southern Scotland, but it was fundamentally the collection of a chemist with an interest in rare species, and that is the prism through which it is best viewed. It contained a complex assemblage of rare species, with a particular emphasis on halides; minerals containing precious metals; mercury, arsenic and thallium minerals; sulphides and sulphosalts; tellurides and selenides; rare elements; and uranium minerals. Although it was not focussed on particular localities, there were excellent locality suites from Broken Hill in Australia, the Atacama Desert in Chile, several uranium mines in France, and the alkaline rocks of the Kola Peninsula in Russia.

Surprisingly, there are prolific localities from which rare species were readily available during Jim's lifetime, which are hardly represented. The most notable is Mont Saint Hilaire in Canada. Given the similarities between Mont Saint Hilaire and the Russian alkaline pegmatites, from which a good suite of species was obtained, it seems a strange omission, but resources are inevitably limited and no doubt a line had to be drawn.

The following sections describe aspects of the collection that were of particular interest to the authors. There is little doubt that if Jim were writing the text it would have a different focus and would not begin with a description of minerals from the British Isles. The analysis is based on the 2200 specimens from the collection that were examined by the authors and recorded in a database; a survey of the register (which was digitised by Peter Briscoe); and a series of albums with photos of the specimens that Jim considered the most important in his collection.

British Minerals

British minerals, especially rare species, appear to have been a particular interest in the late 1960s and 1970s when Jim was associated with the Manchester group and Richard Barstow. The first six hundred specimens in the collection catalogue are typically poor examples of common species, and are best thought of as a beginner's collection; they are gradually displaced by more interesting specimens, many from the British Isles, from number 600 onward. British localities are numerous on most catalogue pages up to specimen number 2500; foreign localities dominate thereafter.

Classic localities in Devon and Cornwall, northern England and southern Scotland are well represented in the collection. Of particular note in the Cornish suite is an exquisite stokesite with mica and orthoclase feldspar (Figure 12; see also Tindle (2008) for a different photo) from Halvosso Quarry, Longdowns, collected by Richard Barstow (Couper and Barstow, 1977). It is one of very few specimens from the locality, and at 6.5 mm has the largest crystal from the find. It is not accompanied by a Barstow label, but Jim told one of the authors:

> Dick had given me the option of buying it after the identification was confirmed by the Natural History Museum

(a sign, if any were needed, of their friendship). In 2006, Jim asked for a photo of the termination of the stokesite crystal at the highest resolution possible, using the then-new technique of image stacking. He suspected that it might have unusual faces and was interested in what that might imply about the crystallography (see Couper and Clark (1977) for an idealised crystal drawing). After some trial and error, an image was assembled (inset to Figure 12), but what appeared to be a "flat termination" under Jim's microscope proved to be a collection of prisms and pyramids.

Other notable specimens in the Cornish suite include an exceptional 'aikinite' from Wheal Maudlin (Figure 13). 'Aikinite' in this context refers not to the sulphosalt, but to a pseudomorph of wolframite after scheelite, one of the most unusual and desirable Cornish 'oddities' of the nineteenth century. Other classic Cornish specimens include a fine suite of arsenates from St Day, notably liroconite, chalcophyllite and clinoclase; excellent connellite, olivenite and cuprite from the same area; stephanite with pyrargyrite from Wheal Ludcott (Figure 14, see p. 44); and bournonite from Wheal Boys. More contemporary pieces include a fine meta-autunite from Cheesewring Quarry, almost certainly collected by Richard Barstow, but lacking his label. Numerous specimens of botallackite from Levant Mine, St Just (Figure 15, see p. 44) were collected on field trips with Richard Barstow (Knight, 2002). They were regarded as the finest known examples of the species until the spectacular discovery at Cligga Head (Merry and Weiß, 2007).

Figure 12. Pale pink bipyramidal stokesite crystal, 6.5 mm long, collected by Richard Barstow in June 1975 from one of two boulders at the Penryn Granite Company's quarry at Halvosso, Longdowns, Cornwall. The dominant crystal forms are bipyramids {121} and {243}. The inset shows the crystal termination at high magnification, a feature which Jim was particularly interested in. The flat termination {010}, figured in Couper and Clark (1977), is not present; the prism faces may be m {110}, and there are at least two unidentified bipyramids. Specimen number 2500 in the Jim Knight collection, acquired from Richard Barstow in 1975 for £25. The code RRR written in the collection catalogue indicates great rarity. Photos David Green.

Jim had a particular fondness for gold and owned a rich specimen from Hope's Nose in Devon (Figure 16, see p. 45). Specimens from the southwest of England are not common in the later part of the collection (after about number 2500), but rarities still attracted Jim's attention. Specimen 3309, for example, has minute beige spherules of the rare iron zirconium phosphate malhmoodite[2] from Kerriack Cove on the north coast, the second world occurrence at the time (Elton and Hooper, 1995).

Minerals from the Mendips include an almost complete suite of the then known oxychorides from Merehead Quarry. Jim was particularly keen to obtain parkinsonite and often asked the authors if they had any spare specimens. There is a specimen in the collection labelled as such, but it does not appear to have parkinsonite on it. Oddly, Jim had a synthetic specimen of parkinsonite, which was made by his friend Richard Braithwaite.

Although he made many field trips to Wales, Welsh specimens are not well represented in the Knight Collection. There are a few pieces from the alpine veins in Snowdonia, but fine brookite is conspicuous by its absence. Large platy

Figure 13. Sharp pseudomorphs of wolframite after scheelite from Wheal Maudlin, Cornwall. Described in the nineteenth century using the name 'aikinite', they are among the most sought after of Cornish oddities. Jim Knight specimen number 1755; field of view is 40 mm across. Photo Nigel Hoppé.

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[2] Malhmoodite is the approved spelling of the mineral (CNMNC, 2017), which was named in the honour of Bertha K. Malhmood of the U.S. Geological Survey. In the original description the name was written "mahlmoodite" (Milton *et al*., 1993) and this spelling has propogated into later works.

crystals of cerussite from Logaulas Mine (often incorrectly written Log-y-Las), are present; the best were collected by Richard Braithwaite and Tim Greenland on 5th September 1962. A suite of supergene minerals from Halkyn Mountain includes malachite after azurite, anglesite, cerussite, and phosgenite. A number of self-collected specimens of millerite from Deep Navigation Colliery, Treharris, are listed in the catalogue (Nos 739–744, 1624 and 1625). Other millerite specimens were collected at Bedwellty Pit near Tredegar (Figure 17). Three specimens of Welsh gold (Nos 1858–1860) were self-collected. A vein of pale brown axinite with a few crystal surfaces and a specimen of epidote from Penmaenmawr Quarry on the north coast of Wales are of particular interest as more recent field trips have failed to find the exposure. Jim collected at the site with Richard Braithwaite and Tim Greenland on 8th March, 1964. There was no road or track to the quarry and an approach had to be made over the mountain. Quarry wagons had to be assembled on site after the components had been hauled up a steep incline, which was the only connection the quarry had with the outside world. The axinite was a localised occurrence in the east wall of the lower bench of the quarry; the epidote was found in the wall of the upper bench and, like the axinite, was a localised occurrence; both have been quarried away.

Figure 14. Prismatic pyrargyrite on stephanite, about 1 mm long, from Wheal Ludcott, Liskeard, Cornwall. Specimen 1731B in the Jim Knight collection; the field of view is 4 mm across. Photo Nigel Hoppé.

A superb specimen of matlockite (Figure 18) and a phosgenite (No. 466) from Bage Mine are the most important specimens in the Derbyshire suite. The baryte, calcite and fluorite for which the county is famed are conspicuous by their absence, although there are numerous examples of supergene minerals such as smithsonite and aurichalcite from the mines around Matlock (Figure 19). There are also a few supergene minerals from the mines at Alderley Edge, perhaps the nearest collecting locality to Jim's house in Manchester. These include azurite, anglesite, cerussite, pyromorphite and, from Mottram Mine at nearby Mottram St Andrew, mottramite.

Ecton Mine in Staffordshire was a favoured locality for the Manchester group; Jim collected celestite from Clayton Adit with Richard Braithwaite and Tim Greenland in the 1960s (Figure 1 and Figure 20). Serpierite and

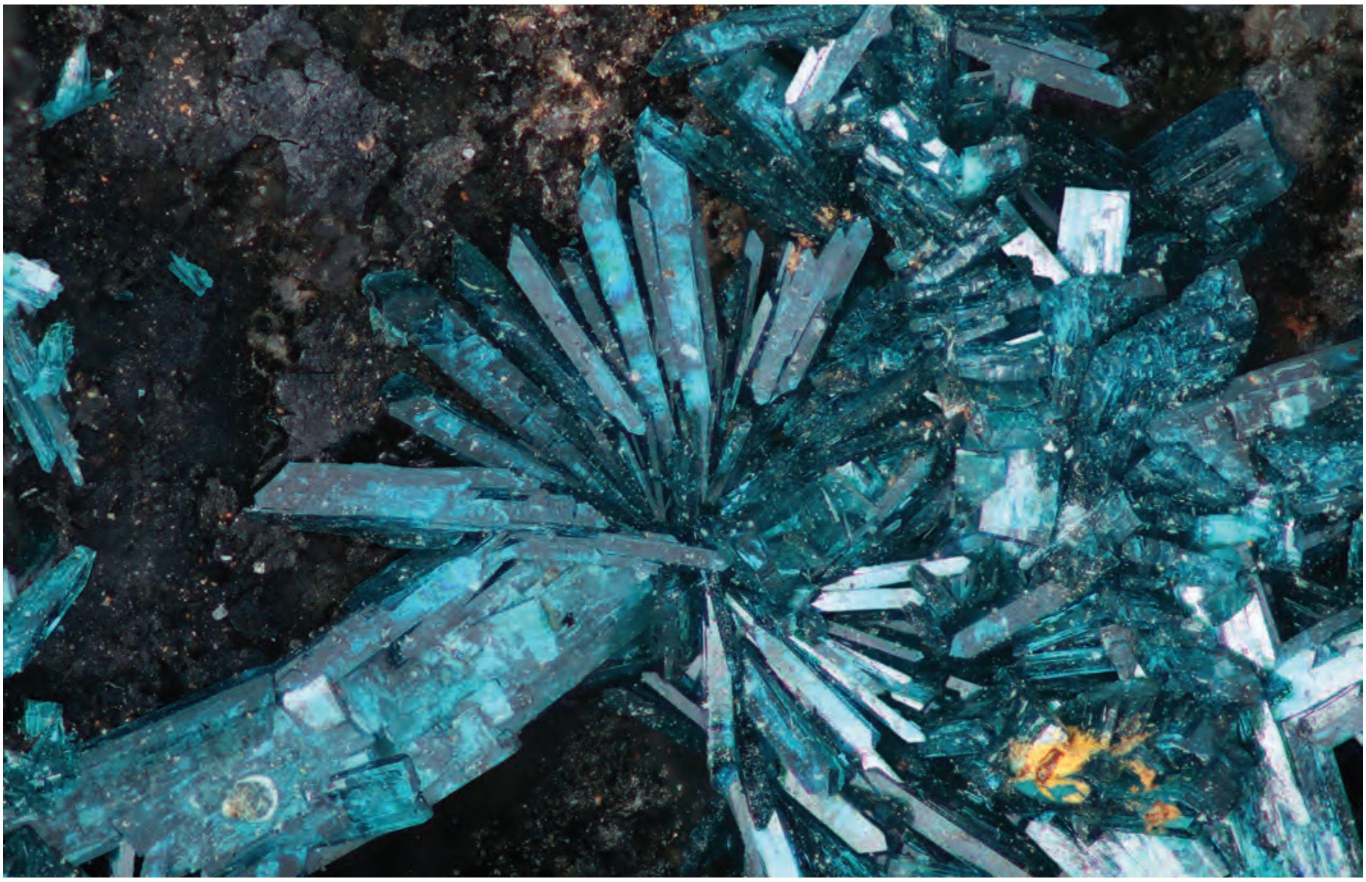


Figure 15. Monoclinic botallackite blades up to about 2 mm in length from Levant Mine, St Just, Cornwall. Specimen 3161 in the Jim Knight collection, registered many years after it was collected. Photo John Chapman.

aurichalcite on post-mining gypsum came from a shaft in the underground engine chamber (Braithwaite and Knight, 1968). The serpierite was discovered by a party that included Jim, Roy McDonald, Richard Braithwaite, and his then-fiancée Sheila, on 24th January 1965.

Specimens from the Caldbeck Fells, a popular collecting area for the Manchester group in the 1960s, include 'pottsgillite' an uncharacterised species from Potts Gill Mine which was later shown to be an intermediate

Figure 16. Rich fronds of gold from Hope's Nose, in Devon, etched from calcite matrix using dilute acid. Jim Knight specimen number 3018; 50 × 30 × 10 mm with gold fronds to 10 mm. Photo Nigel Hoppé.

Figure 17. Millerite on siderite in a crack in a Coal Measures ironstone nodule from Beddwelty Pit, SO 154 064, Tredegar, Monmouthshire, one of the localities Jim visited in 1964 with the Manchester group. Jim Knight specimen number 1503; the whole specimen is 120 × 75 × 40 mm with acicular millerite up to 22 mm long. Richard Bateman specimen; photo Peter Briscoe.

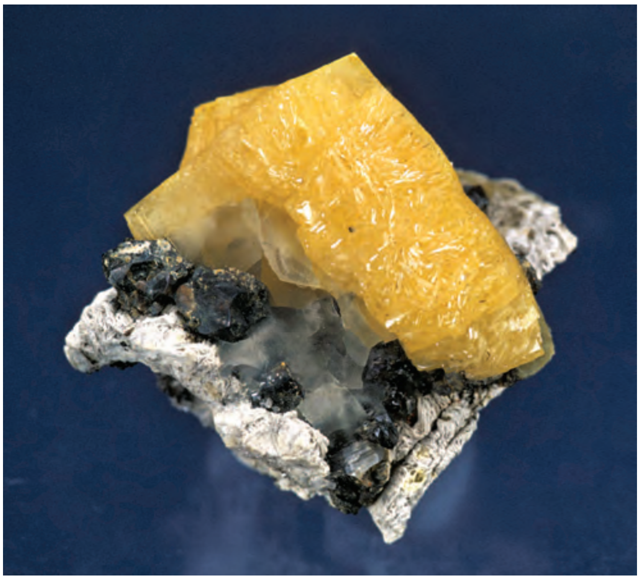


Figure 18. Yellow tabular matlockite crystal 25 mm on edge from Bage Mine, Wirksworth, Derbyshire. Specimen 975 in the Jim Knight collection. Photo David Green.

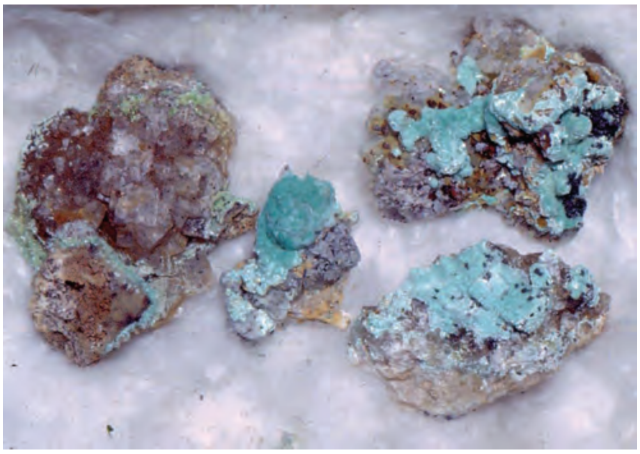


Figure 19. Aurichalcite specimens collected by the Manchester group at Rutland Cavern, Matlock, Derbyshire. Jim Knight photo from one of his mineral albums, the whereabouts of the specimens is unknown.

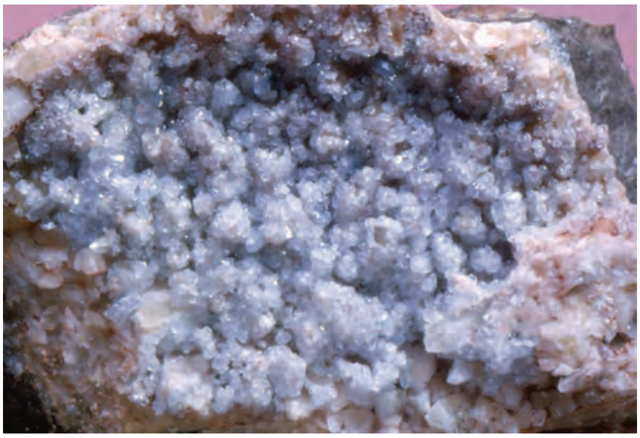


Figure 20. Celestite on calcite from Ecton Mine, Ecton, Staffordshire collected in the mid-1960s by the Manchester group. Two Ecton celestite specimens were found in the Knight Collection in 2016: of the two, an unlabelled specimen, number 731, with celestite crystals up to 4 mm, is very similar to the figured specimen. The whereabouts of the figured example is unknown. Jim Knight photo from one of his mineral albums.

between philipsburgite and kipushite. Carrock Mine was one of Jim's favourite localities and he acquired an exceptional gold (Figure 21) and a suite of tellurides. Roughton Gill is represented by numerous pyromorphite specimens and a plumbogummite, which has a label stating it is from the 'specimen stope'. Other notable specimens include mimetite from Dry Gill Mine. As well as the classic rounded campylite crystals for which the locality is famous, two specimens have orange, hexagonal prisms (Figure 4). Self-collected apatite, galena, leadhillite, molybdenite, scheelite, smithsonite, sphalerite, stolzite, and wolframite are listed from Brandy Gill Mine.

Two suites of Scottish specimens stand out. The U–Cu–As–Bi–Co mineralisation from Needles Eye on the Solway Coast near Dalbeattie is of particular interest for its diverse chemistry and unusual supergene minerals. It includes rare species such as eulytine, kahlerite, metakahlerite, schoepite, vandendriesscheite, and walpurgite, which were new to Britain at the time they were collected (Braithwaite and Knight, 1990). Surprisingly, the specimens were not catalogued or numbered when they were found in the mid to late 1960s, but instead appear sporadically through the collection catalogue over a period of more than 20 years. The reason for this is unclear. It shows that Jim was not driven to catalogue his discoveries immediately, perhaps preferring to work on them as time permitted (specimen 3192, a silver from Kongsberg in Norway provides an extreme example, Jim acquired it in 1968, but it was not catalogued until 2001).

The second important Scottish suite in the collection is from the Leadhills–Wanlockhead area. It includes material collected in the 1960s and 1970s, and a number of 'old time' specimens. A prized specimen was catalogued as "Lanarkite with Leadhillite" in the late 1960s (Figure 22). One of the authors (David Green) remembers being shown it: "What do you think of that, then?". Under a hand lens it became apparent that as well as lanarkite and leadhillite, scotlandite crystals covered a large area. Mattheddleite and susannite were also identified, but the key species is scotlandite. Jim added the words "MATTHEDDLEITE" and "SCOTLANDITE" to the catalogue entry in block

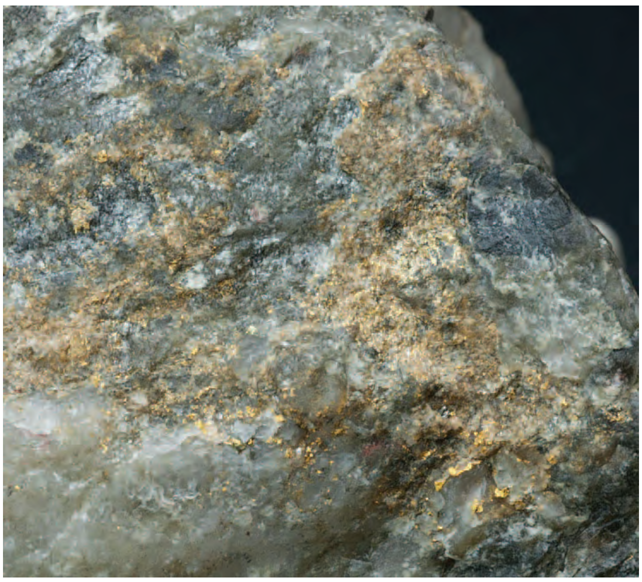


Figure 21. Rich gold with minor scheelite in vein quartz from Carrock Mine, Caldbeck Fells, Cumbria; specimen 1687 in the Jim Knight collection. A 40 × 35 mm area of a 90 × 60 × 42 mm specimen. Unlike most of Jim's other Carrock specimens this does not appear to have been self-collected. Photo Peter Briscoe.

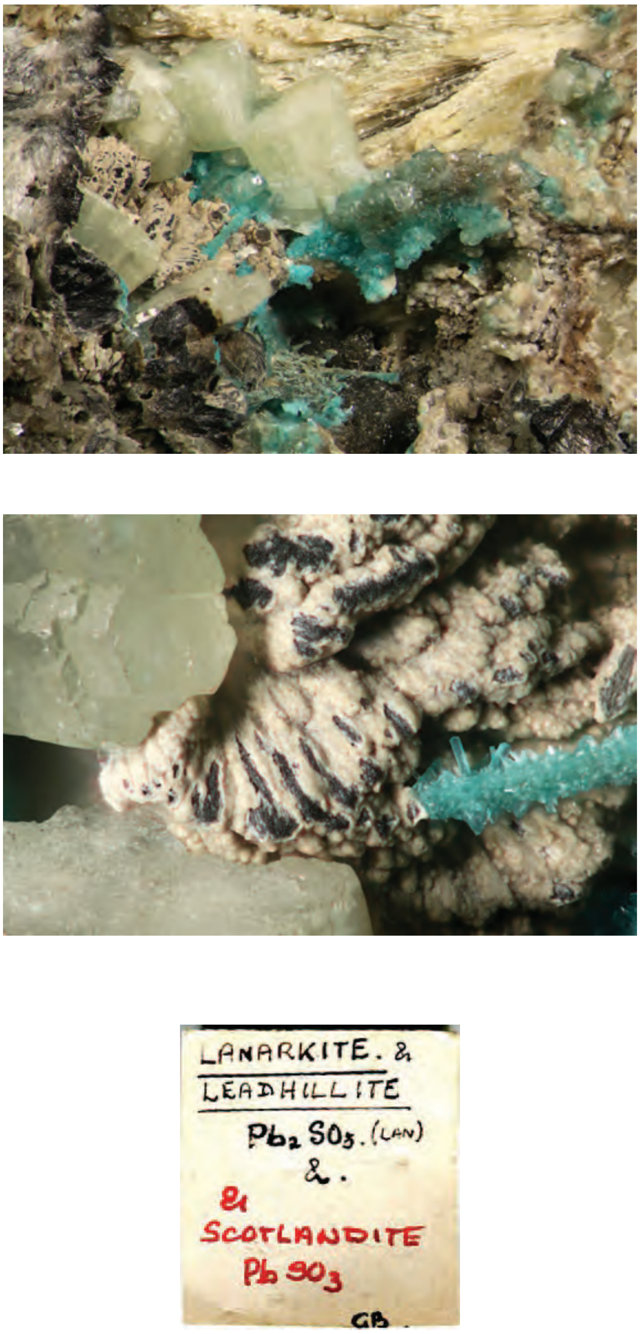


Figure 22. Scotlandite as dark brown radiating crystal groups up to about 0.7 mm across coated in an unknown white phase (possibly anglesite), associated with bladed lanarkite, blocky pale green leadhillite and blue prismatic caledonite. Specimen 979 in the Jim Knight collection, originally catalogued and labelled as lanarkite and leadhillite; anglesite, cerussite, pyromorphite, linarite, susannite, mattheddleite, possible macphersonite and scotlandite are also present, the last three of which were unknown when Jim acquired the specimen. An early file card notes that it was acquired in December 1964 from Gregory and Bottley of London. Scotlandite is a late addition in red writing on the specimen label and although mattheddleite is not noted Jim was aware that it was present. John Chapman photos.

capitals. Both species were unknown in the late 1960s when the entry was first written, but Jim was well aware they were "something interesting". He was offered "wealth beyond the dreams of avarice" by an unspecified collector if he would part with the scotlandite (after the species had been formally described by Paar *et al*. (1984)), but would not accept. As a rare-species collector, he realised that that was what he already had!

Greenockite crystals are a prize in any collection of Scottish minerals and Jim had a number of specimens including a 4 mm crystal on prehnite from the Bishopton Railway Tunnel (Figure 23). As with most of his 'old-time' pieces, there is no record of where it came from. Uraninite features strongly in Jim's radioactive suite and although almost all of the specimens are rich, few show euhedral crystals. Many of the uraninite specimens are from Cornwall or the Solway coast. Of particular interest, however, is a specimen from Tyndrum Mine in Perthshire. It was collected in 1957 by George Ryback and shows well formed botryoidal pitchblende with chalcopyrite in calcite matrix.

Ireland is rather poorly represented in the collection despite Jim's friendship with Richard Barstow who made many important discoveries there. The only notable specimen from Silvermines is a small piece of ore from the 'Silver Chamber' at Mogul Mine which contains rare silver sulphosalts including the germanium-bearing mineral argyrodite. Tynagh Mine, which produced a prolific suite of supergene minerals, is also poorly represented, although there is an excellent cornwallite with azurite.

Worldwide Minerals

Like many collectors with a chemical background, Jim was interested in native elements. There are good to excellent examples of all the well known species and a scattering of rare phases. Unfortunately, the collection of diamond crystals, of which Jim was particularly proud, was not among the material that was examined by the authors. It disappeared after Jim's death. There were, however, at least 25 gold specimens including rich examples from Australia and South Africa, and pieces from hard-to-get British localities such as Treore in Cornwall and Carrock Mine in Cumbria. Silver specimens include many from Central European localities, and among the coppers there were sculptural pieces from Mufulira Mine in Zambia and a rich 'half-breed' from Michigan (probably from David Hardman, a Manchester group member with a particular interest in Michigan copper country). Jim had tubes of panned platinum and a pea-sized platinum nugget from Goodnews Bay in Alaska.

Less common native elements include rhenium and indium from unspecified Transbaikalian localities and panned specks of most of the rare platinum-group elements. Specimens of native mercury and its alloys include a fine crystal of moschellandsbergite from the type locality. Jim was fond of the semi-metals. A small, well crystallised arsenic from St Andreasberg in the Harz Mountains (No. 548) is one of the first noteworthy specimens in his collection. Much later he was able to obtain a rich example of the rare orthorhombic polymorph arsenolamprite from the Alacrán Mine, Pampa Larga, Copiapó, Chile. The best sulphur is from the deposit at Vodinskoe, Samaraskaya oblast', Russia, which produced crystals of unparalleled transparency and lustre.

Most people seem to develop a fondness for certain groups of minerals over the years. It is hard to judge which Jim was most enthusiastic about, but he had a life-long love affair with halides. The mineral villiaumite, NaF, seems to have had a particular fascination and Jim had specimens from the type locality, an obscure pegmatite on Rouma Island in the Los Archipelago off the coast of Guinea, and many other localities including the well known deep red

Figure 23. A 4 mm greenockite crystal in a cavity in prehnite from the classic locality at Bishopton Railway Tunnel, west of Glasgow. Jim Knight specimen 1472. Susan Tyzack specimen; photo Peter Briscoe.

Figure 24. Rich matrixless coralloidal mass of bromian chlorargyrite (embolite) with iodargyrite and tabular yellow stolzite (on the right hand side). Specimen 2164 in the Jim Knight collection, 35 × 35 × 30 mm, listed as "cerargyrite" from "BHP . NSW" in the register. An unusually rich example of an uncommon association (cf Birch *et al*., 1982). Photo Nigel Hoppé.

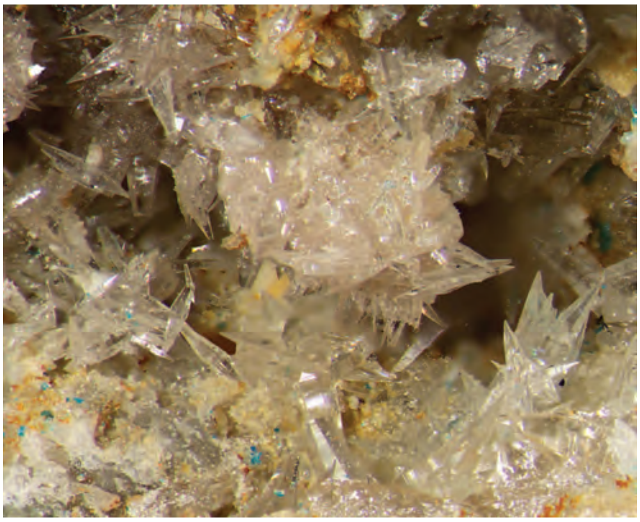
cleavages with embedded zeolites from the carbonatites of the Kola peninsula. The same cannot be said of fluorite; despite a fondness for collecting in Weardale, he often asked: "How many fluorites do you need?".

The silver halides from Broken Hill in Australia are particularly impressive, they include rich specimens of chlorargyrite (Figure 24, see p. 47), bromargyrite and iodargyrite; an outstanding marshite with yellow tetrahedral crystals scattered on gossanous matrix (Figure 25); and a small rich miersite. The best specimens of each of these species are comparable to those figured in the classic *Minerals of Broken Hill* (Birch *et al*., 1982) and seem likely to have come *via* Richard Barstow from Albert Chapman, the doyen of Broken Hill collectors. There were fine examples of many of the supergene species for which Broken Hill is famous in the collection, notably anglesite, cerussite, hemimorphite, raspite (Figure 26) and stolzite.

The copper deposits of the Atacama Desert in Chile are famous for halide minerals. Jim had excellent examples of the eponymous copper chloride atacamite and the rare basic lead chloride penfieldite, one of a group of species

Figure 25. Characteristic orange tetrahedral marshite on gossanous matrix; specimen 2365 in the Jim Knight collection (field of view 1 mm), catalogued as "BHP. Mine, NSW". Marshite was the first new species to be described from Broken Hill; well crystallised examples are exceedingly rare (Birch *et al*., 1982). Photo Nigel Hoppé.

Figure 26. Prismatic raspite on gossanous matrix; specimen 2638 in the Jim Knight collection (field of view 1.5 mm). Raspite is one of the most sought after species from Broken Hill; Jim had several specimens from the locality (and an excellent example with stolzite from the lesser known Cordillera Mine which is also in New South Wales). Photo Nigel Hoppé.



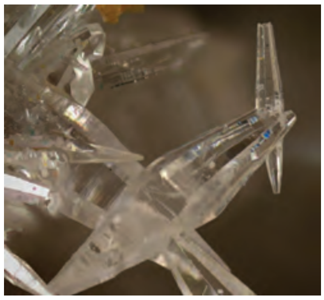


Figure 27. Millimetre-size penfieldite crystals with minor blue boleite from Casucha Mine, Caracoles, Sierra Gorda, Antofagasta, Chile. Jim Knight specimen number 3386. The inset (0.6 mm field of view) shows the characteristic steeply pyramidal double terminated crystal habit. Harry and Chris Critchley collection; photo John Chapman.

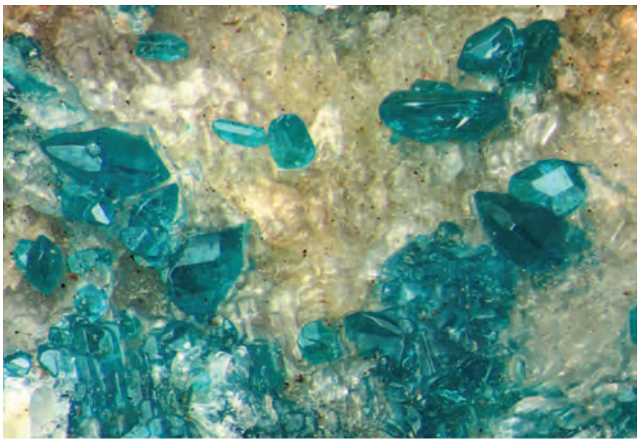


Figure 28. Transparent blue crystals of the rare copper iodate salesite up to about 0.8 mm across from Chiquicamata, Calama, Antofagasta, Chile. Jim Knight specimen number 2771. Harry and Chris Critchley collection; photo John Chapman.

which require particular curatorial care as they alter on immersion in water (Figure 27). He also had a suite of the soluble iodide and iodate minerals for which the desert is famous, including the rare copper iodate salesite (Figure 28), and the sodium sulphate-iodate hectorfloresite.

No collection of halide minerals could be considered complete without specimens of the lead copper hydroxyl chlorides from the unique deposit at Santa Rosalia, Boleo, Baja California. Although boleite has tetragonal symmetry it almost always forms near-perfect pseudocubic crystals, seldom more than 5 mm on edge. Jim had one of the rare specimens that reveals boleite's underlying tetragonal symmetry: an undamaged dark blue columnar crystal 10 mm long.

Uranium minerals were a key part of Jim's collection, and they appealed greatly to his chemical curiosity. The uranyl cation allows uranium to combine with a remarkable number of elements to produce minerals that are stable in oxidising environments. Although many rare species have a reputation for being 'aesthetically challenged', some of Jim's are well crystallised. His bright orange spriggite, pale yellow triangulite and pale green vyacheslavite are very rare and all have fine crystals for the species.

Most of the European uranium minerals are from collecting trips to France. Parsonsite (4 specimens), torbernite and/or metatorbernite (12 specimens), kasolite (7 specimens), meta-autunite (19 specimens) and uraninite (17 specimens) are the most abundant and (meta)zeunerite, phosphuranylite and uranophane-β are also present. Other noteworthy European uranium minerals include metalodèvite from Lodève, France; uranocircite from Vogtland, Germany; bergenite from Krueckelbach and Mechelsgrun, Germany; walpurgite from the Schmiedestöllen dump, Germany; uranospathite from Pedro Alvaro, Spain; and two fine (meta)torbernites from Bois Noir, France, one of which is shown in Figure 29.

Towards the end of his life Jim expanded his interest in uranium minerals and began to collect specimens from the famous mines in the Democratic Republic of Congo. The best known Congolese localities are Musonoi Mine and Shinkolobwe Mine (a couple of early specimens from the latter are labelled "Chinkolobwe" in the collection records). Specimens from these mines include the more common species: cuprosklodowskite, derriksite, marthozite, sklodowskite, and vandenbrandeite; and rarities such as astrocyanite-(Ce), kamotoite-(Y) and shabaite-(Nd), from Shaba East Opencut. The astrocyanite-(Ce) is unusual in that it normally occurs as stellate aggregates of blue bladed crystals, but Jim's specimen shows a very rare globular aggregate. Other notable specimens include an incredibly rich cabinet-size specimen of soddyite from Swambo Mine and masuyite on studtite from Shinkolobwe Mine.

The Mounana Mine in Gabon is well known among species collectors for its rare uranium minerals; excellent examples of curienite, francevillite, mounanaite, and vanuralite are well known from the locality. Jim's collection contained a small handful of specimens, including

Figure 29. One of two torbernite specimens from Bois Noir, Saint Priest la Prugne, Auvergne, France; specimen 2212 in the Jim Knight collection, 42 × 22 mm with crystals up to 5 mm across. Alan Barnes specimen and photo.

Figure 30. Interpenetrant cubes of the thorium oxide thorianite, about 5 mm on edge, from an unidentified alluvial deposit in Madagascar; specimen 1360 in the Jim Knight collection. Photo John Chapman.

a cabinet-size specimen of chervetite in association with mounanaite and francevillite.

Boltwoodite, although relatively common, is only represented from the classic Arandis area of Namibia. Seven specimens are catalogued and all are different. One shows a stellate aggregate of fine acicular crystals with a beautiful silky lustre, others consist of golden yellow columnar crystals or globular aggregates of orange or yellow bladed prismatic crystals.

Uranium minerals from America are not extensively represented in the collection, the only specimens worthy of note being carnotite from Colorado; uraninite, coffinite, tyuyamunite, uranophane and zippeite from Grants County, New Mexico; voglite from White Canyon, Utah; zeunerite from Myler Mine, Nevada; weeksite from the Autunite No. 8 Claim, Utah; liebigite from Schwartzwalder Mine, Colorado and haynesite from Repete Mine, Utah. The reason for the limited number of specimens is not clear as Jim would have had the opportunity to acquire specimens from dealers such as Tony Nikischer and Gunnar Farber. It may, once again, be a reflection of finite financial resources.

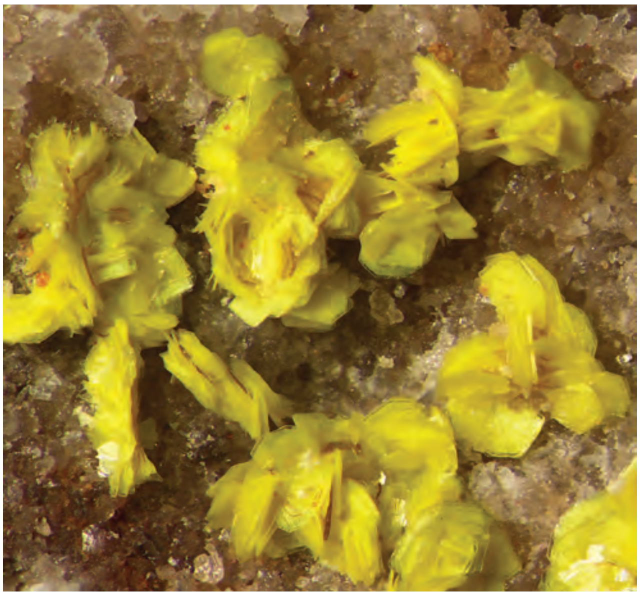


Figure 31. Yellow plates of the calcium uranyl vanadate tyuyamunite, up to 0.7 mm across, from the Marie Mine, Carbon Co., Montana, USA. Jim Knight specimen 3249. Photo John Chapman.

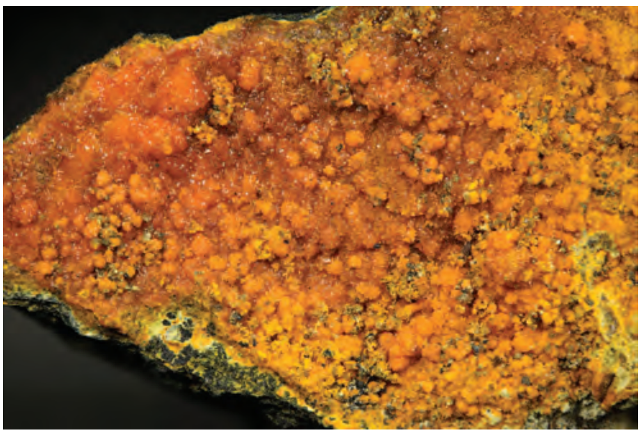


Figure 32. The rare and colourful vanadium oxysalt lasalite from the Vanadium Queen Mine, La Sal District, Utah; specimen 3518 in the Jim Knight collection. Alan Barnes specimen; photo John Chapman.

Thorium is a poor relation to uranium in terms of its supergene chemistry, and has a much less diverse mineralogy. Jim had a few thorium-bearing species, perhaps the best of which is a small but well-formed crystal of the oxide thorianite (Figure 30, see p. 49).

Vanadium occurs in many different oxidation states. It is commonly associated with uranium in supergene minerals such as tyuyamunite (Figure 31), of which Jim had several good examples. Many vanadium species have a very restricted occurrence; Jim had excellent examples of vanadium oxysalt species such as lasalite (Hughes *et al*., 2008), which is known from very few localities (Figure 32). He also had specimens of most of the more widespread species, such as the calcium copper vanadate tangeite from the ancient Glücksstern Mine, Thuringia, Germany (Figure 33).

Jim had a fascination for minerals containing precious metals. These combine rarity and intrinsic value with unusual chemistry and mineralogy. The collection of native elements has been discussed in the foregoing text. Minerals containing platinum-group elements are surprisingly diverse, but have a tendency to occur as microscopic inclusions in ultrabasic rocks. Jim certainly had the opportunity to purchase some of these as they feature in mineral lists in the archive associated with his collection. The fact that he did not suggests that his collecting was not simply a 'box-ticking' exercise. Why spend a significant sum on an invisible speck of a rare platinum-group mineral if the same investment would purchase something equally rare, but of more visual interest? The most impressive platinum-bearing specimen in Jim's collection is a sperrylite crystal in sulphide matrix from the remote Russian locality at Noril'sk (Gressmann *et al*., 2010) (Figure 34). There were small sperrylite crystals from other localities (in different geological situations), something of an achievement given the rarity of the species. The platinum sulphide cooperite was the nearest Jim got to collecting 'ultrabasic specks',

Figure 33. Pseudohexagonal florets of tangeite, up to about 1 mm across, from the Glücksstern Mine, Gottlob Hill, Friedrichroda, Thuringia, Germany. This ancient iron and manganese mine is the type locality for crednerite, gottlobite, vesigniéite, and wakefieldite-(La). Specimen 993 in the Jim Knight collection. Photo John Chapman.

but it is relatively rich; numerous tiny metallic inclusions are visible in dark green matrix.

The suite of gold and silver tellurides includes a handful of calaverite specimens from the type locality in Calaveras Co., California and Cripple Creek, Colorado; a remarkably rich and heavy petzite from Kalgoorlie in Australia, a locality from which it is extremely difficult to obtain specimens of any sort (Noble, 2017); hedleyite from British Columbia; outstanding crystals of hessite from Romania and Russia; several rich nagyágites from the type locality in Romania (Figure 35); and well crystallised sylvanite from Cripple Creek. There were also ruby silvers:

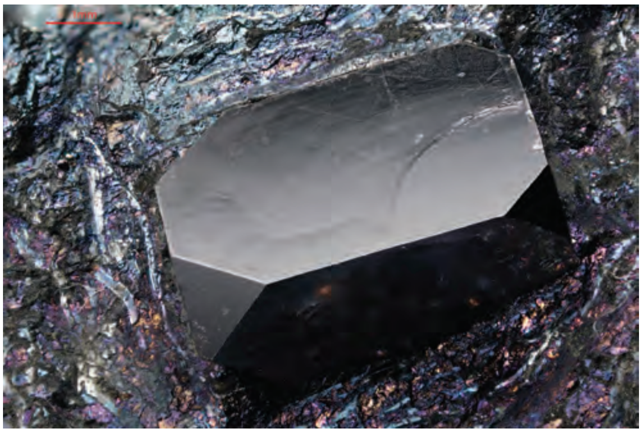


Figure 34. A sperrylite crystal, 5 mm on edge, which has been worked out of enclosing sulphide matrix. Many sperrylite crystals have fissures running through them, perfect examples such as this specimen, 3232 in the Jim Knight collection, are rare. The Talnakh specimens caused a sensation when they first appeared at mineral shows in the late 1990s (Cooper, 1997). Harry and Chris Critchley specimen; photo John Chapman.

Figure 35. Rich platy nagyágite from the type locality, Sacarîmb (Nagyág), Deva, Hunedoara Co., Romania. Specimen 1982 in the Jim Knight collection (57× 53 mm with platy crystalline masses to 13 × 8 mm) Alan Barnes collection and photo.

pyrargyrite from Chañarcillo, Copiapó, Chile and the Harz Mountains, Germany; and proustite from Peru and several localities in central Europe. The European silver suite was surprisingly diverse, including such rarities as freieslebenite from the Hiendelaencina deposits, Guadalajara, Spain (Figure 36).

Jim had a particular interest in tellurides and selenides of the base metals. Unusual specimens include well crystallised tiemannite in carbonate matrix from Querétaro, Mexico; rich cleavages of altaite from Hilltop Mine, New Mexico (and many other localities); and an extraordinarily well crystallised clausthalite from Bois Noir in France. There were specimens of the mercury telluride coloradoite from a number of localities, including a large mass from Kalgoorlie in Western Australia. The tellurides, tellurites and tellurates from the famous Moctezuma Mine, Sonora, Mexico are extensively represented, with fine specimens of spiroffite, klockmannite and quetzalcoatlite among others.

Thallium minerals were another interest. There are numerous specimens of the interchangeable thallium sulphosalts from Lengenbach Quarry in Switzerland. Crookesite, the first thallium-bearing mineral to be recognised, which is named after Sir William Crookes the co-discoverer of the element, is represented by rich specimens from Norway and the USA. There are several hutchinsonite specimens overgrown by orpiment and baryte from the famous Quiruvilca Mine in Peru (Figure 37, see p. 52). Lorándite is represented by two specimens from the type locality in Macedonia. Well crystallised galkhaite is present in massive orpiment from Getchell Mine in the USA and associated with gruzdevite, supposedly from Khaidarkan in Kyrgyzstan, but more probably from the nearby Chauvai Sb-Hg deposit, which is also in the Osh oblast'.

A fascination with exotic (and poisonous) elements extended to arsenic and mercury. Jim had numerous specimens of realgar and orpiment, including crystals from China and Peru. One of the best realgar specimens has beautiful vermillion prisms associated with pyrite and dense

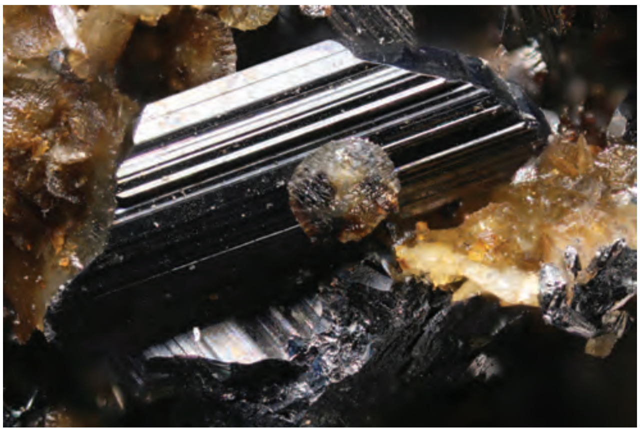


Figure 36. A striated crystal of the rare silver-lead sulphosalt freieslebenite, 3.5 mm long, on siderite from Hiendelaencina, Guadalajara, Spain. Specimen 2166 in the Jim Knight collection. Photo John Chapman.

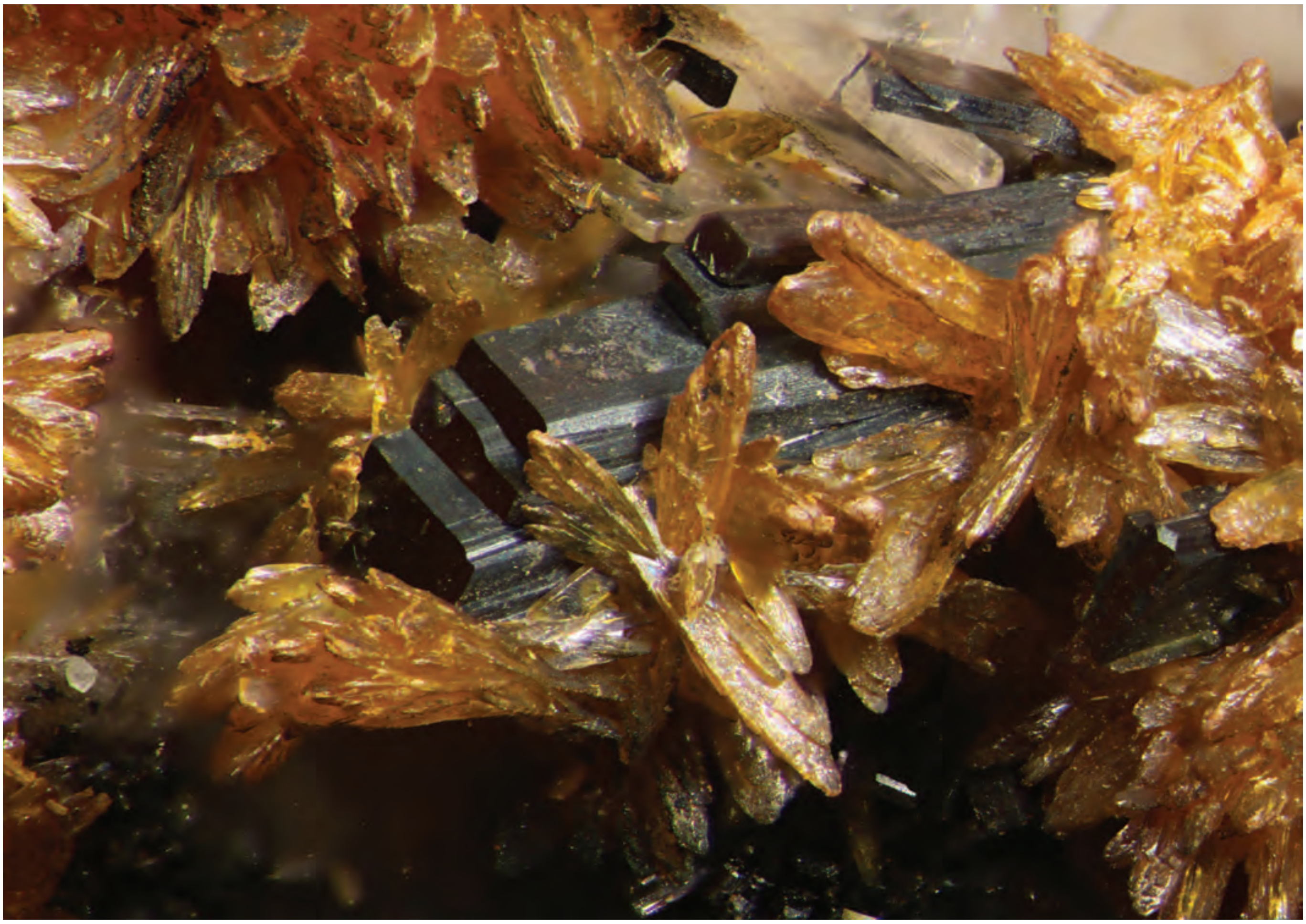


Figure 37. Dark prismatic hutchinsonite, about 5 mm long, overgrown by orpiment, from Quiruvilca Mine, Santiago de Chuco, La Libertad, Peru (probably 50 Level, San Nombre Vein, from which there was an almost identical specimen). Specimen 2715 in the Jim Knight collection. Photo John Chapman.

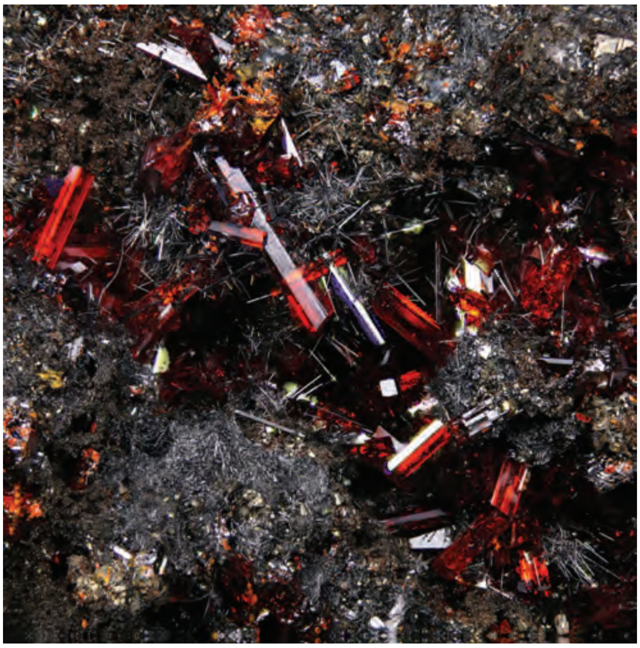


Figure 38. Dark red prismatic realgar crystals to 4 mm long with acicular zinkenite from Boldut Mine, Cavnic, Romania. Specimen 3126 in the Jim Knight collection, one of the last to be catalogued in his register (in 2002). Photo John Chapman.

Figure 39. Yellow aggregates of the unusual mercury mineral kleinite, $Hg_2N(Cl,SO_4)\cdot nH_2O$, about 1.5 mm across, from the McDermitt Mine, Humboldt Co., Nevada, USA. Specimen 2650 in the Jim Knight collection. Photo John Chapman.

needles of zinkenite from Boldut Mine, Cavnic, Romania (Figure 38); light sensitive, the specimen was preserved in a box with an opaque lid. As well as mercury and cinnabar, Jim's suite of mercury-bearing minerals includes a suite of mercury-nitrogen minerals such as kleinite (Figure 39), gianellite, mosesite, and comancheite. He must have had good contact with someone working in the mercury mines of the southern USA, as a variety of other species including terlinguaite and eglestonite are also catalogued.

Although they are in the same group in the Periodic Table, antimony has a significantly different supergene chemistry to arsenic; its ionic radius mitigates against the formation of tetrahedral antimonate oxyanions. Antimony, nonetheless, has an interesting supergene chemistry and Jim amassed a significant number of species. He had several fine crystalline kermesite specimens from central Europe and a large crystal spray from the remarkable discovery at an unnamed antimony mine in the Damingshan Range, Dafeng, Shanglin Co., China, in 2002. There is rich sarabauite from the type locality, Sarabau Mine in Borneo; valentinite from the type locality at Les Chalanches Mine, France; and onoratoite, cetineite, mopungite and klebelsbergite from Italy. The famous Tsumeb Mine in Namibia is represented by a tiny phial containing a powder-puff spray of the rare antimony-molybdenum mineral biehlite; a chemist's species if ever there was one. The ideal formula, $Sb^{3+}{}_2MoO_6$, is more commonly written $(Sb^{3+},As^{3+})_2MoO_6$, to recognise the small but significant substitution of As for Sb in natural material from the type (and only) locality.

It would be easy to continue listing minerals in their respective groups; the foregoing text provides a flavour of the quality and variety of Jim's systematic collection. In the remaining paragraphs, noteworthy specimens which do not fit into an obvious category are highlighted.

Harmotome is a good place to start. Specimen number 672 is an attractive example with white blocky crystals on yellow drusy fluorapophyllite-(K) from the famous locality at Korsnäs Lead Mine, near Vassa, Finland (Sahama, 1967). It is one of the first specimens in the collection that can be described as a 'fine cabinet piece' (Figure 40), and perhaps marks the start of Jim's transition from beginner to advanced collector. Many of the specimens from this locality came from a large pocket encountered on the –190 m level; although the apophyllite crystals appear to be sharp tetragonal prisms, they are complex twins (Sahama, 1965).

Jim does not seem to have had a great deal of interest in the zeolite family of minerals, although he had good examples of most of the common species and a scattering of rarities including hsianghualite and gobbinsite. If, however, a zeolite had an unusual chemical association it was of more interest; there are several fine examples of the calcium molybdate powellite associated with Indian zeolites. Indeed,

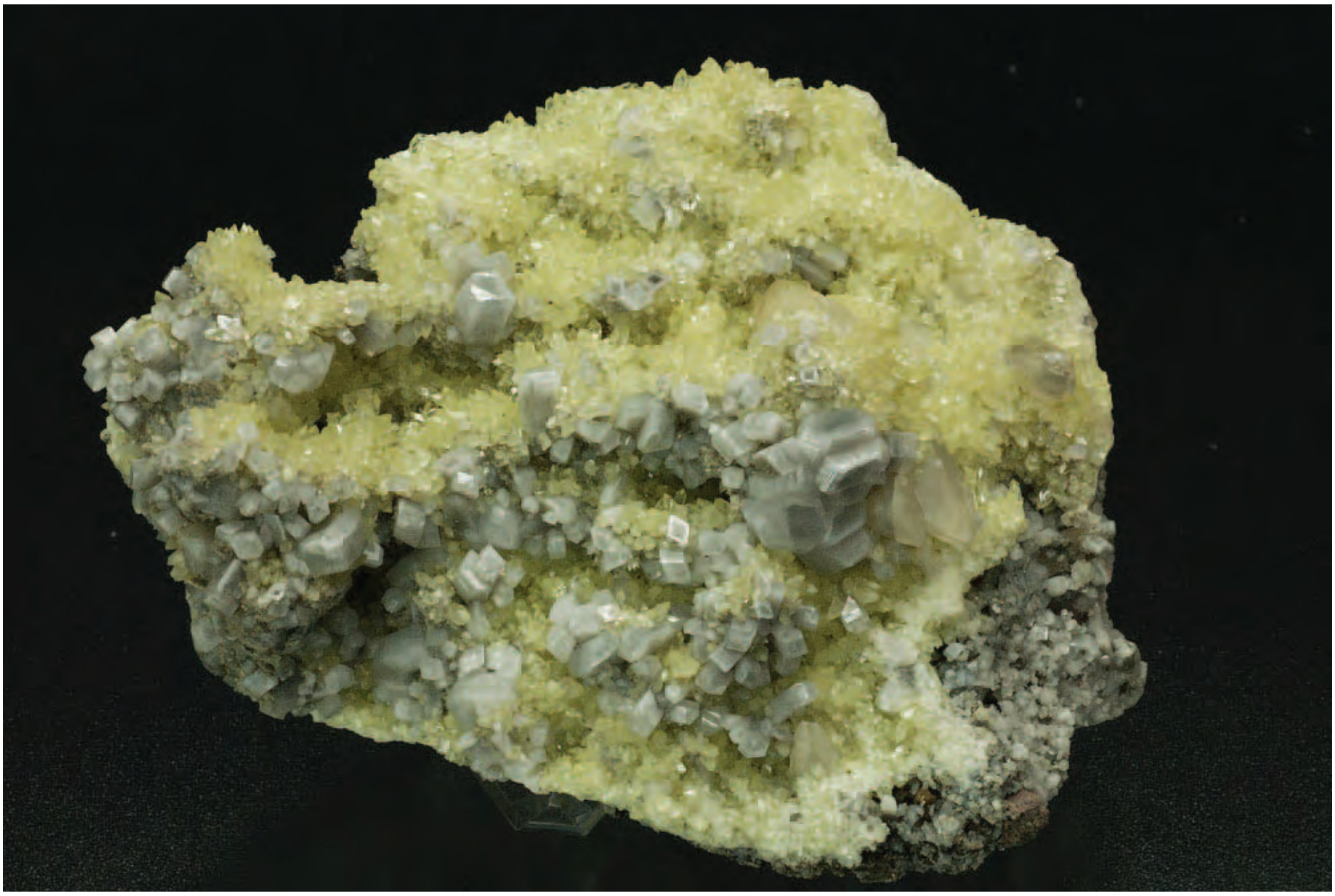


Figure 40. Blocky white harmotome crystals on yellow drusy fluorapophyllite-(K), 100 mm across, from Korsnäs Mine, near Vassa, Finland. Specimen 672 in the Jim Knight collection, purchased in the early 1960s. Photo Peter Briscoe.

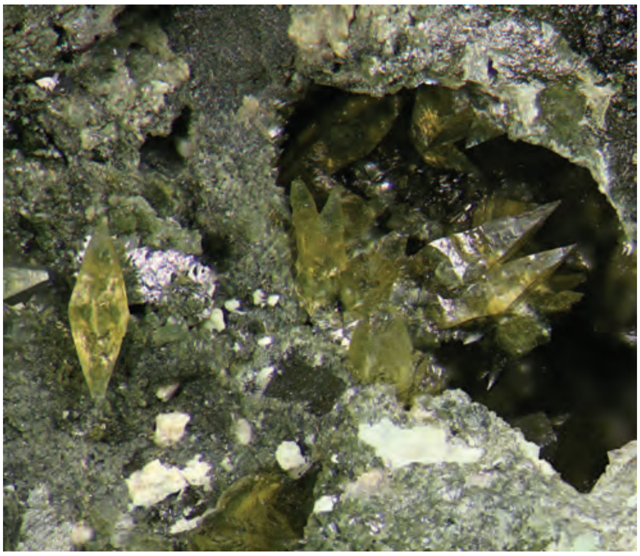


Figure 41. Bipyramidal powellite up to 1.8 mm long from Jardinera No. 1 Mine, Inca de Oro, Chañaral, Chile. The specimen, 3603, one of the last Jim acquired for his collection, also has sharp pseudomorphs of powellite after molybdenite. Harry and Chris Critchley specimen; photo John Chapman.

Figure 42. A 2 mm crystal of the rare and structurally complex feldspathoid mineral tsaregorodtsevite, $N(CH_3)_4Si_4(SiAl)O_{12}$, from Yaruta Mountain, Polar Urals, Western Siberia, Russia. Specimen 3259 (with a spooneristic error, 3295, on the specimen box) in the Jim Knight collection. David Green specimen; photo John Chapman.

powellite from any locality was a particular favourite, Jim had many other specimens including one of the remarkable pseudomorphs after molybdenite from Chile (Figure 41).

One of Jim's favourite minerals has a structure not unlike the zeolites, but with a silicate framework that is closed rather than open, and which traps tetramethylammonium radicals to produce a charge-balanced structure; it belongs to the feldspathoid family. Tsaregorodtsevite is found at Yaruta Mountain in western Siberia (Figure 42) and (possibly) one other locality. A marvel of chemistry, with a remarkable structure and a name that rolls off the tongue, Jim delighted in showing it to visitors.

The complex silicates deerite, howieite and zussmanite[3] are arranged as a triptych in one of Jim's larger boxes. They are from the type locality, Laytonville Quarry in California, and have consecutive numbers, 1273–1275. They were acquired in 1966 and all, appropriately, are rock-forming. That a mineral might only occur as a rock-forming species did not exclude it from Jim's collection. There are several examples of the complex purple silicate charoite, associated with aegerine, canasite, tinaksite and other rare phases, from the Murunskii Massif, Charo River, Yakutia, Russia.

Jim managed to obtain genuine specimens of one of the oddest carbonate minerals on Earth. Oldoinyo Lengai in Tanzania is a very unusual volcano. It was first described to one of the authors as a "baking soda volcano". "Surely you're having me on?" is the almost instinctive reply. But no, Oldoinyo Lengai erupts sodium carbonate lavas. They are cooler and less viscous than silicate melts and the technical term for them is natrocarbonatite. The two principal minerals in the fresh lava are nyerereite (named after Julius K. Nyerere, the long-serving president of Tanzania) and gregoryite (named after the explorer John W. Gregory). The minerals alter very quickly on contact with the atmosphere. Jim's specimens were collected from freshly erupted hot lava by his friend Terry Seward, and sealed to prevent alteration. Terry also gave Jim a tiny specimen of the rare calcium iron arsenate sewardite (No. 3172), which is named in his honour. It consists of a few sub-millimetre grains in a small phial within a Jousi box. The type specimen (it too is extremely small) is held at the Natural History Museum, London.

AFTERWORD

Although he realised it was important and valuable, Jim does not seem to have left any indication of what should happen to his mineral collection after his death. A number of specimens appear to have passed to his friend and companion in later life, Rick; their whereabouts is currently unknown, but it has come to the authors' attention that Rick passed away relatively recently. Most of the other specimens were inherited by family members and found their way to Jim's niece, who retained them until personal circumstances forced their disposal. Ike Wilson was contacted regarding the disposal of the collection, which he acquired shortly before Christmas, 2015. Ike, a good and long-standing friend of Jim, selected a number of specimens *in memoriam*, and sold the remainder to other dealers; more than 2200 eventually found their way to one of the authors (Peter Briscoe).

There is no doubt that the collection in its entirety would have been a magnificent addition to a public institution with suitable research capabilities. The catalogue and associated

[3] Professors William Alexander Deer, Robert Andrew Howie and Jack Zussman, are responsible for a landmark five-volume series on the rock-forming minerals (Deer *et al*., 1967) and a popular text – *An Introduction to the Rock-Forming Minerals* – aimed at undergraduate and post graduate students (Deer *et al*., 1966; 1992; 2013).

data would then have been preserved with the collection, a situation that would allow future research on both the specimens and their collector. However, it is unlikely that this is what Jim would have wanted. He was not impressed by the standards of care, continuity and expertise in many institutions and had seen too many mineral collections ‘abandoned in cellars’.

In today’s austere climate, it is unlikely that any British institution would have the resources and enthusiasm to accept the collection, even if it were to be offered as a donation. The gap between the world as it is and world as it could be, encapsulated in the German word “weltschmerz”, is wider than at any time in a generation.

Fortunately, the specimens came into the hands of collectors and dealers (including many Russell Society members) who recognised the value of making a record. It was decided that some of Jim’s legacy should be preserved, and that an article in the Society journal was the most practical way to achieve this end. A database of about 2200 specimens was assembled in Microsoft Excel. Although time consuming, it proved to be a valuable tool as it was possible to analyse the collection in a variety of ways, and make a record of what happened to the specimens, even the 250 or so that were discarded. Populating the database necessitated a careful examination of every specimen. This proved to be a useful process; the showiest specimens were not always the most interesting or important. Indeed, many important specimens, including Jim’s pyrargyrite with stephanite from Wheal Ludcott, were not at all obvious on casual inspection.

Guided by the principle that ‘the whole is greater than the sum of the parts’, it was decided to divide the collection into smaller elements and ask fellow collectors if they would be interested in them in their entirety. In this way some parts of the original collection would be preserved together. This process highlighted the philosophical difference between the way Jim (and some other Manchester-group members) collected, and current collectors in the UK. Most modern British collections are locality based, a few concentrate on aesthetic specimens, but very few are systematic. Inevitably, some of the systematic sub-collections ‘fell between camps’. The halides, for example, were divided between the Cornwall and Devon, Broken Hill (Australia), Chile, and Kola Peninsula sub-collections. The remaining specimens were so depleted that they did not form a coherent sub-collection on their own.

Some of Jim’s specimens remain with one of us (Peter Briscoe). They include many of the display specimens, sub-collections from Germany and central Europe, and arsenic-bearing species. It is hoped some of these will also pass to collectors in their entirety, although inevitably, many will not be dispersed in this way. There is currently some uncertainty about the best place to preserve Jim’s collection catalogue, photos, file cards, and mineralogical ephemera. The catalogue and some of the photos are available in digital form, most of the other records form a paper archive. The authors are happy to share information with anyone who is interested.

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MAGNETITE MINERALISATION ASSOCIATED WITH THE GREAT WHIN SILL OF UPPER TEESDALE, NORTHERN PENNINES: A PRELIMINARY REPORT

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Recent field work has revealed the hitherto unreported presence of magnetite-rich mineralisation within contact rocks of the Great Whin Sill, at several places within Upper Teesdale. Whereas detailed petrological or chemical investigations of this mineralisation have yet to be undertaken, in view of its widespread distribution and significance in adding to the understanding of the sill's emplacement, it is considered appropriate to record a preliminary outline of the occurrences. The following description, based almost wholly upon field observations and visual descriptions of hand specimens made with stereomicroscope and elementary physical and chemical tests, is discussed in the context of the local and regional geology and current understanding of the nature and origins of the Great Whin Sill and its contact rocks. The magnetite mineralisation is here provisionally interpreted as a skarn deposit resulting from metasomatism within the contact rocks of the sill, perhaps with some contribution from early Northern Pennine mineralising brines.

GEOLOGICAL SETTING OF UPPER TEESDALE

Upper Teesdale, as considered here, is taken to be the valley of the River Tees upstream from High Force [NY 8800 2840]. The dale is excavated in Carboniferous sediments and the Great Whin Sill and occupies a roughly central position on the Alston Block. This comprises a major fault-bounded structural unit composed of a comparatively thin cyclothemic succession of Carboniferous limestones, mudstones and sandstones which rest on a foundation of Lower Palaeozoic sedimentary and volcanic rocks, in which occur the Caledonian granites of the Northern Pennine Batholith (Trotter and Hollingworth, 1928; Dunham, 1990; Kimbell *et al*., 2010; Stone *et al*., 2010). The area is covered by British Geological Survey 1:50 000 sheets 25 (Alston) and 31 (Brough-under-Stainmore) with detailed descriptions of the geology provided by Burgess and Holiday (1979) and Dunham (1990).

The essential features of Teesdale geology are shown in Figure 1.

The main course of Teesdale and, west of Langdon Beck, its continuation as the Harwood Valley, is determined by the roughly NW–SE trending Teesdale Fault, a complex belt of normal faulting which exhibits an aggregate northerly downthrow of up to several tens of metres. In the vicinity of Langdon Beck the continuity of the Teesdale Fault is disrupted by the roughly N–S trending Burtreeford Disturbance, a complex roughly N–S trending eastward-facing faulted monoclinal structure which bisects the Northern Pennines. At the intersection of these two structures, Ordovician rocks belonging to the Skiddaw Group and possibly also the Borrowdale Volcanic Group of the Lake District, which lie unconformably beneath the Carboniferous rocks, crop out over several km^2 in the Teesdale Inlier (Gunn and Clough, 1878; Johnson, 1961; Burgess and Holiday, 1979).

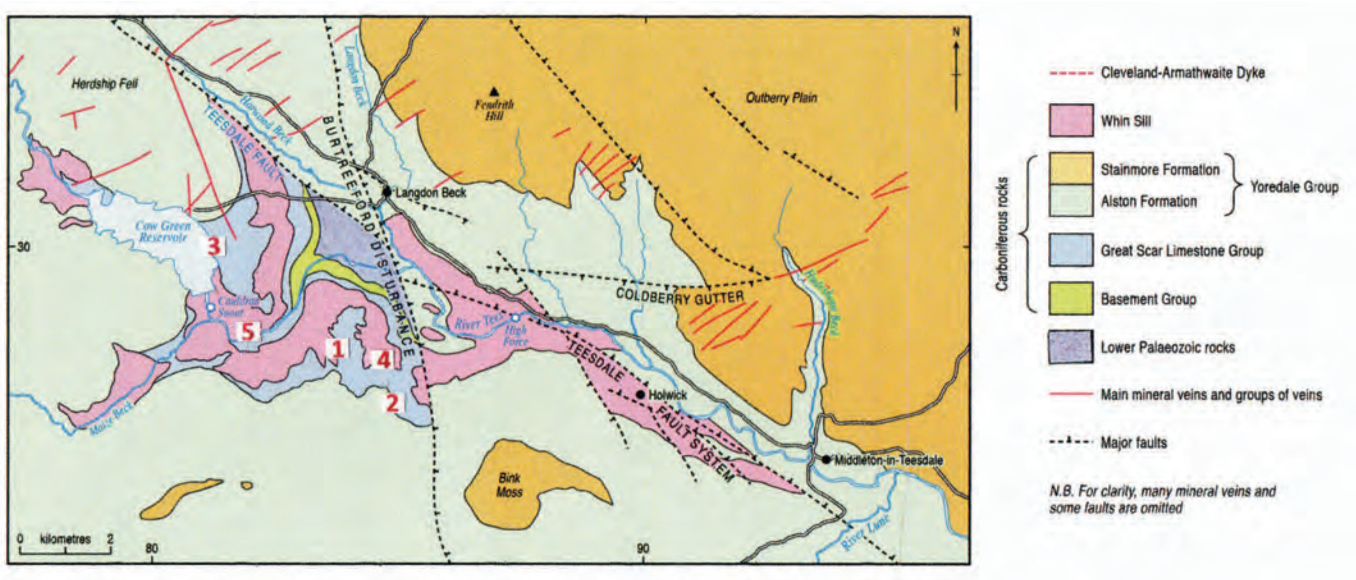

Figure 1. Simplified solid geological map of Teesdale showing locations of magnetite mineralsiation within the contact rocks of the Great Whin Sill. Magnetite locations: 1. Cronkley Scar – Thistle Green; 2. Noon Hill; 3. Cowgreen Reservoir, 4. White Force Level; 5. Falcon Clints. Based on Young (2017; Figure 4b).

West of the Burtreeford Disturbance, the Ordovician rocks are overlain by conglomerates, mudstones and sandstones of the Lower Carboniferous Basement Group and these in turn are overlain by the cyclothemic succession of limestones, mudstones and sandstones of the Great Scar Limestone Group and the succeeding Alston Formation of the Yoredale Group. The Great Scar Limestone Group includes, in ascending order, the Melmerby Scar, Robinson and Peghorn limestones and their interbedded mudstones and sandstones. These limestones are typically mid- to pale-grey unevenly bedded, locally crinoid-rich limestones in which nodular and pseudobrecciated limestones and thin mudstone partings are common (Johnson and Dunham, 1963).

East of the Burtreeford Disturbance, higher Carboniferous sediments belonging to the Alston and Stainmore formations of the Yoredale Group crop out.

Intruded into these Carboniferous rocks is the dolerite of the Great Whin Sill which is described more fully below.

All of these rocks are cut by the numerous lead, zinc, iron, fluorine and barium mineral-bearing veins of the Northern Pennine Orefield, of late Carboniferous – early Permian age (Dunham, 1990).

THE WHIN SILL

The Whin Sill-swarm is the collective name applied today to the widespread suite of four separate, though closely related, sills and associated ENE–WSW trending dykes of Permo-Carboniferous age which crop out extensively across north east England from the Farne Islands in the north, through Northumberland and the Roman Wall country, to parts of Teesdale and the Pennine escarpment. The intrusions underlie at least 4500 km^2 of the region with a total volume of not less than 215 km^3. Recognition of the Whin Sill's intrusive igneous origin in the 19^{th} century (Sedgwick, 1827) established it as the 'type' or original 'sill' of geological science (e.g. Stephenson *et al*., 2003; Stone *et al*., 2010).

The four component sills, all of which are emplaced within Carboniferous sedimentary rocks, are the Farne Islands and Alnwick sills of north Northumberland; the Great Whin Sill of the Roman Wall country, the Northern Pennines and the Pennine escarpment; and the Little Whin Sill of Weardale.

The sills, together with their associated suite of dykes, all consist predominantly of fine to medium-grained dark grey tholeiitic quartz dolerite, associated locally with small bodies of coarse-grained dolerite pegmatite and rarer pink granophyric rocks. These rocks have long attracted research into their petrology, chemistry, structure, modes of emplacement and age, resulting in a voluminous published literature, comprehensive references to which are cited in major summaries by Dunham (1970), Dunham and Strasser-King (1982), Francis (1982), Randall (1995), Dunham (1990), Stephenson *et al*. (2003) and Stone *et al*. (2010). Radiometric dates obtained from the Whin Sill intrusions range from 301±6 Ma to 294±2 Ma. (Stone *et al*., 2010).

The thickness of the sill complex, which in places occurs in two or more leaves, varies markedly across the region, but in the area of Teesdale described here, where it is present as a single leaf, it varies in thickness from 73.1 m to 67.5 m, its greatest recorded thickness at surface outcrop; its maximum known thickness of 90 m was recorded underground at Blackdene Mine, Weardale (Dunham, 1990).

Compared with the rocks of the intrusions, the associated metamorphic rocks have attracted very much less research interest. However, it is clear that the metamorphic effects on the adjacent country rocks vary considerably across the outcrop. Over wide areas, most notably where the sills are thinnest, metamorphism is comparatively slight. Elsewhere, particularly adjacent to the thickest parts of the intrusion, notably within Teesdale, metamorphism is much more intense (e.g. Robinson, 1970; Randall, 1995). Previously described metamorphism related to the sill in Teesdale is outlined below.

A suite of minerals including quartz, calcite, chlorite, pectolite, apophyllite and zeolites including analcite, chabazite and stilbite, together with the sulphides pyrite, pyrrhotite, galena and sphalerite, were deposited in veins and vesicles in the sills during an episode of hydrothermal activity within the intrusions' final phases of cooling (Randall, 1995; Ixer *et al*., 2005; Ixer and Stanley, 1987; Dunham, 1990; Young *et al*., 1991). Although the Whin Sill is cut by numerous mineralised veins within the Northern Pennine Orefield, where it formed an important wall-rock for several commercial fluorspar, barytes and witherite orebodies, the above suite of minerals is unrelated to the main Northern Pennine mineralisation.

In Upper Teesdale, the Great Whin Sill is emplaced at its lowest stratigraphical horizons within these Carboniferous rocks. West of the Burtreeford Disturbance it lies within beds extending upwards from the Melmerby Scar to the Lower Little limestones. East of the Disturbance it lies higher, in beds between the Tynebottom and Single Post Limestone (Dunham, 1990). This abrupt change of horizon at the Burtreeford Disturbance suggests that the sill was emplaced along a horizontal plane which cut through the pre-existing fold (Dunham, 1990), though the dislocation of the sill's outcrops seen today indicates subsequent post-emplacement movement of the Butreeford structure. The magnetite occurrences reported here, all lie within the area west of the Burtreeford Disturbance.

In the area considered here, the base of the sill occupies a more or less constant stratigraphical position within the Melmerby Scar Limestone in the Cowgreen and Widdybank areas, though with minor downward transgressive features of up to a few metres at its base near the foot of Cauldron Snout. Over much of Widdybank Fell and Cowgreen the roof of the sill is a more or less planar surface. However, east of the River Tees on the summit of Cronkley Scar and in the Noon Hill area, its roof is remarkably irregular passing upwards from the Melmerby Scar Limestone and its overlying mudstones and sandstone to the Robinson and locally Peghorn limestones.

Figure 2. The Great Whin Sill outcrop of Cronkley Scar, one of Teesdale's most conspicuous landscape features, on which occur several of the magnetite occurrences described in this paper. Brian Young photograph.

The landscape of Teesdale derives its uniqueness amongst Pennine dales from outcrops of the Great Whin Sill (Figure 2). The dark grey columnar-jointed crags of Holwick Scars and Cronkley Scar, together with the waterfalls of High Force, Low Force and Cauldron Snout, and a number of large abandoned roadstone quarries, provide the finest and most extensive exposures of Whin Sill dolerites within the Northern Pennines. The metamorphic rocks of its contact aureole are more extensively developed in Teesdale than elsewhere in the sill's outcrops across northern England. Previous descriptions of these metamorphic rocks are summarised below.

PREVIOUS DESCRIPTIONS OF THE WHIN SILL CONTACT ROCKS OF UPPER TEESDALE

The earliest detailed descriptions of these metamorphic rocks in Upper Teesdale are those by Hutchings (1895, 1898). Subsequently, Wager (1928), Dunham (1990), Robinson (1970, 1971, 1973) and Burgess and Holiday (1979) have published descriptions of these rocks including brief comments on the chemical and physical conditions prevailing during their formation.

Limestones with a low organic content, particularly the Melmerby Scar Limestone, and locally the Robinson and Peghorn limestones, have typically been altered (marmorised) to coarse-grained saccharoidal marbles which, from their distinctive crumbly weathering, are known locally as 'sugar limestone' (Robinson, 1970, 1971). The unusual rendzina soils developed on outcrops of this rock, particularly on Cronkley and Widdybank fells, have long been famous as the substrate for a major part of Upper Teesdale's celebrated relict alpine flora (Bradshaw and Clark, 1965).

Impure limestones and mudstones have been altered to calc-silicate hornfels, locally rich in garnet, with smaller amounts of chlorite, feldspar, diopside, prehnite, epidote and andalusite (Hutchings, 1895, 1898; Robinson, 1970, 1973; Burgess and Holiday, 1979; Dunham, 1990). Wollastonite was reported by Robinson (1970) forming white radiating crystals, associated with minor amounts of diopside and calcite, in a band up to 460 mm thick at the junction between the Lower Robinson Limestone and the underlying sandstone in a site investigation borehole for the Cowgreen Dam [NY 814 290]. The name 'whetstone' is locally applied to these rocks (Robinson, 1970), though no records are known of their use as sharpening stones. Sodium and potassium metasomatism of mudstones to form feldspars has been described locally by Hutchings (1895, 1898) and Wager (1928, 1929).

Sandstones are typically partially recrystallised.

Original diagenetic pyrite nodules within a mudstone bed between the Cockle Shell and Single Post limestones, a few metres above the roof of the sill at Scoberry Bridge, Newbiggin [NY 9128 2730], have been metamorphosed to pyrrhotite (Dunham and Walkden, 1968).

MAGNETITE OCCURRENCES ASSOCIATED WITH THE GREAT WHIN SILL IN TEESDALE

Whereas Ixer and Stanley (1987) refer briefly to magnetite within calc-silicate contact rocks adjacent to the Whin Sill at Ratcheugh Quarry, near Alnwick, Northumberland [NW 230 152], to date the only reported occurrence of magnetite mineralisation associated with the Great Whin Sill of Teesdale is at Lady's Rake Mine and nearby trial workings in the Harwood Valley where Young *et al*. (1985) described a high temperature skarn assemblage that, in addition to abundant magnetite, includes the ore minerals niccolite, gersdorffite, ullmanite, galena, sphalerite and pyrrhotite, accompanied by smectite, talc and garnet. Subsequent investigations of this mineralisation now add antigorite and a chlorite intermediate between clinochlore and chamosite to this assemblage which was attributed by these authors to the interaction between early Northern Pennine mineralising fluids and the Whin Sill and its contact rocks whilst these were at temperatures in excess of 550°C, very soon after the sill's emplacement. More recently, Searle *et al*. (2016) have demonstrated that the magnetic characteristics of this unique Northern Pennine orebody were re-set by the emplacement of the Palaeogene Cleveland Armathwaite Dyke.

Described below are hitherto unrecorded occurrences of magnetite mineralisation within the contact metamorphosed rocks both above and below the sill. Numbers refer to locations indicated on Figure 1.

Magnetite occurrences within the roof rocks of the Whin Sill

1. Cronkley Scar – Thistle Green

As noted above, the roof of the Whin Sill exhibits an unusually irregular profile on the summit of Cronkley Scar, known as Thistle Green (centred around NY 8410 2910) where it transgresses upwards from the highest parts of the Melmerby Scar Limestone, through its overlying mudstones and sandstones, to the Robinson Limestone. All of these sediments exhibit intense thermal metamorphism with the limestones altered to coarse-grained marble ('sugar limestone'), and calcareous mudstones to fine-grained calc-silicate hornfels ('whetstone'). Sandstones have been recrystallized, though this alteration is not obvious in hand specimen. Despite a rather widespread thin veneer of peat, these rocks are generally well exposed here with an abundance of fresh soil brash and debris plainly derived from the adjoining exposures.

The calc-silicate hornfels, seen both in small exposures and in abundant soil brash, is typically a pale cream to pale greenish grey rock in which occur cavities up to several centimetres across, locally lined with small bright crystals of orange to brown euhedral garnet up to 0.5 mm across and more rarely colourless prismatic vesuvianite crystals up to 1 mm long. The precise identity of the garnet within these contact rocks remains undetermined, though Dunham (1990) suggested that the garnet present at nearby Falcon Clints was probably grossular. Limited petrographical examination of thin sections reveals that, in addition to fine-grained garnet, these rocks are typically dominated by sheet silicates, predominantly illite–muscovite and chlorite, but with intergrown kaolinite and iron oxides and locally some actinolite, albite and biotite.

Low crags at the northeast end of Thistle Green [NY 8466 2850] expose calc-silicate hornfelsed mudstone between the Melmerby Scar and Robinson limestones, which locally include a single bedding-parallel band of magnetite up to around 5 cm thick. Fragments of magnetite up to several cm across are common within the soil brash adjacent to these exposures.

Approximately 600 m south west of these exposures, magnetite is particularly abundant as fragments typically <4 cm across, but locally as blocks up to 15 cm across, in the soil brash derived from weathering of the beds between the Melmerby Scar and Robinson limestones, over an area of many tens of square metres centred around NY 8428 2815 (Figure 3). Smaller concentrations of exactly similar magnetite fragments are also common in the soil brash over an area of several square metres centred around NY 8426 2836.

In all of these occurrences the magnetite typically exhibits a comparatively pure dense fine-grained crystalline texture, though some specimens exhibit an internal cellular structure with small cavities up to around 3 mm across. In many specimens, dark brown earthy goethite is intergrown with magnetite (Figure 4). Euhedral greenish brown garnet crystals up to 3 mm across have also been seen associated with magnetite in a few fragments at around NY 8426 2836.

2. Noon Hill

On the remote fell-side west of Noon Hill, beds from the Melmerby Scar Limestone up to the Robinson and overlying Peghorn Limestone are intermittently exposed from beneath a mantle of peat (centred around NY 8535 2720). Mapping reveals that the roof of the Whin Sill here lies within a few metres of the surface outcrop of these beds which, like those

Figure 3. Magnetite-rich soil brash on weathered outcrop of beds between the Melmerby Scar and Robinson limestones; Location 1, Thistle Green, Cronkley Scar. The abundant dark grey fragments are magnetite: the pale-coloured blocks are mainly metamorphosed sandstone. The hammer shaft is 30 cm long. Brian Young photograph.

exposed on the summit of Cronkley Scar, clearly lie within the contact aureole of the sill.

Although poorly exposed, the base of the marmorised Peghorn Limestone at NY 8520 2716 locally exhibits a band of magnetite, exactly similar to that seen at the locations described on Cronkley Fell. Due to the poor exposure, the thickness of this band is difficult to establish, but seems to be less than 3 cm. Small (>1 cm) fragments of magnetite are present in the adjacent soil brash.

As none of the beds between the Melmerby Scar and Peghorn limestones are exposed here, details of their lithology or possible magnetite content, are unknown.

3. Cowgreen

The roof of the Whin Sill, here within the Melmerby Scar Limestone, crops out on the eastern shores of Cowgreen Reservoir where it is exposed at several places during periods of low water level. Whereas here, as elsewhere on the adjoining parts of Widdybank Fell, the limestone has been altered to typical coarse-grained white marble ('sugar limestone'), original clay-rich beds within it have been altered to calc-silicate hornfels similar to those seen at Cronkley Scar. Patchy concentrations of magnetite, mainly up to around 0.5 m across, are also present locally within the marble exposed here, notably at around NY 8150 2980. The magnetite is mainly present both as very fine-grained patches interstitial to the calcite grains of the marble, and as discrete subhedral to anhedral grains <0.25 mm across scattered through the marble, giving the rock an overall dark grey colour which contrasts strikingly with the usual pale colour of this rock. Very faint remnants of original features such as isolated white crinoid ossicles occur in some examples of this rock. More rarely, magnetite is concentrated into dense, almost pure, irregular masses up to 3 cm across.

Figure 4. Cut surface of massive magnetite with internal cellular structure, adjoining pale grey hornfelsed mudstone; Location 1, Thistle Green, Cronkley Scar. Specimen is 10 cm across. B. Young Specimen No. BY8486/B; Jane Young photograph.

Although conspicuous in this small area of the reservoir's shoreline, such magnetite concentrations at this horizon must be of very limited extent here as, despite the extensive barytes workings at this level within the nearby Cowgreen Mine, no instances of magnetite-bearing rock were ever reported from the mine workings and no examples of such rock were ever found on the extensive dumps prior to their being submerged beneath the reservoir.

Magnetite occurrences within rocks beneath the Whin Sill

4. White Force Level

At White Force [NY 8521 2801] which lies near the foot of the stream known as Black Ark, the base of the Whin Sill lies within the Melmerby Scar Limestone, here altered to the coarse-grained white 'sugar limestone' lithology seen elsewhere in the vicinity. In order to prospect a galena-bearing vein exposed in the upper reaches of this stream, at some time in the 19th century the London Lead Company drove an exploratory adit, known as White Force Level, for about 240 m from the foot of White Force (Dunham, 1990). The vein was not found and the trial proved unsuccessful but the remaining dumps record the drive through typical marmorised Melmerby Scar Limestone. Prominent on the extremity of the dumps, and therefore likely to have been derived from the foreheads of the adit, are substantial amounts of white marble in which concentrations of magnetite are conspicuous. As at Cowgreen Reservoir, the magnetite occurs here both as very fine-grained interstitial patches and as scattered subhedral to anhedral grains <0.25 mm across, concentrated into irregular veins up to 3 cm across which surround roughly rounded cores of white marble up to 5 cm across. Small white crinoid ossicles are locally conspicuous within some parts of the magnetite-rich rock (Figure 5). A little dark green chlorite appears to accompany the magnetite locally.

Whereas at first sight this magnetite-bearing rock resembles a brecciated limestone with concentrations of magnetite developed between clasts, its form is probably

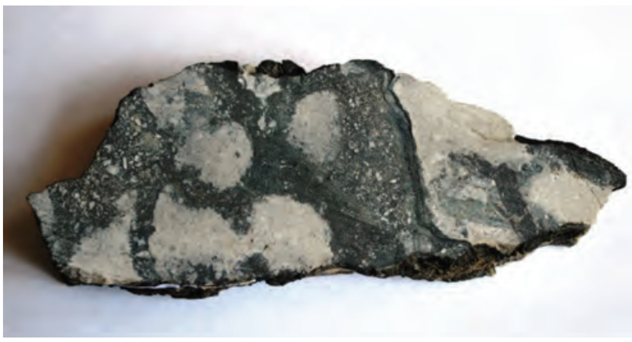

Figure 5. Cut surface of magnetite concentrations surrounding marble cores in altered pseudobreccia. Note the abundant white crinoid ossicles contrasting with the surrounding dark grey magnetite. Dump from White Force Level – Location 4. Specimen is 14 cm across. B. Young Specimen No. BY8485/B; Jane Young photograph.

more consistent with it being an example of a limestone pseudobreccia in which the magnetite has developed preferentially within the fine-grained, perhaps slightly more clay-rich, matrix of the original pseudobreccia. Pseudobreccias of this sort are well-known from the Melmerby Scar Limestone outcrops in the immediately adjoining areas (e.g. Johnson and Dunham, 1963).

5. Falcon Clints

On the left bank of the River Tees downstream from Cauldron Snout the base of the Whin Sill lies within the Melmerby Scar Limestone along the foot of the river cliff known as Falcon Clints (between NY 8320 2860 and NY 8210 2810). Here, as elsewhere in the vicinity, this limestone is altered to coarse-grained white to pale grey marble, with the underlying mudstones and impure limestones altered to garnet, vesuvianite and feldspar-bearing hornfels.

Immediately adjacent to the sill contact, the marble locally contains dense concentrations up to >1 m across in which magnetite occurs, as at Cowgreen Reservoir and White Force Level, as interstitial masses and scattered anhedral gains <0.25 mm across, scattered through the marble. Well preserved white crinoid ossicles are particularly conspicuous within some examples of the mid- to dark-grey magnetite-rich marble at this location (Figure 6). More rarely, magnetite occurs as dense fine-grained almost pure concentrations up to 3 cm across similar to those described from Cowgreen Reservoir. Large blocks of this magnetite-bearing marble are locally common amongst the fallen blocks that litter the slopes alongside the footpath beneath Falcon Clints (Figure 7).

Figure 6. Fine grained dark grey magnetite in marble. Note the conspicuous white crinoid ossicles. Falcon Clints – Locality 5. Specimen is 5 cm across. B. Young Specimen No. BY3719; Jane Young photograph.

Figure 7. Disseminated magnetite imparting patchy dark grey colour to marmorised Melmerby Scar Limestone in a boulder at the foot of Falcon Clints – Location 5. Hammer shaft is 30 cm long. Brian Young photograph.

DISCUSSION

In considering the origins of this mineralisation, the following possibilities merit examination: either thermal metamorphism of pre-existing iron-rich rocks, or iron metasomatism related to the intrusion of the Whin Sill, perhaps related to the mineralisation of the Northern Pennine Orefield.

Thermal metamorphism

The only recorded instance of thermal alteration of an existing iron mineral by the Whin Sill in Teesdale is that of the conversion of authigenic pyrite nodules to pyrrhotite in the mudstones above the Cockle Shell Limestone at Scoberry Bridge, Newbiggin [NY 9128 2730] (Dunham and Walkden, 1968). Beyond Teesdale, no published records are known of any other examples of thermal metamorphism of pre-existing iron minerals by the Whin Sill, though the writer has observed small amounts of massive magnetite developed in thermally altered clay ironstone nodules exposed in 2005 in a seatearth in the beds beneath the Oxford Limestone adjacent to the Whin Sill contact at Cragmill Quarry, near Belford, Northumberland [NT 110 344].

As the Melmerby Scar, Robinson and Peghorn limestones of the Northern Pennines are typically rather pure limestones with minimal iron content; simple thermal alteration of these rocks cannot account for the widespread presence of magnetite within their metamorphosed equivalents. Similarly, as no ironstones or beds of ironstone nodules are known from the Carboniferous rocks between the Melmerby Scar and Peghorn limestones of the Northern Pennines, thermal alteration of pre-existing sedimentary ironstone may be discounted. Another source for the iron must therefore be identified.

Iron metasomatism

As has been noted by previous workers (e.g. Hutchings, 1895, 1898 and Robinson, 1970), the Whin Sill contact rocks locally offer evidence of sodium and potassium metasomatism. Whereas no evidence has been advanced for iron metasomatism associated with the sill, the possibility of the introduction of iron-rich fluids, at least locally, from this source cannot be discounted and merits further consideration.

In this context it may be significant that, as discussed by Dunham (1990), alteration of Whin Sill dolerite adjacent to many Northern Pennine mineral veins has resulted in the removal of very substantial amounts of iron from the original dolerite, resulting in the formation of the distinctive carbonate–clay-rich rock known locally as ‘White Whin’. The possibility that this leaching and subsequent mobility of iron in the mineralising system may account for the abundance of iron carbonate minerals within many of the northern Pennine veins was suggested by Dunham (1990). However, whereas magnetite mineralisation is so far known only from the deposits hosted within the Teesdale Fault at Lady’s Rake and adjacent workings in the Harwood Valley where Young *et al*. (1985) attributed its presence to reaction between Northern Pennine mineralising brines and Whin Sill contact rocks at high temperatures soon after the sill’s emplacement, these authors clearly demonstrated that the sill’s emplacement was very closely followed by the onset of Northern Pennine mineralisation. Similarly, the presence of abundant pyrrhotite within the sulphide assemblages of several Northern Pennine veins within, or close to, Whin Sill wallrocks may also reflect the influence of high temperatures related to the sill’s intrusion at the time of mineralisation of these veins (Dunham, 1990). It is therefore tempting to speculate that fluids with enhanced iron contents derived from the sill’s dolerite, perhaps associated with an early input of mineralising brines, could have been present locally elsewhere in the contact rocks of the Whin Sill where, at suitable local ‘hot spots’, iron metasomatism could have created bodies of magnetite of the sort reported here.

Although a handful of minor baryte and galena-bearing veins cut the Whin Sill and its contact rocks on the summit of Cronkley Scar, spoil from trial workings in these exhibits no sign of either magnetite or of ‘white whin’. Notwithstanding the lack of any obvious association between these veins and this magnetite mineralisation, it is conceivable that these or other nearby fault fissures could have provided pathways for the fluids necessary to generate the iron metasomatism and resultant magnetite mineralisation. It is suggested that the magnetite rocks described here could, like those at Lady’s Rake, be interpreted as skarn-type deposits related to metasomatism in the contact rocks of the Whin Sill. The baryte and galena, present in the Cronkley Scar veins, may have been deposited by a later pulse of fluids introduced later in the main mineralising episode at significantly lower temperatures than those responsible for the magnetite mineralisation.

Plainly, further detailed geochemical and mineralogical investigations would be required to resolve the admittedly speculative interpretations offered here as a possible explanation of the origins of this magnetite mineralisation.

In conclusion, the comparatively widespread and abundant occurrence of magnetite reported here invites an explanation of why it has hitherto gone unrecognised, or at least unrecorded. A number of factors may be relevant.

Firstly, many of the magnetite-rich rocks described from such locations as Falcon Clints and Cowgreen exhibit the dull mid-grey colour so typical of many of the Northern Pennine limestones, even some of those that have experienced severe thermal alteration close to the Whin Sill; these rocks may simply have been overlooked. Only when the increased density is noted and the rocks are checked with a hand magnet does the presence of magnetite become apparent.

Secondly, in the case of the comparatively pure magnetite blocks present in the Thistle Green area of Cronkley Scar, the writer clearly recalls that at the time of his detailed study of this area in the late 1960s no evidence of magnetite mineralisation was found. It is known, however, that during subsequent years severe soil erosion has removed substantial areas of the peat cover from these areas, exposing the previously concealed magnetite-rich soil brash. Whatever the reasons, this discovery plainly highlights the possibility of significant new finds being made in areas where the geology is assumed to be well-known.

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Whereas the sites described in this paper all lie on Access Land, it should be recognised that they also lie within the ecologically sensitive protected environment of the Moorhouse – Upper Teesdale National Nature Reserve.

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