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# Great Orme Copper Mines

[SH 770 830]

## Introduction

Mining for copper on the Great Orme (Figure 5.78) and (Figure 5.79), a prominent headland overlooking Llandudno and Colwyn Bay, goes back to Bronze-Age times, and the mine is well renowned as an archaeological site of international importance. In addition, the style of mineralization worked here, belonging to the copper-dolomite class of deposits, is of considerable metallogenic importance.

Bronze-Age mining features are well preserved at the Great Orme due to the sealing in of many artefacts by aragonite flowstone. Stone hammers and antler picks have been recovered and the early mining dates have been confirmed by <sup>14</sup>C dating (Lewis, 1990). Mining since that time has continued intermittently until the late 19th century (Bick, 1985), and in 1842 a new drainage adit, driven in at sea level, broke through into the workings. The high-grade ore obtained at the Great Orme was often sent to Amlwch, on Anglesey, for smelting with lower-grade produce mined at Parys Mountain. According to Hunt (1884), the mine was abandoned when unexpectedly the sea broke into the workings along hidden fissures which could not be sealed off. Between 1804 and 1881, the mines (initially worked as the two separate ventures known as 'New Llandudno' and 'Old Llandudno') produced a total of 26 506 tons of copper ore concentrates, of an unknown copper content. Production prior to 1804 remains unknown but was clearly substantial.

The metallogenesis and mineralogy of the site have received considerable attention. William Vivian, working as Mine Captain for John Taylor & Sons, reported in 1859 the presence of arborescent native copper in the workings (Vivian, 1859). Hunt (1884) gave a full description of the mine, abstracted by Dewey and Eastwood (1925). In Hunt's account, four sub-parallel N–S-trending lodes were described, plus a number of minor cross-veins. Workable ores were said to occur where these lodes traversed certain beds of crystalline limestone, and particularly in the vicinity of junctions of the lodes with the cross veins. Hunt (1884) also referred to the presence of an extensive oxidized zone in the upper part of the mine, below which chalcopyrite was the main ore mined.

More recently, studies into the mineralization have revealed the presence of a number of rare minerals. A specimen of 'linnaeite' from the Great Orme, in the collections of the National Museum of Wales, was shown by Ixer and Stanley (1996) to be siegenite and to be associated with traces of sphalerite, tennantite and Ni-Co-Fe arsenides and sulpharsenides. The presence of uranium-bearing vein hydrocarbons was reported by Parnell (1988b), while secondary clinoclase and erythrite were reported by Jenkins and Johnson (1993). The first detailed description of the paragenesis of the mineralization at the Great Orme was provided by Ixer and Davies (1996), and represents the most in-depth study of the mineralization to date.

## Description

The strata hosting the copper-dolomite deposit at the Great Orme comprise a shallow-water carbonate-dominated sequence of Dinantian (Lower Carboniferous) age. The sequence is dominated by thick limestones intercalated with thinner shaly horizons (Warren *et al.*, 1984). The lithologies are not dissimilar to those exposed in the Halkyn Block of the North-east Wales Orefield, except that the limestones at the Great Orme have been heavily dolomitized.

The mineralization is developed in the Craig Raft Sandstone Member of the Cefn Mawr Limestone Formation and the overlying Red Wharf Limestone Formation. It occurs within a zone in which numerous sub-parallel N–S-trending high-angle faults cut the succession (Ixer and Davies, 1996). The faults show slight displacement (0.5–1.5 m) and are all mineralized, although the most intense mineralization, now worked out, was developed along four particularly large fractures. The mineralization is strongly controlled by the host lithology, being best developed in the thickest beds of dolomitized limestone.

Within the Craig Rofft Sandstone Member, primary mineralization is restricted to joint planes and faults, and consists of minor chalcopyrite accompanied by saddle dolomite and calcite (Ixer and Davies, 1996). The overlying dolomitized limestones are intensively mineralized along the faults, on joints, in void infillings and along bedding planes. Typical primary ore consists of saddle dolomite, forming crusts of typically curved crystals, upon which sphenoidal chalcopyrite crystals, typically 3–5 mm across, are scattered, accompanied by minor, and later, pyrite and marcasite. Traces of sphalerite are associated with the chalcopyrite. Galena is rare, only having been recorded from one fault plane cutting fine-grained dolomitized limestone. The galena contains an inclusion assemblage comprising 5–60 µm grains of pyrite, marcasite, millerite, chalcopyrite and sphalerite (Ixer and Davies, 1996). Siegenite, represented by a single specimen in the mineral collection of the National Museum of Wales (NMW 83.41G.M1489, originally labelled as Tinnæite') forms grey, cubo-octahedra up to 4 mm across. The paragenetic association of the siegenite is not clear as further material has yet to be located.

Supergene modification of the primary mineralization at Great Orme is complex and multi-stage, often obliterating the original primary textures. The supergene mineralization is essentially void-filling, but is associated with limited wall-rock alteration, comprising the de-dolomitization of saddle dolomite and the dolomitized limestone. Chalcopyrite is often altered directly to supergene copper sulphides (digenite, djurleite, spionkopite and covellite). However, malachite and calcite are the principal supergene species present.

Three principal generations of supergene calcite have been determined (Ixer and Davies, 1996). The first generation is of a dull orange-red colour and is luminescent. It is associated with malachite and overgrows altered chalcopyrite. The chalcopyrite is pseudomorphed by limonite, and the pseudomorphs contain patches and veinlets of cuprite, malachite, native copper and tenorite, all of which are fine grained. The second, and principal, calcite generation forms euhedral crystals up to 10 mm, which are strongly zoned, luminescent and vary in colour from dull to bright orange-red. Malachite and limonite crusts have been deposited in between stages of calcite crystal growth. The third calcite generation consists of fine-grained infills of voids in earlier calcite and clear, non-luminescent, coarse-grained crystals, again with included malachite and iron oxides.

Malachite, which occurred at the Great Orme in sufficient amounts to be mined in its own right, tends to form botryoidal crusts, and also pseudomorphs after chalcopyrite, as illustrated by Bevins (1994). Rarely, azurite forms cores to the malachite botryoids. Azurite also forms rare crystalline aggregates on saddle dolomite (Bevins, 1994). A further occurrence of azurite, described by Ixer and Davies (1996), consists of small, spheroidal nodules up to 2 cm in diameter developed within a non-calcareous shale horizon, the 'Azurite-bearing Shale' of Warren *et al.* (1984). In these shales, there are two generations of azurite, an early, fine-grained, greenish-blue phase, sometimes enclosing chalcopyrite, and a later, deep-blue, crystalline phase which lines fractures within the fine-grained material.

The galena-bearing assemblage shows alteration to cerussite, accompanied by digenite, djurleite, covellite and spionkopite. A further alteration assemblage comprises the 'copper dhu' or black copper ore, which infills veins lined with dolomite, malachite and goethite. The 'copper dhu' is extremely fine-grained and fails to give a clear X-ray diffraction pattern. Ixer and Davies (1996) reported that X-ray fluorescence analysis of the 'copper dhu' revealed the presence of major Fe, Cu and Ni, with minor Co, As, Pb, Mn and Cr.

## Interpretation

With the exception of the galena-bearing fracture, which has been assigned (Ixer and Davies, 1996) to the North-east Wales Orefield mineralization, and the isolated siegenite specimen, the primary mineralization at the Great Orme consists of saddle dolomite, chalcopyrite, minor iron sulphides, and calcite filling veins and voids within dolomitized limestones. This assemblage has been assigned to the copper-dolomite association (Ixer and Stanley, 1996), a worldwide class of mineralization, which is genetically associated with exhalative lead-zinc or MVT deposits. Typically, such associations are deposited at temperatures of 60°–150°C (Radke and Mathis, 1980), often in positions marginal to MVT orefields.

Using the mineralization at Tynagh, in Ireland, and Mount Isa, in Australia, as case studies, Russell (1983) constructed a model to explain the connection between the copper-dolomite associations and sedimentary exhalative Pb-Zn deposits.

The exhalative deposits are produced by deepening hydrothermal cells developed during episodes of crustal extension. Towards the end of the depositional cycle, the hydro-thermal fluids become magnesium-rich and sulphur-poor, and deposit saddle dolomite as they pass through carbonate sequences at high crustal levels. Should the fluids circulate through either deeply buried red-beds or volcanic rocks, they take copper into solution, which then combines with the remaining sulphur to form chalcopyrite, which co-precipitates with the saddle dolomite.

This model may be applied to the Great Orme, either by invoking fluid interactions with the Permo-Triassic rocks of the Irish Sea Basin or alternatively with the Lower Palaeozoic volcanic rocks which outcrop just to the south-west of the Great Orme. Ixer and Davies (1996) suggested that a Permo-Triassic source-basin would imply that the copper-dolomite association at the Great Orme was deposited in late Mesozoic to early Tertiary times, on the basis that the Irish Sea and Cheshire basins attained their maximum burial depth during late Jurassic to early Cretaceous times, prior to rapid uplift in late Mesozoic times.

This age for the mineralization is, however, at odds with isotopic dates obtained from this and adjacent sites. Both galena samples and uranium-bearing bitumens have yielded Pb-Pb dates which suggest the mineralization is of early Triassic age (Parnell and Swainbank, 1990; Rohl, 1995). This model age is similar to that obtained for the MVT mineralization of the North-east Wales Orefield (Fletcher *et al.*, 1993). However, Ixer and Davies (1996) considered that the dates obtained from the bitumens merely represent the age of migration of the bitumen, as opposed to the age of the copper mineralization.

Ixer and Davies (1996) argued, albeit on limited evidence, that the galena-bearing vein, which they associated with the North-east Wales MVT mineralization, is earlier than the copper-dolomite mineralization. Both types of mineralization clearly post-date Variscan faulting, but it is clear from the above discussion that the precise post-Variscan age remains to be clearly established. However, there is further evidence to consider. The 'copper dhu' ore, which is a wad-like, fine-grained, amorphous, post-dolomite deposit containing elevated concentrations of Fe, Cu, Ni, Co and Mn, amongst other elements, bears a close resemblance to the earthy Fe-Ni-Co-Mn oxide mineralization which was mined in now largely overgrown workings in the Prestatyn area, on the eastern margin of the Permo-Triassic-filled Vale of Clwyd (Warren *et al.*, 1984; Bevins and Mason, 1999). This has been interpreted (Bevins and Mason, 1999) as being formed by the circulation of oxidizing groundwaters in Triassic times. This would suggest that the copper-dolomite mineralization was formed prior to that time.

An alternative interpretation of the 'copper-dhu' and Vale of Clwyd-type mineralization, however, could relate it to a widespread oxide-fades mineralization event, which has been noted at several sites in the Welsh Caledonides, such as the Mynydd Nodol Mine GCR site. This mineralization, with associated pervasive bleaching of the volcanic or sedimentary host-rocks, is poorly understood but consists of botryoidal Fe-Mn oxides filling available fracture spaces, and may have formed during Tertiary sub-tropical deep weathering. If this were the case, the late Mesozoic to early Tertiary age for the Great Orme mineralization, suggested by Ixer and Davies (1996), may be more realistic.

The supergene alteration of chalcopyrite at the Great Orme, comprising initial conversion to copper sulphides and limonite followed by multiple generations of calcite and malachite, is interpreted as being related to an increase in oxidation potential through time (Ixer and Davies, 1996). This is supported by cathodo-luminescence of the supergene calcite, which is restricted to the first two generations. Cathodoluminescence in calcite is activated by the incorporation of divalent manganese into the mineral, where it substitutes for calcium. Divalent iron counters the effect. Hence, the phenomenon is a good indicator of prevailing oxidation-reduction conditions, since both Mn and Fe are common in groundwaters. With increasing oxidation potential, Mn may remain divalent while Fe precipitates as trivalent oxides. At still higher oxidation potentials, both metals are deposited as trivalent oxides, hence the final, non-luminescent calcite generation is associated with Fe-Mn oxides.

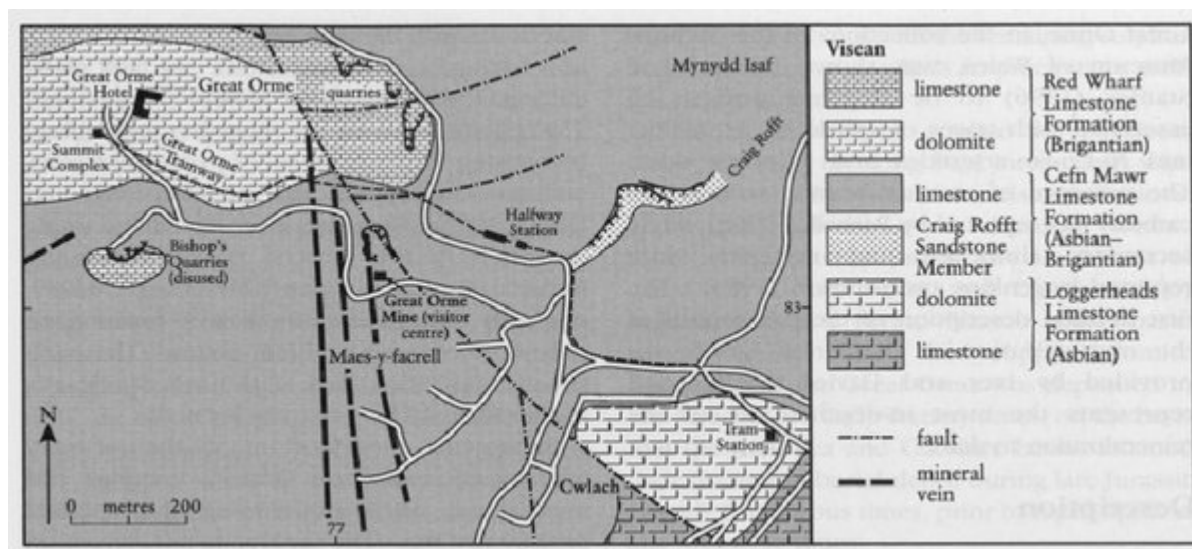
The relative scarcity and early paragenetic position of azurite relative to malachite was explained by Ixer and Davies (1996) as being related to pH. Malachite is stable at much higher pH values than azurite. Within the dolomitic rocks of the Great Orme, the mine groundwaters, with a pH of 7–10, are within the malachite stability field but only marginal with respect to azurite. However, the predominance of azurite in the shale unit is explained by the non-calcareous nature of the shales; acidic fluids produced by the oxidation of pyrite and chalcopyrite would lack the necessary carbonate input to

buffer the groundwaters to pH values in excess of 7. Under these conditions, azurite would be the more stable phase.

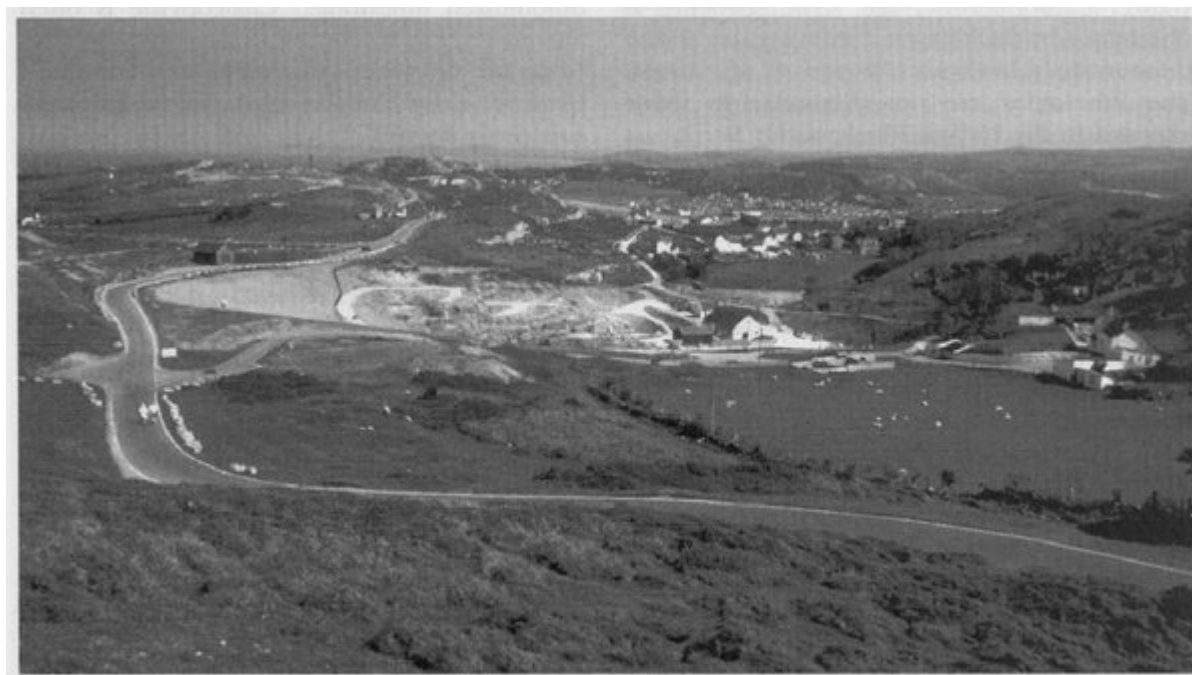
## Conclusions

The simple primary copper-dolomite association at the Great Orme represents the first deposit of this class to be recognized in the UK. The mineralization is believed to have been deposited from magnesium-rich, sulphur-poor, copper-bearing hydrothermal fluids towards the end of a major hydrothermal episode, probably during Mesozoic times. The secondary alteration of the deposit is extremely complex and reflects alteration of the primary copper-bearing mineralization in an increasingly oxidizing environment by circulating groundwaters which were, except very locally, of a highly alkaline nature. The relationship of the mineralization and its alteration to that within the adjacent North-east Wales Orefield, with its Mississippi Valley-type mineralization, warrants further investigation.

## References



(Figure 5.78) Map of the Great Orme Copper Mines GCR site. After British Geological Survey 1:50 000 Sheet 94, Llandudno (1989a).



(Figure 5.79) Photograph of the Great Orme Copper Mines GCR site. (Photo: S. Campbell.)