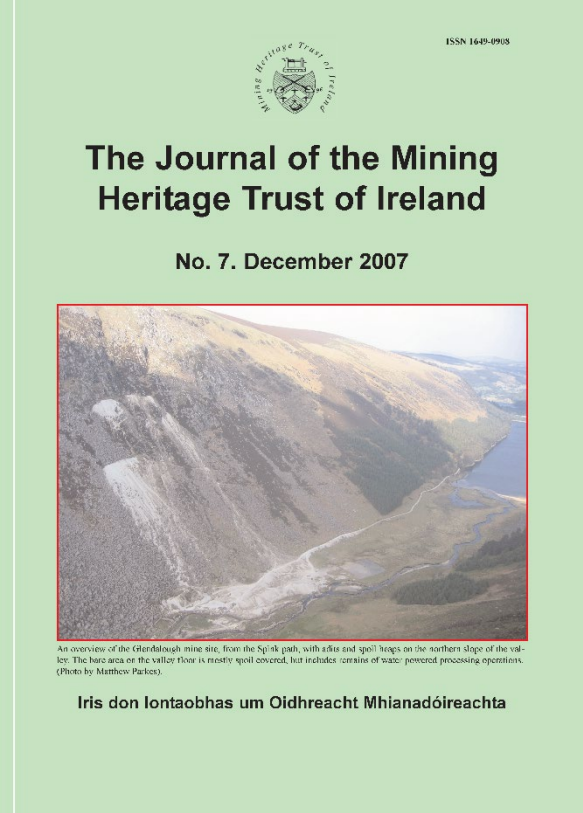

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THE MINERALOGY OF THE WICKLOW LEAD MINES

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Abstract: The low temperature hydrothermal lead-zinc-copper veins exploited by the Wicklow lead mines contain a diverse assemblage of primary and supergene minerals. Quartz and galena are ubiquitous, but there is some zonation in the distribution of sphalerite, fluorite and barite. Two rare zeolite minerals harmotome and brewsterite-Ba have been identified, and several very rare supergene minerals are also present including caledonite, kottigite, leadhillite, orthoserpierite, redgillite, wroewolfeite and wulfenite. Cerussite is the commonest supergene lead mineral present but there are also some excellent examples of pyromorphite-dominated supergene assemblages, a style of mineralisation otherwise rare in Ireland. Their occurrence is explained in terms of prolonged oxidation in a granitic wallrock environment at a relatively low carbonate activity. The mines are a good venue for educational purposes and scope remains for further mineralogical discoveries. *Journal of the Mining Heritage Trust of Ireland,* **7,** 2007, 19-32.

INTRODUCTION

The mines in the valleys of Glendalough, Glendasan and Glenmalure were Ireland's principal lead producers in the nineteenth century. Mining began around 1800 in Glenmalure, and in 1807 in Glendasan. It continued into the twentieth century, with production peaking in the 1860s. A detailed historical account of the Glendalough and Glendasan mines is provided by Cantwell (2001), and the Baravore mines, in Glenmalure, are covered by Chester and Burns (2001). Contemporary sources include Weaver (1819), Smyth (1853), Haughton (1854) and Jukes and Du Noyer (1869) and their work is summarised by Cole (1922).

Modern studies of mineralisation in the Wicklow Mountains have concentrated on the geology and origin of the deposits themselves, with little description of the individual minerals that are present. The mines worked low-temperature hydrothermal vein deposits which formed in fractures in the host rocks by crystallisation from metal-rich brines. The veins are best developed in the granite, tending to die out in the adjoining schist. The brines are thought to have migrated from the surrounding metasediments into much earlier fractures, which had formed along the granite margin as it cooled (Kennan *et al.* 1986).

It is clear from scattered nineteenth century reports that the mines once had a reputation for interesting minerals, specimens of which are present in a few museums. Haughton (1878) lists just eight minerals from the mines (fluorite, schieferspar calcite, barite, cerussite, anglesite, pyromorphite, galena and sphalerite) and gives few details. His earlier account (1854) depicts cross-sections of the veins and refers to fluorite in pale shades of green, violet and brown, the last as cubes up to two inches across. Smyth (1853) gives further details of the veins, which he said contained quartz, sphalerite and calcite crystallised in cavities. Weaver (1819) gives the most mineralogical detail. He refers to abundant drusy vugs, or "lough-holes", acicular "white lead ore" (cerussite) and "green lead ore" (pyromorphite), all from Luganure Mine. From Glendalough he reports abundant drusy cavities, some containing cerussite, and from Ballinafunshoge more crystallised cerussite.

Other tantalising, but sometimes vague, reports include fine specimens of barite from Glenmalure (Sowerby 1817), "beautiful crystals of native silver" from Luganure Lode (Jukes and Du Noyer 1869), cerussite "in fine specimens" from Seven Churches, anglesite and "fine crystals" of pyromorphite from Glenmalure (Greg and Lettsom 1858) and cruciform harmotome from Glendalough (Giesecke 1832; Joly 1886). The last author also remarked, "Specimens of hexagonal calcite, sometimes found here implanted in solitary whiteness on ice-like drusy quartz, are very beautiful".

The mines are in the Wicklow Mountains National Park, an area of great natural beauty, which receives attention from a variety of client groups including mine historians, mineralogists and geologists. Surprisingly there is no comprehensive description of the minerals of the area. This would seem to be an essential prerequisite for fieldtrip organisers, mineralogists, and those charged with managing the park's resources.

For the purposes of this study every mine waste tip in the district was examined. Those that appeared to contain interesting material at surface were carefully sampled and the material collected recorded and labelled with an eight-figure grid reference determined using a GPS system. Minor excavation was needed in some instances to penetrate the weathered surface and obtain fresh material. Where visual examination under a stereomicroscope was insufficient to characterise the minerals present, resort was made to micro-chemical tests, energy dispersive X-ray analysis (EDX), quantitative wavelength dispersive X-ray spectrometry (WDS) and X-ray powder diffraction (XRD).

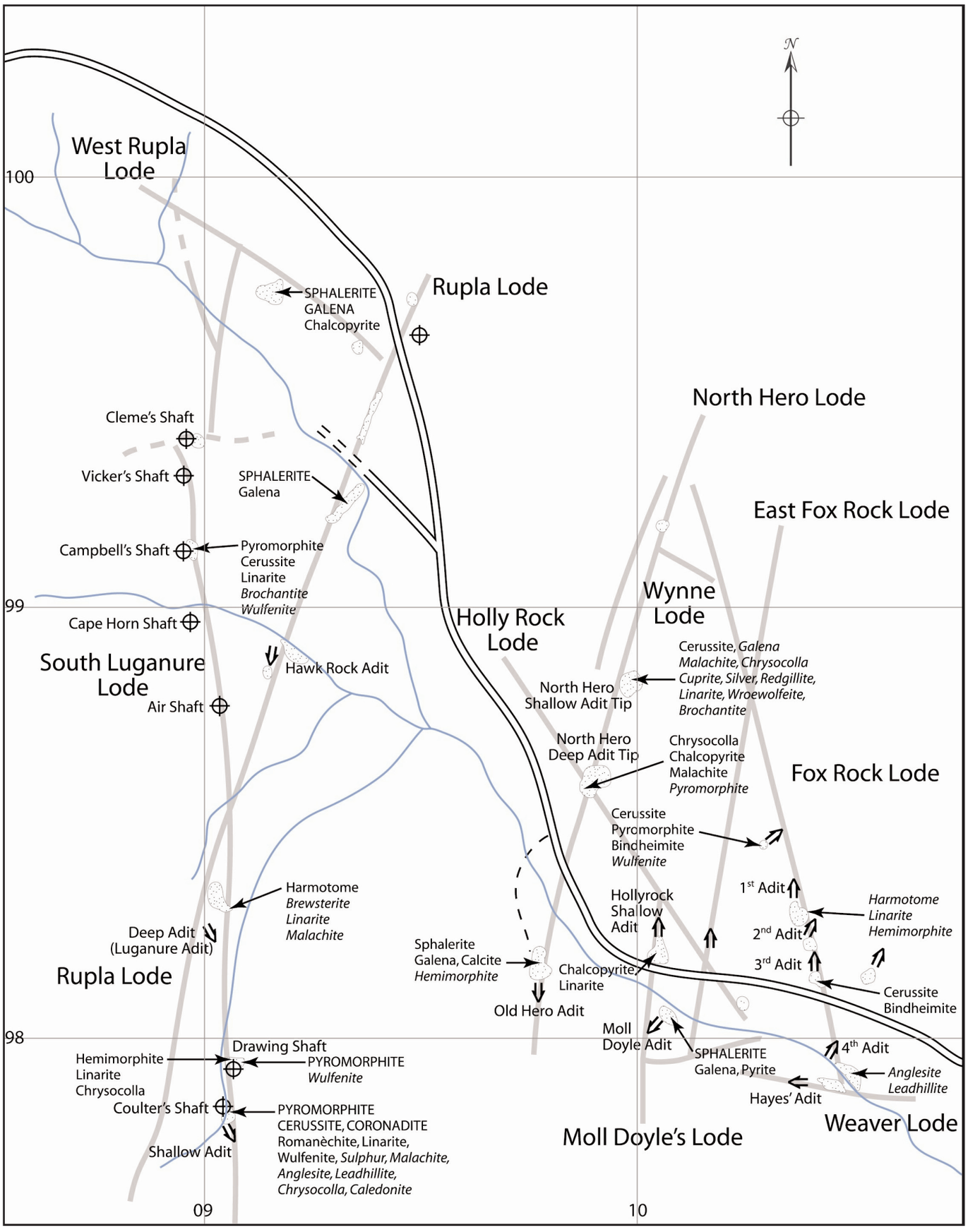

Figure 1. The Glendasan mines. For explanation see text.

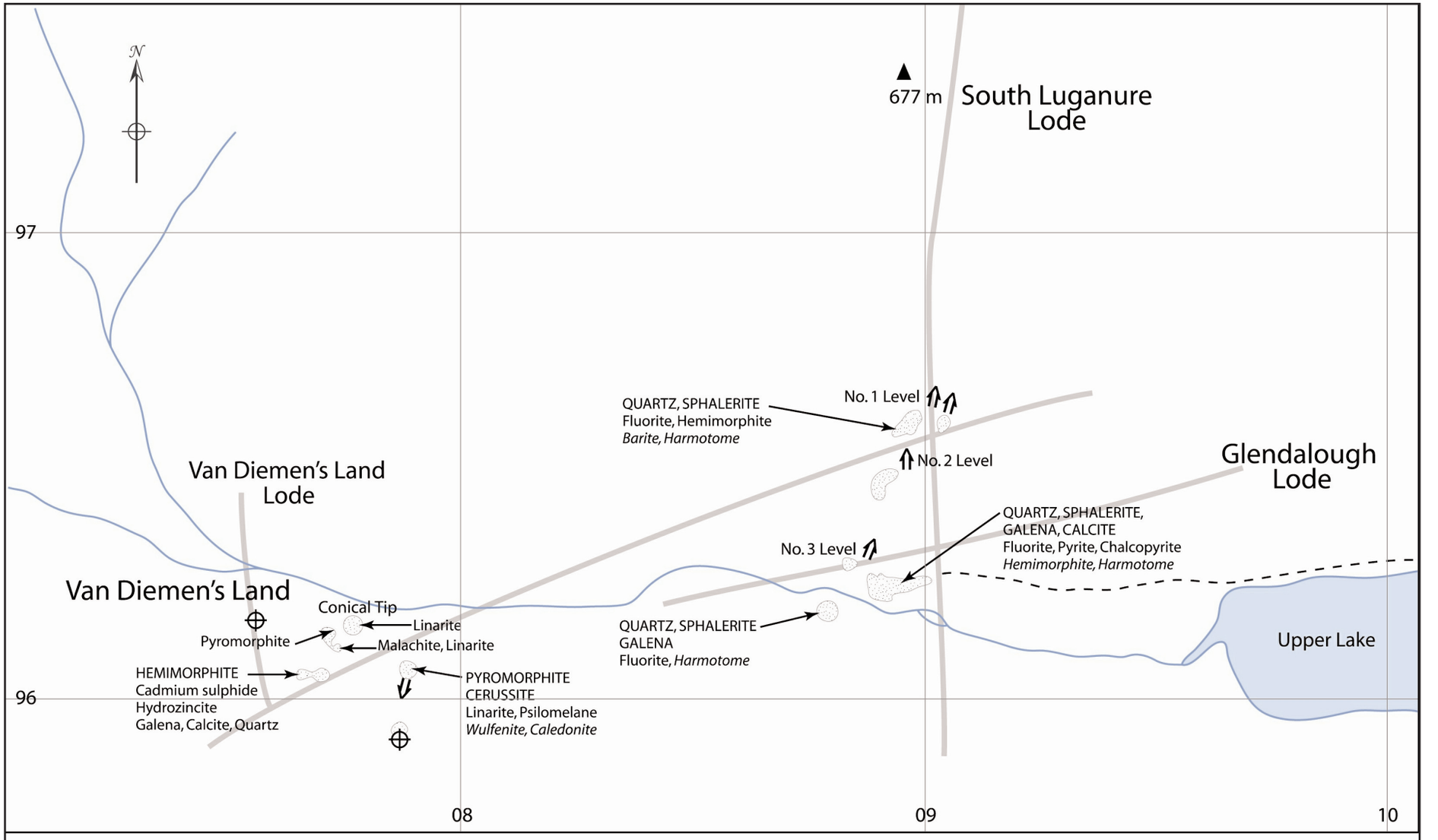

Figure 2. The Glendalough mines. For explanation see text.

TOPOGRAPHIC SETTING

The major mines in the Wicklow Mountains are in Glendalough and Glendasan, two parallel valleys separated by the mountain Camaderry, or Seven Churches. There are also mine workings in Glenmalure, to the south, and a small working at Lough Dan, to the north. The mines at Ballycorus and Killiney, although mineralogically similar and genetically related to the Wicklow Mountain deposits, are outside the area described here.

The accompanying maps of Glendasan and Glendalough, compiled from the Six Inch Ordnance Survey maps (Wicklow, numbers 17 and 23) and maps by Haughton (1854) and Kennan *et al.* (1986), show the mineral veins, the principal workings and summarise the various minerals found on surface at each site.

Having been abandoned for many years, the mine sites are in varying stages of decay. Some of the mine tips have been dug into and partially removed, probably as a source of aggregate. All are weathered, surface material being fractured by frost, penetrated by algae, or covered by lichen. The rock on many of the tips shows extensive deterioration due to the disintegration of the granite, which is partially kaolinised and rapidly crumbles when exposed to the weather.

The underground workings are now mostly inaccessible. A few were examined in the course of fieldtrips organised by the Mining Heritage Trust of Ireland in June 2003. These included the two upper levels on the north side of Glendalough and a few of the levels in Glendasan. Most of the levels have collapsed, or have silted up. Of some no surface trace remains. The few that remain open are commonly flooded. Those at Baravore in Glenmalure, have been described by Chester and Burns (2001).

MINERALOGY

The primary minerals, which include the sulphide ores of lead, zinc and copper, together with quartz and smaller quantities of calcite, fluorite and barite, occur in fissure veins in the granite. The primary mineralogy is simple. Galena and sphalerite are the principal sulphides, often accompanied by minor chalcopyrite and pyrite, in quartz veins. Fluorite, barite and calcite are usually minor components of the vein assemblage, although they may be locally abundant. The wallrocks near the veins are extensively altered and white powdery kaolin can be found in cavities in the veins themselves.

Supergene alteration of the primary ores is widespread and extensive. Most of the tips contain minor cerussite and specimens of galena frequently show cerussite oxidation rinds. The distribution of the other supergene minerals is more restricted. Particularly well-developed suites of supergene minerals have been identified from two mine dumps. Both of these contain spoil derived from high-level, near-surface workings. They are the highest tip on Camaderry, Glendasan (grid ref. T 0908 9772), and the first tip above the waterfalls in Glendalough (grid ref. T 0787 9601). From the description by Haughton (1854) the former is the Shallow Adit of the Old Luganure Mine and will hereafter be referred to as such, although the tip material is also mingled with waste from the adjacent Coulter's shaft. The latter is part of the Van Diemen's Land workings but is not named.

MINERALS

In alphabetic order a description of the minerals is provided below. Some of the rare species, including all of those identified in Ireland for the first time, were identified by the modern analytical techniques listed above.

Anglesite. $PbSO_4$

Anglesite was briefly noted from Glenmalure by Greg and Lettsom (1858). It occurs on oxidised galena as small, blocky to prismatic crystals on specimens collected from the tip outside the Shallow Adit, Luganure mine with sulphur, linarite and caledonite. A single specimen was also recorded with leadhillite from the bottom of Glendasan (G. Ryback, personal communication).

Annabergite. $Ni_3(AsO_4)_2.8H_2O$

A light green, minutely mamillated coating on a specimen of sphalerite and galena overgrown with calcite and minor quartz, from the hanging wall at the foot of a stope in Hayes' Adit, Moll Doyle mine, was identified by a combination of XRD and EDX as a calcium-rich annabergite. It is concentrated at the interface between the sulphides and the calcite.

Aurichalcite. $(Zn,Cu)_5(CO_3)_2(OH)_6$

A trace of a pale greenish mineral from Moll Doyle Mine was described by Russell (1907) as "probably aurichalcite". A tiny tuft of blue-green crystals from Glendalough may also be aurichalcite (David Jordan, personal communication). This mineral requires confirmation.

Barite. $BaSO_4$

Massive, platy, white, pinkish and iron-stained barite is widespread in small amounts in the Wicklow mines. The principal concentrations are on the tips of the workings of Baravore and on the opposite side of Glenmalure at Ballynagoneen. Crystals are rare and small (generally only a few millimetres in length). They occur occasionally at Ballinafunshoge, Glenmalure, at the Old Luganure mine, Glendasan, and on the tips from No. 1 Level (the upper level) at Glendalough. A few 1mm white rhombic crystals of a plumbian barite (EDX identification) were found with cerussite in the highest tip on Foxrock Lode (T 1033 9848), and are probably supergene in origin.

In contrast to the paucity of crystallised barite in the mine tips, the National Museum of Ireland's collections include several magnificent examples. Specimen G17 comprises translucent crystals about 12 cm long from Glendalough, G1 is a selection of loose, clear brown crystals up to ca. 4 cm long from Glenmalure and G1086 is a large hand specimen of barite in an unusual acicular habit from Glenmalure.

Bindheimite. $Pb_2Sb_2O_6(O,OH)$

Yellow, powdery coatings with cerussite from the highest tip on Foxrock Lode (T 1033 9848), and in cavities in quartz from No. 3 Adit of the same mine, were identified by XRD as bindheimite. EDX analysis confirmed the presence of Sb.

Brewsterite-Ba. $(Ba,Ca,Sr)Al_2Si_6O_{16}.5H_2O$

Brewsterite-Ba, a rare member of the zeolite group of minerals, has been identified by a combination of XRD and quantitative WDS as crusts of pale yellow blocky to prismatic crystals on drusy quartz and sphalerite on a specimen collected from a small dump derived from the Deep Adit (Luganure Adit) at Old Luganure Mine (T 09058 98353) (Green *et al.* 2005). This is the first known occurrence of brewsterite-Ba in Ireland and the second report from the British Isles.

Brochantite. $Cu_4SO_4(OH)_6$

A greenish black powdery residue in a cavity left by the oxidation of galena in a pyromorphite rich specimen from Campbell's shaft (T 08950 99121) was identified by XRD as a mixture of covellite and brochantite. Green crusts with wroewolfeite on cuprite, from N. Hero Shallow Adit tip (T 1002 9883) were also found, by XRD, to be brochantite.

Cadmium sulphide. CdS

Thin greenish yellow stains of amorphous cadmium sulphide accompany hemimorphite on quartz in the tip at T 0768 9606 at Van Diemen's Land and are probably derived from oxidising sphalerite. Identification was by EDX.

Calcite. $CaCO_3$

Calcite is abundant on the Glendalough tips, often as platy, hexagonal crystals ("schieferspar") of a pale cream to white colour. These may reach 3 cm across but are almost invariably badly damaged owing to their softness and poor resistance to weathering. More massive material, occasionally with small cavities containing euhedral crystals, may sometimes be found in the tips above the conical one at Van Diemen's Land. Calcite is also relatively common on some of the tips in Glendasan, where it occurs in similar crystal habits to those described from Glendalough. The tips at T 0980 9823, just west of the lead works, and on the line of North Hero lode, contain weathered crystals. Particularly fine schieferspar calcite, with paper-thin crystals, occurs in Hayes' Adit, Moll Doyle mine, Glendasan.

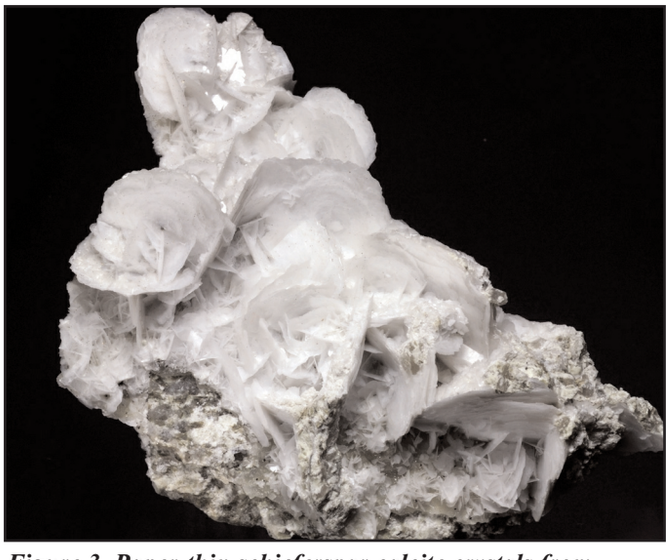

Figure 3. Paper-thin schieferspar calcite crystals from Hayes' adit, Moll Doyle mine. 85 x 65 mm.

Caledonite. $Pb_5Cu_2CO_3(SO_4)_3(OH)_6$

Caledonite was first reported in Ireland by Russell (1907) from Ballinafunshoge, as minute, imperfect crystals with microcrystalline linarite. It has also been identified at the Van Diemen's Land tip (T 0787 9601) on one specimen as a few tiny (ca. 0.1 - 0.3 mm) crystals with decomposing galena and on the tip from Shallow Adit at Luganure Mine as prismatic blue crystals to 0.5 mm in decomposed galena with leadhillite and minor covellite. This latter occurrence was confirmed by XRD.

Cerussite. $PbCO_3$

Cerussite is widespread, in minor amounts, as small (generally < 10 mm) white, acicular crystals in cavities in iron-stained quartz, or as colourless to white crystals associated with corroding galena. It is present at most of the mine sites. At Ballinafunshoge it forms dark, glassy masses up to several centimetres across. The principal occurrences, however, are the tip from the Shallow Adit of the Old Luganure mine, the tip at grid ref. T 0787 9601 at Van Diemen's Land and the tip at T 1041 9819 (Foxrock No. 3 Adit). At these sites the cerussite crystals occasionally reach 2 cm long, and they occur in far more varied habits, including intergrown reticulated forms and (at Foxrock) "jackstraw" cerussite.

Chalcopyrite. $CuFeS_2$

Massive, golden-coloured chalcopyrite appears to be present as a minor ore mineral at all the veins in the Wicklow Mountains. It is usually finely disseminated, although masses up to several centimetres across may occasionally be found at Lough Dan, at Holly Rock mine, Glendasan (grid ref. T 1017 9820), and the tip at the intersection of Holly Rock and North Hero lodes at T 0990 9855 (North Hero Deep Adit and Mitchell's shaft). Crystals are rare, small (< 1 mm) and usually associated with sphalerite.

Figure 4. Tiny golden chalcopyrite crystals on sphalerite on quartz. 70 x 60 mm. Main tips in Glendalough.

Chrysocolla. $(Cu,Al)_2H_2Si_2O_5(OH)_4.nH_2O$

The principal occurrence of chrysocolla is on the crest and front edge of a tip associated with workings on the Holly Rock and North Hero lodes (grid ref. T 0990 9855, derived from North Hero Deep Adit and the adjacent Mitchell's shaft) in Glendasan. It forms sky-blue and blue-green patches and coatings in and on quartz accompanied by malachite and decomposing chalcopyrite. Minute mammillated chrysocolla is sometimes overgrown by a thin film of crystalline supergene quartz. Another minor occurrence is in the tip derived from North Hero Shallow Adit and adjacent shafts (grid ref. T 1002 9883), a few hundred metres to the NNE. Here chrysocolla is associated with silver, malachite, cuprite and cerussite. Traces also occur in the tip from Drawing Shaft, below the Shallow Adit at Old Luganure Mine (T 0908 9793), and in the Shallow Adit tip itself. It occurs also in the upper tip at Lough Dan.

Coronadite. $Pb(Mn^{4+},Mn^{3+})_8O_{16}$

Black and dark brown, mamillated crusts of manganese oxide commonly accompany pyromorphite in the tip from Shallow adit, Old Luganure mine. Four of these have been confirmed as hollandite-group by XRD. Quantitative analysis by WDS has shown these to be of coronadite composition, with lead contents in excess of that predicted from the above formula (Moreton *et al.* 2006). Three others were mixtures of romanèchite and a hollandite-group mineral, presumably also coronadite.

Covellite. CuS

Covellite occurs as thin exsolution rims surrounding galena, which can be identified by their characteristic metallic blue lustre, at many of the mine sites.

Cuprite. Cu_2O

Bright red translucent patches of cuprite up to 5 mm across, accompanying decomposing chalcopyrite, were found in a single cerussite-rich lump in a tip associated with North Hero Shallow Adit (grid ref. T 1002 9883). Malachite, chrysocolla, linarite and very minor native silver, redgillite and wroewolfeite were also present in the same specimen. Cuprite was confirmed by XRD.

Devilline. $CaCu_4(SO_4)_2(OH)_6.3H_2O$

Tiny blue laths on sphalerite from tips near the road in Glendasan gave an XRD pattern close to devilline. Microchemical tests detected Cu but no Zn (George Ryback, personal communication).

Fluorite. CaF_2

The main Glendalough workings have long been known for fluorite (Haughton 1854, Greg and Lettsom 1858). The mineral is common as inconspicuous masses of white to pale yellow massive material up to several kilograms in weight. Pale lilac and green shades also occur but much more rarely. Euhedral crystals are uncommon, and almost invariably damaged when found on the tip.

Elsewhere, yellowish fluorite cubes up to 10 mm in quartz have been found on the principal tip in Baravore ("level no. 6" of Chester and Burns 2001). Cubic epimorphs in quartz, rarely containing corroded relict fluorite are an occasional feature of the tips of Ballinafunshoge mine, Glenmalure and the main Glendalough tips. More rarely, Foxrock Mine and Old Luganure Mine, Glendasan yield similar material. Weaver (1819) reported traces of fluorite at the latter locality.

Galena. PbS

Galena, the principal ore of lead, is ubiquitous. It typically occurs as coarsely crystalline masses in quartz matrix. Crystals are rare and usually overgrown by calcite. When they do occur, simple cubes up to ca. 1.5 cm are the most common habit. These frequently show octahedral modifications. The best examples occur at the Glendalough tips, and in the tip at T 0925 9977 on West Rupla Lode, Glendasan. Less frequently galena may be found in tips from North Hero Lode behind the lead works (T 0983 9810), in a tip at T 0768 9606 (Van Diemen's Land, above the prominent conical tip) and in a tip at T 1007 9802 near Moll Doyle Adit. In all these cases except the last, the mineral is normally covered in calcite. In the last case it occurs as (highly oxidised) free-grown crystals accompanying sphalerite on quartz.

Occasionally galena exhibits spinel-law twinning. This is most often seen in Glendalough where crystals showing this unusual habit form thin, hexagonal plates up to 1 cm across on quartz matrix. These are very delicate and commonly detach as soon as the enclosing calcite is dissolved away. A few spinel law twins were also found in a single boulder on the N. Hero Shallow Adit tip at T 1002 9883 in Glendasan, and also at West Rupla.

According to Jukes and Du Noyer (1869) the galena from Luganure Lode yielded about 11 oz silver per ton after dressing. Smyth (1853) gives the slightly lower value of 6 to 8 oz.

Figure 5. Spinel law twinned galena crystals up to 10 mm on quartz, from North Hero Shallow Adit tip.

Gypsum. $CaSO_4.2H_2O$

Gypsum has been identified by XRD on a single specimen collected from No. 3 Adit, Foxrock mine, as small colourless euhedral crystals (< 3 mm) associated with orthoserpierite and malachite. Similar crystals (identified by wet chemistry) occur with orthoserpierite in the level below (No. 4 Adit). It is common at the far end of Hayes' Adit, Moll Doyle mine, as delicate, colourless, acicular crystals up to 2 cm in length (XRD identification). In all cases it is post-mining in origin.

Harmotome. $(K,Ba)(Al_2Si_5)O_{14}.5H_2O$

Harmotome was first reported from the Wicklow mines by Charles Geisecke (1832), who described it as "of a greyish-white colour, partly in small single prisms, partly in twin-crystals … in the Lead-mines of Luganure". Later in the century, Joly (1886) noted small (< 1 cm) cruciform twins on quartz from Glendalough. Sir Arthur Russell collected specimens from the dumps of Glendalough, and his manuscript notes, now preserved at the Natural History Museum (London), record "colourless to cloudy white cruciform twinned crystals, up to nearly 1 cm in length and often doubly terminated". Russell also found harmotome at a "recently re-opened level of the West Foxrock lead lode" which he visited with G.J. Williams, who was an inspector of mines, in 1919 and 1920. The specimens, preserved in the Russell collection at the Natural History Museum, London, display colourless crystals of harmotome up to 5 mm long associated with crystalline barite, galena and sphalerite on drusy chalcedonic quartz.

In the course of this study harmotome has been identified at Glendalough as white, cruciform twins up to 8 mm long on minutely crystalline, almost chalcedonic, quartz with brown sphalerite. Almost identical material occurs very rarely just below the upper of the main tips of Foxrock Mine, just above No. 2 Adit (at about T 1043 9829). A tiny patch (a few metres across) of sphalerite-containing material at T 09058 98353 on the north side of the path and east side of the upper end of the tips from the Deep Adit (as named by Haughton, (1854)) or Luganure Adit (as shown on mine plans in the Geological Survey of Ireland), Old Luganure Mine, yielded several harmotome specimens and one of brewsterite-Ba. It is also present in the large tip adjacent to this spot. In all cases the mineral is exceedingly rare, and tends to be weathered, especially at Glendasan. WDS analysis of samples from each of the three localities has confirmed the predominance of barium over potassium, calcium and other cations (Green *et al.* 2005). Harmotome is a minor late-stage component in the primary paragenesis. It is otherwise rare in Ireland, the only other known localities being Conlig-Whitespots mines at Newtownards near Belfast (Moles and Nawaz 1996) and Tara mine near Navan (Green *et al*. 2005).

Figure 6. Cruciform twins of harmotome up to 3.5 mm in length, from main tips in Glendalough.

Hematite. Fe_2O_3

Specimen BM 1964R, 2583 in the Russell collection at the Natural History Museum (London) consists of micaceous hematite with sphalerite, barite and quartz, from Clonkeen Mine, Glenmalure (T 0764 9294).

Hemimorphite. $Zn_4Si_2O_7(OH)_2.H_2O$

The Russell collection at the Natural History Museum (London) includes three specimens of mammillated, light blue crusts of hemimorphite from Old Luganure Mine (George Ryback, personal communication). Despite much searching at this site, no blue material was found here during this study, although one specimen of mammillated, microcrystalline white hemimorphite was found on the second highest tip at T 0908 9793 (Drawing shaft). A single mammillated crust with a very delicate blue tint was found in the tips at T 0983 9810 very near Old Hero Adit. A weathered, thin white crust on quartz was found at Foxrock mine, near No. 2 Adit. Spherules and mammillated crusts of white to cream hemimorphite on quartz occur in the spoil from the highest level on the north side of Glendalough, and are common in the tip at T 0768 9606 at Van Diemen's Land. All these were identified by wet chemistry (positive for zinc and silicate). One specimen, showing tiny (< 1 mm) crystals on limonitic quartz was found on the main tips at Glendalough (specimen N13752 at Manchester Museum, confirmed by XRD). Minor crystalline hemimorphite has also been found on tips near the road in Glendasan (George Ryback, personal communication).

Hydrozincite. $Zn_5(CO_3)_2(OH)_6$

Thin white coatings on oxidised sphalerite from the tip at T 0768 9606 at Van Diemen's Land are hydrozincite. The richest occurrence of the mineral is on the walls and floor of No. 1 Level (the top level on the north side of Glendalough) where hydrozincite forms snow-white crusts and stalactites up to 2 cm long. In both cases it is post-mining in origin and was identified by wet chemistry (positive for zinc and carbonate). The occurrence in No. 1 Level was also confirmed by XRD.

Kaolinite. $Al_2Si_2O_5(OH)_4$

Soft, white material coating sphalerite from Hayes' Adit, Moll Doyle Mine (T 1041 9789) and also from the main tips in Glendalough was identified by XRD as a mixture of kaolinite

and calcite. The kaolinite is probably derived from the alteration of the granite by the mineralising fluids.

Kottigite. $Zn_3(AsO_4)_2.8H_2O$

A white powdery coating on a specimen of sphalerite and galena overgrown with calcite and minor quartz, from Hayes' Adit, Moll Doyle mine, was identified by a combination of XRD and EDX as kottigite. It is present as a component of a white powdery crust associated with a clay mineral and gypsum on a specimen with pale green poorly crystalline crusts of annabergite.

Langite. $Cu_4SO_4(OH)_6.2H_2O$

Tiny crystals of langite were found in 1963 on tips near the road in Glendasan (George Ryback, personal communication).

Leadhillite. $Pb_4SO_4(CO_3)_2(OH)_2$

A single cluster of platy leadhillite crystals up to 3 mm, associated with anglesite, was found in 1963 on tips in the bottom of Glendasan (George Ryback, personal communication). This was most probably from the lowest level (No. 4 Adit) of Foxrock mine (T 1048 9798) as the ore from Hayes' Adit opposite is unoxidised. Blocky pseudohexagonal transparent crystals to 0.2 mm and thin pseudohexagonal plates with sulphur and anglesite have been identified by XRD in waste from the Shallow Adit of Old Luganure Mine.

Linarite. $(Pb,Cu)_2SO_4(OH)_2$

Linarite is widespread in trace amounts as deep blue crystalline patches up to a few millimetres across associated with cerussite and oxidising galena. Well-formed crystals are rare, and usually < 1 mm. In this study it was found at Lough Dan (O 1372 0422), Baravore (level no. "6" of Chester and Burns 2001), Ballinafunshoge, Foxrock, Shallow Adit and Deep (Luganure) Adit of Old Luganure Mine, and the conical tip at Van Diemen's Land (T 0777 9616). Linarite occurs with malachite and chalcopyrite in the tip just above and to the east of the conical tip at Van Diemen's Land (T 0774 9611), and a tip on North Hero Lode (T 1002 9883). Some of the best examples were found in the tip at T 0787 9601, Van Diemen's Land, an overgrown tip at T 0895 9912 on Luganure lode (Campbell's Shaft), and at Holly Rock Mine, Glendasan (T 1017 9820). Linarite, as blue coatings of post-mining origin, is quite common in the second highest tip of Old Luganure Mine (Drawing Shaft, T 0908 9793). Russell (1907) reported it from Ballinafunshoge and Moll Doyle mines.

Malachite. $Cu_2CO_3(OH)_2$

Deep green coatings on quartz, some with a fibrous radiating structure, associated with chrysocolla, occur on the crest of the N. Hero Deep Adit tip at T 0990 9855. A single example of similar material, without chrysocolla, was found on the tip from Shallow Adit, Old Luganure Mine. Attractive, but small (< 3 mm), spherules and sprays of acicular crystals have been found in a single cerussite-rich boulder in the tip at T 1002 9883 (N. Hero Shallow Adit). A single rich specimen was found beside the path near the harmotome occurrence at Deep, or Luganure, Adit, Old Luganure mine (T 0905 9835). Green malachite stains accompany linarite and disseminated chalcopyrite rarely in the tip just above and to the east of the conical one at Van Diemen's Land. Deep green coatings, and spherules occur on the uppermost tip at Lough Dan (O 1372 0422). Post-mining malachite, of an unusual light bluish colour, occurs as 1 mm spherules, and mamillated crusts on a fallen boulder in No. 3 Adit, Foxrock mine (T 1041 9819). It was confirmed by XRD. EDX analysis of this detected Al and Si, suggesting that it may be mixed with a clay mineral, which would account for the unusual colour.

Minium. Pb_3O_4

Greg and Lettsom (1858) mention minium from "Lugganure" but give no details. Two specimens labelled "minium" (nos. 2696 and 2697) from Kate Rock, Glenmalure, are preserved in the Trinity College collections. This mineral requires confirmation.

Psilomelane. Undifferentiated manganese oxides

Psilomelane is a general term for hard manganese oxides of indeterminate composition. As manganese oxides are notoriously difficult to identify it is often simpler to place them under this title. Coatings, sometimes mamillated, occasionally minutely stalactitic, of black manganese oxide are common in the waste from Shallow Adit, Old Luganure Mine. Some of these have been confirmed as coronadite, some as romanèchite. Similar material, although less well formed, and not investigated by XRD, may also be found in the Van Diemen's Land tip at T 0787 9601. A sample from Ballinafunshoge that tested positive for Mn was completely amorphous to X-rays. A sample from Old Hero Adit gave a possible XRD match with hollandite-group, but was largely amorphous.

Orthoserpierite. $Ca(Cu,Zn)_4(SO_4)_2(OH)_6.3H_2O$

Orthoserpierite is a rare supergene mineral which has been identified at very few localities worldwide (Gaines *et al.* 1997). It has been confirmed by XRD on a few specimens from No. 3 Adit, Foxrock mine (T 1041 9819) as aggregates of rather brittle blue-green lath-like crystals associated with malachite and gypsum. Richer material, as light blue, microcrystalline stains and coatings, with gypsum crystals, on decomposed, slickensided granite on the wall of a collapsed section of the level below (No. 4 Adit, T 1047 9798) has also been confirmed by XRD as orthoserpierite. This is the second Irish occurrence of orthoserpierite which has been previously identified only from Tynagh Mine in County Galway (Sarp *et al.* 1987).

Pyrite. FeS_2

Pyrite occurs in small amounts as disseminated grains and crystals up to ca. 2 mm in quartz throughout the district. Concentrations occur in parts of Foxrock and Old Luganure mines. Cubic crystals up to 3 mm on sphalerite occur in the tip at T 1007 9802 near Moll Doyle Adit, with galena and sphalerite in Hayes' Adit, and occasionally on minutely crystalline quartz and scattered through late-stage calcite in Glendalough.

Pyromorphite. $Pb_5(PO_4)_3Cl$

Pyromorphite is particularly abundant at two localities: the Shallow Adit of Old Luganure mine, and the Van Diemen's Land tip at T 0787 9601. It occurs in a considerable diversity of crystal habits at the former locality. Acicular crystals to 8 mm, hexagonal prisms to 5 mm, rounded hexagonal barrels to 1 mm and various intermediate forms, sometimes with several crystal habits on the same specimen, make this possibly Ireland's most diverse pyromorphite occurrence. The colour ranges from almost sulphur yellow through to deep green. The mineral commonly accompanies black manganese oxide, and is occasionally coated by the same. The matrix is invariably quartz. At Van Diemen's Land the colour is universally green and the crystal habit generally simple hexagonal prisms up to a few millimetres in length, although more acicular forms occur occasionally.

Smaller quantities of pyromorphite, which is generally less well crystallised, occur in a small tip derived from Drawing Shaft, about 100 metres below the tip from the Shallow Adit of Old Luganure Mine (T 0908 9793). In the valley floor, but still on the Luganure lode, crystalline crusts of pyromorphite may be found in a small overgrown tip at T 0895 9912, derived from Campbell's Shaft nearby. A few specimens of tiny (1 mm) green crystals were found in waste immediately above the conical tip at Van Diemen's Land. A few tiny crystals and green crusts are also present at an isolated working on West Foxrock Lode at T 1033 9848. This is the highest working on the north side of the valley. Tiny (< 1 mm) slender, pale yellowish to colourless crystals embedded in chrysocolla were found in one specimen from the N. Hero Deep Adit tip at T 0990 9855. Minute, colourless prisms have been found at Ballinafunshoge (George Ryback, personal communication) and it is present as greenish coatings on quartz at Lough Dan (O 1372 0422).

Greg and Lettsom (1858) record fine brown pyromorphite from Glenmalure but, sadly, there is no trace to be seen now. The Natural History Museum (London) has a magnificent specimen of pyromorphite from Glenmalure showing two generations of growth, one brown, one green. EDX analysis of specimens G48 and G52 from Glenmalure in the National Museum of Ireland, and of material collected in the course of this study in Glendalough and Glendasan, has found it to be all phosphate end-member material, with little or no arsenate.

Figure 7. Hexagonal pyromorphite prisms up to 2 mm long, from Shallow Adit, Old Luganure mine.

Figure 8. Acicular pyromorphite crystals up to 2 mm long, from Shallow Adit, Old Luganure mine.

Quartz. SiO_2

Quartz is probably the single most common vein mineral in the district. It is usually massive but where crystallised in vugs forms white to colourless hexagonal pyramids up to 2 cm across, although usually much smaller. A microcrystalline, almost chalcedonic, variety is commonplace, especially in Glendalough and at Moll Doyle Mine. In spite of its abundance, well-formed crystals of quartz are scarce. Foxrock mine, Glendalough and the tips above the conical one at Van Diemen's land probably offer the best specimens. A small vein crossing the No. 2 Level in Glendalough has yielded small, undamaged specimens of heavily iron-stained drusy quartz, some of which show prism faces. Vugs of drusy quartz may also be seen in the top level at Lough Dan (O 1372 0422).

Redgillite. $Cu_6(OH)_{10}(SO_4).H_2O$

Acicular crystals of redgillite up to a few micrometres wide and less than 0.1 mm long occur in patches up to a few tenths of a millimetre across in hairline fractures in a small fragment of the silver and cuprite-bearing material from the N. Hero Shallow Adit tip (T 1002 9883). The redgillite is associated with thin blue crusts of a langite group mineral, linarite, malachite and possibly devilline. Redgillite was identified by comparison of

its EDS spectrum with undoubted redgillite from the type locality. This, together with its characteristic colour, is sufficient to identify it since it has a unique Cu:S ratio for a green supergene copper sulphate (Pluth *et al.* 2005).

Romanèchite. $(Ba,H_2O)_2Mn_5O_{10}$

Romanèchite was mentioned by Ryback and Moreton (1993) as accompanying pyromorphite at Shallow Adit, Old Luganure mine. XRD re-examination of the original specimen found a mixture of poorly crystallised possible coronadite with pyromorphite. There is likely some variation within the sample. Romanèchite has been confirmed by XRD in two other specimens from the same tip. WDS analyses of these show it is intergrown with coronadite (Moreton *et al.* 2006).

Siderite. $FeCO_3$

Hemispherical siderite aggregates on quartz, ca. 8 mm across and turning brown on the surface, are known from a specimen collected in the 1970s from Glenmalure and subsequently acquired by one us (S.M.). The mine is not stated but is most likely Ballinafunshoge. The collections of Trinity College also include two specimens from Glenmalure (nos. 5364 and 5370). Smyth (1853) reports a vein of siderite up to 8 feet thick in Glendalough. Iron-stained epimorphs, possibly after siderite, occur occasionally in the pyromorphite tip at Van Diemen's Land.

Silver. Ag

When describing the Luganure Lode, Jukes and Du Noyer (1869) state that "Beautiful crystals of native silver have been found in this lode". Only one likely specimen of this is known to the authors. Specimen BM 1964R, 3580 in the Natural History Museum (London), dated 1876, consists of both wiry and crystalline silver intergrown with galena, and in cavities in galena, from Glendalough. The only other mineral present is sphalerite. The specimen shows no sign of oxidation apart from normal tarnish. This is consistent with the silver being of primary origin.

In the course of this study, silver was found in a single cerussite-rich boulder, about 15 cm across from the N. Hero Shallow Adit tip (T 1002 9883). Here it forms crystalline aggregates up to about 0.1 mm across growing out of cerussite and malachite. Foil-like films embedded in chrysocolla and delicate dendrites of similar size also occur. Confirmation was by EDX.

Fiure 9. Silver crystals growing out of cuprite-stained cerussite, with malachite and white cerussite crystals. Field of view 6 x 5 mm. North Hero Shallow Adit tip.

Smithsonite. $ZnCO_3$

Three specimens of smithsonite are preserved in the Russell collection at the Natural History Museum (London). BM 1964R, 6307 from Old Luganure Mine, and two specimens from Glendalough (BM 1964R, 6305 and BM 1964R, 6306), were all collected from mine tips in 1915. The smithsonite forms irregular, porous, peachy yellow and almost white crusts around 1 cm thick with hydrozincite and hemimorphite on dark brown sphalerite. Their identity has been confirmed by XRD (Mike Rumsey, personal communication).

Sphalerite. (Zn,Fe)S

Sphalerite is scarce and usually rather oxidised in the pyromorphite-rich tips in Glendalough and Glendasan. It is otherwise widespread but can only be described as common at Van Diemen's Land in Glendalough (tips at T 0777 9616 and T 0768 9606), the main tips in Glendalough, on tips at T 1007 9802 and T 0925 9977 in Glendasan, in Hayes' Adit (T 1041 9789) and at Ballynagoneen, Glenmalure. Sphalerite forms dark brown to black masses and crystals, the latter often deposited on quartz and overgrown by calcite. The crystal size may reach 1 cm. In Glendalough, paler, yellowish brown, orange and reddish translucent crystals, usually badly weathered, occur occasionally in addition to the darker shades. The different colours probably reflect variations in iron content. The paler varieties tend to be associated with minutely crystalline, almost chalcedonic, quartz, and calcite, and appear to be relatively late-stage.

Figure 10. Lustrous dark brown sphalerite crystals on almost chalcedonic quartz, 85 x 53 mm. Hayes' Adit, Moll Doyle mine.

Strontianite. $SrCO_3$

Strontianite was reported by Joly (1886) at Glendalough but was not identified during this study.

Sulphur. S

Sulphur occurs as pale yellow subhedral crystals to 0.2 mm coating cleavage planes in partly oxidised galena from the Shallow Adit, Old Luganure mine. Rarely, pale yellow euhedral crystals to 0.8 mm occur in cavities with anglesite at the same locality.

Tenorite. CuO

"Black oxide of copper" (tenorite) was reported by Smyth (1853) from the Baravore mines.

Vanadinite. $Pb_5(VO_4)_3Cl$

Thomas Thomson (1836: p.573) noted that he had received vanadinite specimens from Mr Doran, an Irish mineral dealer, who assured him that "he picked them up in an old abandoned lead mine in the County of Wicklow." They are described as light brownish-yellow spheres interspersed through massive phosphate and arsenate of lead and sometimes crystallised as hexagonal prisms. A holograph note in a copy of Thomson's book, made by the Cambridge University mineralogist John Keates, indicates that Thomson's specimens were in fact from the Leadhills district. Vanadinite is well known from the Leadhills area, but as there are no other specimens claimed from the Wicklow mines, its occurrence there must be regarded as unlikely.

Wroewolfeite. $Cu_4(SO_4)(OH)_6.2H_2O$

Wroewolfeite was identified by XRD as blue blocky to elongated prismatic crystals up to 0.5 mm long in the silver-bearing cerussite boulder from the N. Hero Shallow Adit tip (T 1002 9883). It is intimately associated with dark green brochantite crusts, which it generally overgrows, both minerals are crystallised on cuprite.

Wulfenite. $PbMoO_4$

The lead molybdate mineral wulfenite is a rare associate of the pyromorphite in tips derived from the Shallow Adit at Old Luganure Mine. Like pyromorphite it shows a considerable diversity of forms. Simple, square, tabular crystals dominate, but bipyramids also occur. The tabular crystals can be exceedingly thin and may have bevelled edges and corners. The crystal size rarely exceeds 0.5 mm, although a few poorly formed or broken examples up to 3 mm have been found. The colour is variable, ranging from near white, cream and yellow to bright orange. The fact that the yellow crystals are often accompanied by yellow pyromorphite has doubtless led to many being overlooked. Most occur scattered sparsely amongst pyromorphite, sometimes they are found on the black manganese oxide. Electron microprobe analysis of several specimens shows the crystals are pure end-member wulfenite, with no detectable tungsten present. Simple, yellowish, square plates, up to 1 mm, have been found with pyromorphite next to Drawing Shaft, just below the above locality, and 0.1 - 0.2 mm orange pyramids on pyromorphite on a specimen from Campbell's shaft (T08950 99121). These are all on the Luganure lode.

A few, minute (ca. 0.4 mm), poorly formed orange-brown, steeply pyramidal crystals have been found on one specimen at the Van Diemen's Land pyromorphite locality (T 0787 9601). A specimen from the highest working on West Foxrock Lode (T 1033 9848) has several 0.6 mm square plates of greenish wulfenite accompanying pyromorphite of similar colour. Another, from the uppermost tip of Lough Dan mine, shows elongated greenish wulfenite crystals up to 1 mm, with malachite on mamillated pyromorphite.

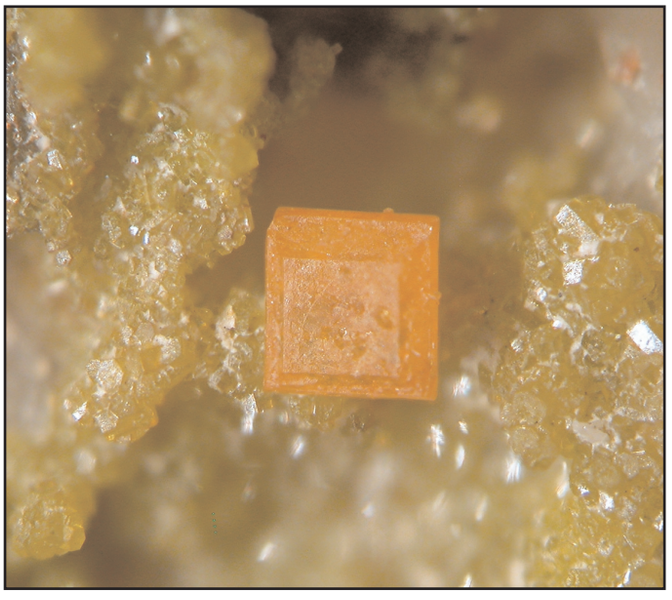

Figure 11. A 0.6 mm orange wulfenite crystal on pyromorphite from Shallow Adit, Old Luganure mine.

DISCUSSION

The accompanying maps (based on Kennan *et al.* 1986, old mine plans in the Geological Survey of Ireland and the Ordnance Survey 6" maps Wicklow 17 and 23) show the approximate positions of the mineral veins and waste tips in the main area (Glendasan and Glendalough), with the Ordnance Survey grid superimposed. The grid squares are 1 km across. Shafts and levels are shown only where these are obvious on the ground. Many have become obliterated with time so that only the waste heaps remain. The names are derived from plans, and Haughton (1854). The latter contradicts the former with respect to one locality. What Haughton calls "Deep Adit" the plans call "Luganure Adit". Here both names are used.

The minerals found on surface at each location are listed. Underground occurrences are not included. In the cases of the principal sulphides and gangue minerals, these are only shown where present as well crystallised examples. Where minerals are abundant, and representative samples easily found, they are cited in upper case script. Where scarcer, and requiring patient search, they are listed in lower case. Where known from three or fewer examples (found in the course of this study) they are listed in italics. Glenmalure has not been included in the maps, as so few worthwhile specimens were found there.

It is clear from this survey that the distribution of the primary and supergene minerals in the Wicklow Mountains is uneven. Quartz and galena are ubiquitous in the primary paragenesis

and calcite is almost so. Barite, fluorite and sphalerite are concentrated in some areas and absent or rare in others. Barite mineralisation is commonest in the south at Baravore, Clonkeen and Ballynagoneen, all in Glenmalure. Fluorite is concentrated in the central area around Glendalough, with lesser quantities to the south in Glenmalure and almost none to the north, in Glendasan. Sphalerite is sporadic in its distribution. It is common on most of the Glendalough and Van Diemen's Land tips, but not the one with abundant pyromorphite. Some of the tips in Glendasan are almost devoid of it whereas in others it is common. It is common at Ballynagoneen, scarce at Ballinafunshoge.

The lack of *in situ* exposures of the veins mitigates against a detailed assessment of the paragenesis. A simplified sequence, based on material from the main Glendalough tips begins with fluorite associated with minor galena and sphalerite and is followed by a main phase of quartz with galena and sphalerite. Brecciation followed, the shattered fragments becoming covered in a subsequent generation of sphalerite with minor galena (often as spinel-law twins) before being cemented by a final phase of calcite.

There are some similarities between the primary mineral assemblage present in the Wicklow Mountains and that at Strontian, Highland Region, Scotland. Both are low-temperature lead-zinc veins associated with Caledonian intrusions, with the same gangue minerals, albeit in differing proportions (more barite, less quartz and almost no fluorite at Strontian). Both localities yield fine schieferspar calcite together with the late-stage barium zeolites, brewsterite and harmotome. The historical (but unconfirmed) report of strontianite at Glendalough adds to the similarities.

Supergene oxidation of the veins is widespread and is most pervasive on the highest ground. The pyromorphite-rich tips of Van Diemen's Land and the Shallow Adit at Old Luganure Mine show the greatest amount of alteration. As it is the most stable and insoluble lead mineral under normal environmental conditions, pyromorphite should be the final product in the alteration sequence from galena through anglesite and cerussite (Scheckel and Ryan 2002). Being on high ground these localities are likely to have experienced lower water tables in the past and, therefore, more extensive alteration. Possibly for the same reason, the highest working on West Foxrock Lode (T 1033 9848) also has pyromorphite although it is absent from the lower tips of this mine in spite of the presence of cerussite. The phenomenon is repeated at Lough Dan where, again, only the highest tip contains pyromorphite.

One might expect to find pyromorphite group minerals wherever lead deposits are extensively oxidised but there are many examples of oxidised lead deposits in which pyromorphite is scarce or absent (e.g. Hudgillburn Mine in Northern England or Parys Mountain in Wales). The reason lies in the geochemistry of the deposits. Whenever galena oxidises in a limestone or carbonate-rich environment, the lead carbonate mineral cerussite, which is also highly insoluble, tends to form, no doubt due to the relatively high activity of the carbonate ion. On the other hand, oxidation in very acid sulphate-rich environments, such as Parys Mountain on Anglesey, tends to produce the lead sulphate mineral anglesite together with minerals of the jarosite group. Where pyromorphite is common (e.g. Leadhills, Caldbeck Fells, Bwlchglas, Struy and Hard Rigg Edge) the wallrock tends to be siliceous and the carbonate gangue relatively minor, but sufficient to buffer the deposit to keep conditions from becoming too acid (Mason 2004). The Wicklow occurrences fit this pattern well. There was clearly sufficient phosphate in the supergene environment to make highly insoluble pyromorphite the stable end-point for the oxidation of galena.

In view of the general dominance of Carboniferous limestone in Irish geology it is not surprising that the most important lead deposits outside of the limestone areas should be home to the country's principal pyromorphite occurrences.

The scarcity of secondary zinc minerals in spite of the abundance of sphalerite is noteworthy. This is probably due to the greater mobility of zinc in the supergene environment. The insolubility of most supergene lead minerals means they precipitate relatively close to the source of lead ions. In contrast the readily soluble zinc salts can leach away more easily. This would account for the scarcity of zinc in the most oxidised deposits (assuming it was there in the first place). Since carbonate is not particularly common in the Wicklow Mountains, the most likely secondary zinc mineral is the silicate hemimorphite. This is certainly widespread but only in minor amounts. The carbonate smithsonite, is known only from three museum specimens.

Some of the secondary minerals are worthy of note simply on account of their rarity. Wulfenite has been reported from only two other localities in Ireland: Lemgare Mine, Co. Monaghan (Rothwell and Mason 1992) and Tynagh Mine, Co. Galway (Green and Moreton 2001). Its occurrence at Luganure Mine is by far the richest yet found in the country. Caledonite was previously only known from Ballinafunshoge (Russell 1907). Orthoserpierite is exceptionally rare, being known in Ireland only from Tynagh Mine in Co. Galway (Sarp *et al.* 1987). The specimens from Foxrock mine are remarkably rich for the mineral. Wroewolfeite and annabergite have previously only been reported in Ireland from Sheeffry mine, Co. Mayo (Moreton and Jackson 1991) although annabergite, as a recent post-mining alteration, is also present in Lisheen mine, Co. Tipperary (authors' unpublished observation). Redgillite is known from Sheeffry mine (Pluth *et al.* 2005), but brewsterite-Ba and kottigite are new to Ireland.

Native silver in trace amounts has been reported from many Irish lead deposits (Kinahan 1886) where it is probably derived from alteration of galena. The single example found during this study is certainly of supergene origin, unlike the Victorian specimen in the Natural History Museum (London). Interestingly, Cole (1922) refers to "silver ore" being raised in Glendasan in 1865. This comprised 184 tons of lead ore yielding 65,951 oz silver. If derived solely from galena this would correspond to nearly 1 % silver, a very unlikely situation. Whether the 1865 material represented a primary deposit, as with the Victorian museum specimen described here, or a localised supergene con-

centration, as with the material found during this study at North Hero Lode, may never be known as no specimens appear to have survived.

The rare species tend to occur as microscopic crystals. This was unlikely to have been the case during the heyday of mining. The supergene mineralisation in Wicklow has similarities with that at Leadhills and in the Caldbeck Fells in Britain. These British mining districts are famous for fine examples of rare minerals such as leadhillite, caledonite, lanarkite and linarite, often in large, well-crystallised specimens. Museums all over the world possess good examples and many others exist in private hands. That similarly fine examples were formerly present in the Wicklow mines seems highly probable.

There is some historical evidence that this was indeed the case. The comment, by Jukes and Du Noyer (1869) about "beautiful crystals of native silver" demonstrates that this mineral, at least, once occurred in spectacular form. Similarly, Glenmalure (most likely the Ballinafunshoge mine) was once noted for pyromorphite "in fine crystals of a clove-brown colour, coated with others of a yellowish-green" (Greg and Lettsom 1858). Greg and Lettsom (1858) also referred to "magnificent crystals" of light brown cerussite but those specimens that remain on the tips today, although representative of the species, can hardly be called "magnificent". Similar arguments apply also to the primary minerals: witness the remarks about calcite "implanted in solitary whiteness on ice-like drusy quartz", although the harmotome was always rare (Joly 1886).

A survey of old museum collections has turned up very few "old-time" specimens. Some fine barites from the area are preserved in the National Museum of Ireland as mentioned above. Also preserved are several rich, if rather battered, well-crystallised cerussites from Glenmalure, and from Luganure mine. Rich cerussite specimens are also owned by the Hunterian Museum, Glasgow. The Natural History Museum (London) has on display a good pyromorphite from Glenmalure similar to the description of Greg and Lettsom (1858) and two attractive calcite specimens as undamaged, hexagonal, platy crystals on quartz from "Seven Churches", in addition to a few dozen samples not displayed. About twenty samples, including harmotome, are preserved in Trinity College.

The scarcity of fine historic specimens, in spite of the high likelihood of their former presence, is almost certainly due to a lack of contemporary collecting. Leadhills and the Caldbeck Fells were visited frequently in the nineteenth century by mineral collectors and dealers. They encouraged the miners to set aside good specimens and paid well for them. Consequently the miners had an incentive to preserve what they found. Ireland, by contrast, had no such tradition. Mineral dealers and collectors were (and still are) a rarity. Tragically for Irish mineralogy, with no reason to keep quality specimens the miners would simply have treated them as ore to be sent to the crusher.

The Wicklow lead mines provide the best Irish example of supergene mineralisation associated with lead-zinc-copper veins in siliceous wallrock. They also host minor occurrences of the rare zeolite minerals brewsterite-Ba and harmotome, which occur as late stage primary vein minerals. In total over 40 different mineral species are now known to occur at these mines. The abundance of representative examples of common species, their proximity to Dublin, and their ease of access, makes them an ideal venue for student parties, fieldtrips and amateur collectors. This fact has been recognised before in their description as a "valuable site for educational use" (Anon. 1981).

Like all resources they are finite, not only in quantity, but in time. Over a century of weathering has taken its toll. Well-crystallised specimens of the softer minerals calcite and fluorite are now almost impossible to find on surface, and underground access is severely limited by the dilapidated condition of the levels. Similarly, no evidence could be found of the smithsonite and blue hemimorphite found by Arthur Russell in the early twentieth century. In time the sulphides will alter and degrade and the tips on the steeper slopes will erode away.

The best way to preserve fragile or vulnerable minerals for future generations is to collect them. The sheer volume of material at the Wicklow lead mines means that, weathering notwithstanding, they will be productive for a few more decades yet. For the time being at least there is scope for the patient collector to continue to make new discoveries.

NOTE

It may be of use to future investigators to know that over 50 specimens of minerals found during this study have been donated to the National Museum of Ireland (specimens NMING: G1771-G1804) and to Manchester Museum (specimens N11884, N13133-4, N13720-4, N13730, N13752, N13754-7, N14325, N14372-5, N15041, N15350, N15361, N19200-1). Six hand specimens have also been donated to the Wicklow Mountains National Park for use in exhibits on the mines.

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