Economic Geology
Vol. 73, 1978, pp. 486-495

Mineralization and Paragenesis at the Mount Wellington Mine, Cornwall

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Abstract

The Mount Wellington mine is the most recent to recommence production in the United Kingdom. It lies on the southwestern extension of the Wheal Jane lodes. About half the production comes from the number 1 lode which lies in the footwall of a shallow-dipping elvan sheet. The numbers 2 and 3 lodes have a similar trend but dip more steeply; they join the main lode without intersecting it. These lodes are generally smaller than the number 1 lode but carry higher grades of tin. The remaining mine production comes from the number 2 lode, but the number 3 is at present unpayable. All these lodes have a similar mineralogy and paragenesis. The mineralization took place in four stages. In each lode the minerals of the two earlier phases replace brecciated fault zones and those of the two later phases fill dilatant fractures in the earlier material. These lodes were cut by the mineralized (but uneconomic) Hot lode which may have formed during the later stages of mineralization of the main lodes. All these lodes are cut by two groups of variously mineralized faults called caunterlodes and crosscourses, respectively. Both the main mineralizations and the elvan were controlled by two sets of faults developed around the cooling Carnmenellis granite cupola, probably in response to fluid overpressures.

Introduction

THE Mount Wellington mine lies near the village of Twelve Heads some 7 km west of Truro and 3 and 4 km respectively from the nearest outcrops of the Carnmarth and Carnmenellis granites (Fig. 1). The area between Truro and Camborne (just to the west of the Carn Brea granite) has been one of the most intensely mined in the Cornish tin province and there are numerous old workings in the Mount Wellington mine area. The mine is one of five currently producing in Cornwall, the others being Wheal Jane, Geevor, South Crofty, and Pendarves. These are all that remain in a province that has had perhaps two thousand operating mines in its history.

The mine is located within lightly metamorphosed Mylor slates, known locally as "killas," and is to the north of the axial line of the Truro anticline. Workings in the mine were probably initiated in the eighteenth century, but the earliest detailed records are from 1923 (Dines, 1956) when parts of the property were worked by the United Mines Group. The property has been worked sporadically since then, but major interest was rekindled in the sixties and an extensive drilling program was initiated in 1964. Of 69 holes drilled, 46 intersected the important number 1 lode beneath an "elvan" (quartz-feldspar porphyry) sheet. Both elvan and lode are southwesterly extensions of the B-elvan and B-lode in the Wheal Jane mine. In 1974 the property was placed under the management of Cornwall Tin and Mining Limited and was brought into production in 1975. The circular Wellington shaft has been lined with concrete and sunk to the seventh level. Four new levels (2, 3, 6, and 7) have been developed and the upper levels have been linked and extended.

There are six lodes in the mine. They are the numbers 1, 2, and 3 (the main lodes), the Wheal Andrew, the Trenares, and the Hot lodes. At present half the production comes from the number 1 lode east of the Wellington crosscourse and half from the number 2 lode west of this fault (Figs. 2, 3, and 4). These main lodes contain Fe, Zn, Sn, As, Cu, Ti, and lesser Pb, Ag, Au, W, Bi, and Sb. They are grossly similar to the Wheal Jane lodes studied by Rayment et al. (1971) and both mines produce tin, copper, and zinc concentrates.

A smaller lode at Mount Wellington—the Hot lode—is rich in copper which was profitably extracted in the nineteenth century but is not economic today. Similarly the Wheal Andrew lode, which was worked in a minor way in this century, is not economic where it is exposed in the workings. The caunterlodes and crosscourses are weakly mineralized but are not of any economic significance.

The Elvans

The Mylor slates were intruded by a series of elvan sheets particularly around the northern margins of the Carnmenellis granite. The elvans postdate the deformation and metamorphism of the killas as well as most of the abundant quartz veining. In the Mount Wellington area the numerous elvans

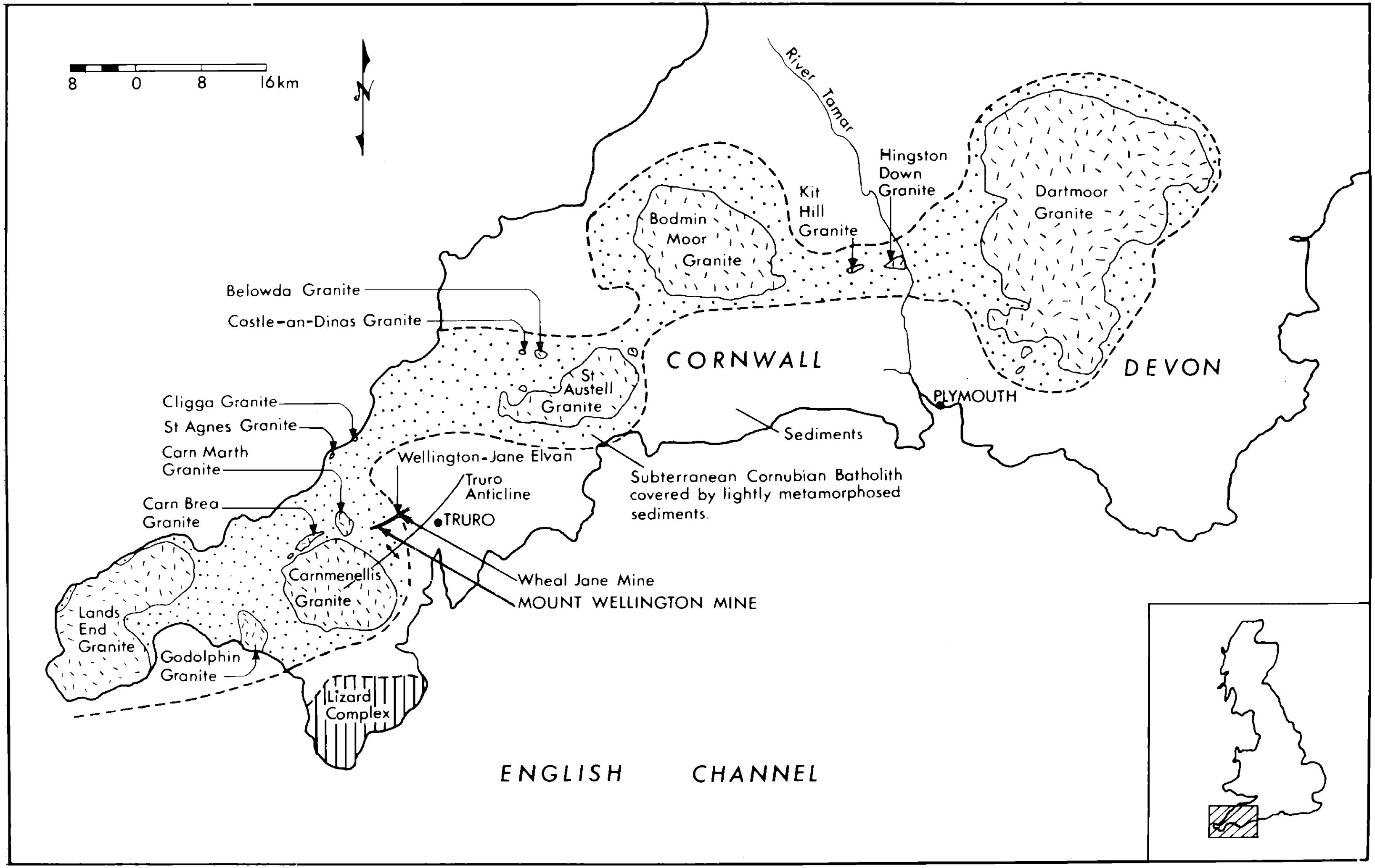

FIG. 1. Inset location map. The Cornubian batholith outlines are simplified from Rayment et al. (1971).

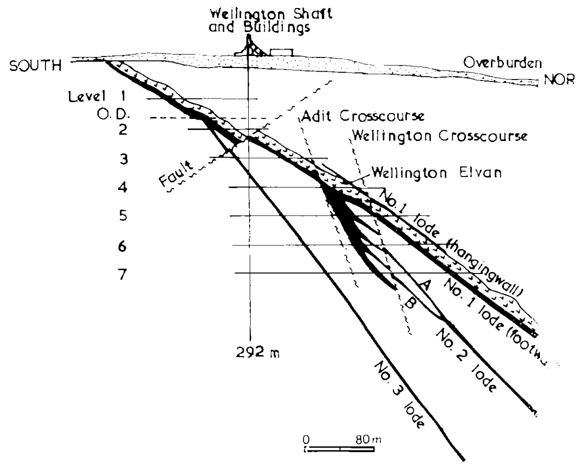

FIG. 2. Schematic cross section of the Mount Wellington mine.

are quartz-orthoclase porphyries. They have well-developed chilled margins and are usually separated by screens of killas. Up to seven adjacent sheets have been recognized at the mine and they are only separable because of their chilled margins. Goode (1973) suggests that some of these finer grained areas are not in fact chilled margins but early intrusions reintruded by coarser porphyritic elvans. Our observations do not support this interpretation.

The most important elvan within the mine workings (Wellington elvan at Mount Wellington and B-elvan at Wheal Jane) is the one which contains the main mineralization (number 1 lode) in its footwall. It strikes about 055°, dipping 35° northwest, and has been traced along strike for over 6 km. It is usually discrete but does join branches of other elvans to the west of the mine area (Cotton, 1972). The elvans are rather irregular in thickness and dip such that domes and basins can be recognized. The significance of these as a control of mineralization is discussed below.

The Wellington elvan has been extensively altered. Adjoining the mineralization it has been sericitized, chloritized, and tourmalinized and silicified areas are locally developed. The elvan is also pervasively kaolinized, an alteration which appears to be overprinted by the others; it therefore presumably predates them, but by how much is debatable. Nevertheless there is evidence of early, hydrothermal kaolinization.

The Lodes

There are five lodes within the mine: a sixth, the Trenares lode, is within the mining leases but not yet incorporated in the workings. The lodes are the numbers 1, 2, and 3, the Wheal Andrew, and the Hot lodes. Of these, only the Wheal Andrew and the Trenares lodes have not been studied.

The number 1 lode lies in the footwall of the elvan (Figs. 2, 3, and 4) which has sharp contacts and is in places sheared, mineralized, and brecciated. It is possible that the elvan was emplaced along an already brecciated plane in the killas, but the main brecciation occurred after elvan emplacement. The resultant breccia of killas and lesser amounts of chilled elvan and vein quartz were replaced by the lode. There is a thin, intermittant development of number 1 lode-type in the hanging wall of the elvan, but this is not economically recoverable at present. The lode has a strike length of over 1.5 km in the Mount Wellington leases and a further 5 km through

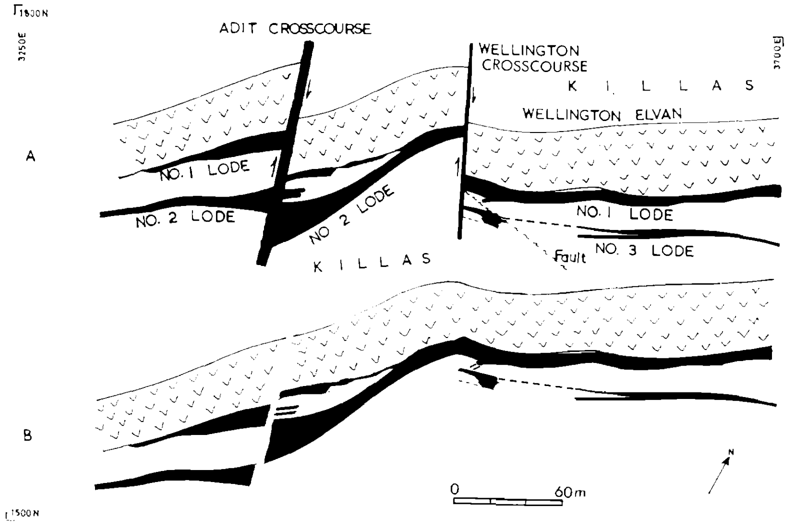

FIG. 3. A. Level 4 map showing the relation between the number 1 and 2 lodes. B. Original structure prior to crosscourse faulting.

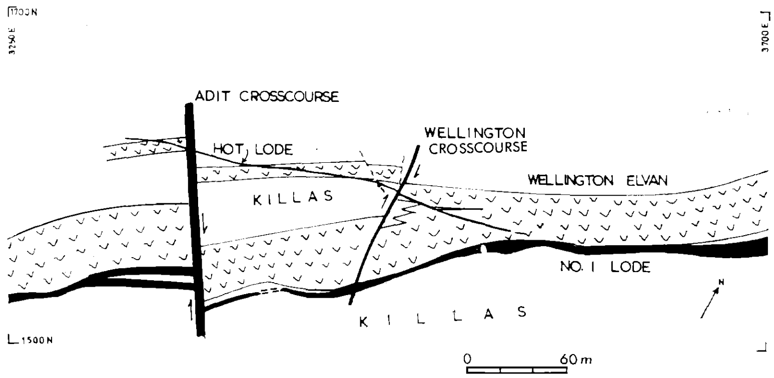

FIG. 4. Level 1 map of structures in the Hot lode area.

the Wheal Jane property. Its thickness varies between 1 and 19 meters at Mount Wellington, with an average of 3.6 meters. It has been recognized in drill core at 300 m depth, but its full downdip extent is unknown. The elvan is extensively altered next to the lode and, where there are, locally, screens of killas between elvan and lode, these too are altered. The tin distribution is inhomogeneous and there are many uneconomic sections in the lode, particularly to the west of the Wellington fault (Figs. 2, 3, and 4).

The numbers 2 and 3 lodes are effectively identical. They strike in the same direction as the number 1 lode but dip more steeply at about 50° northwest. They join the number 1 lode between the second and fifth levels (Fig. 2). The contact areas are extremely complex with lodes sometimes thinning, sometimes thickening, and sometimes ramifying (Fig. 3). These two lodes also occupy brecciated fault zones and the complications at the junctions presumably reflect original complications at the intersections of two active fault systems and are not a reflection of complexities in the mineralizing process. In the junction areas the tin grade is sometimes higher—an observation also made by Rayment (1974) at Wheal Jane—but may also be so low as to be locally unpayable.

The numbers 2 and 3 lodes are thinner than the number 1 lode (2.4 m and 1.8 m averages, respectively) and the alteration halos are also less extensive—recognizable over some 3 m compared with up to 12 m around the number 1 lode. These two lodes occupy less dilatant fault zones than that in the elvan footwall and this lack of dilatancy also inhibited the better development of the later (open space-filling) phases of mineralization. The lack of crosscutting relations between the numbers 1, 2, and 3 lodes and the similarities in their mineralization and paragenesis support the conclusion of this paper that the lodes are coeval. The numbers 2 and 3 lodes are not recognized in the elvan which presumably acted as a structural barrier to the dilatant fault system and thence to the fluids traveling in it. The Trenares lode apparently belongs to this group of lodes as it dips 15° northwest and does not cut the elvan.

The Wheal Andrew and Hot lodes do cut the elvan and the number 1 lode. The former, which was worked mainly for copper ores to the northeast of Mount Wellington, is shown, on the few available maps and sections, as cutting the elvan and number 1 lode near the boundary between the Wheal Jane and Mount Wellington leases. It has a strike and dip similar to the Hot lode, but no samples were available for study. Both lodes dip steeply with a strike of about 080°. The Hot lode cuts the elvan and what is probably a branch of the elvan (Fig. 4) and an exposure on the adit level shows it cutting the number 1 lode. However, the nature of the mineralization suggests that it fills a fracture generated during the later phases of the main mineralization. This lode, whose thickness varies between 15 cm and 3.4 m, is possibly the eastern extension of a similar lode outcropping in the Teagues openworks some 2 km east of the Carnmarth granite (Fig. 1).

Two sets of faults, known as caunterlodes and crosscourses in the mines, cut the elvan and the other lodes. The caunterlodes usually strike 090° and dip at 40° to 60° south. The narrow fault planes are weakly mineralized with sulfides, chlorite, and quartz but are of no economic significance. Two important crosscourses in the mine offset earlier mineralizations and are weakly mineralized with what may be material remobilized from the main lodes. Although the lodes and elvan are significantly offset by the crosscourses, variations in style and tenor in the main lodes at these junctions suggest that there may have been some premineralization perturbation along the lines of these crosscourses.

The Adit crosscourse (Figs. 2, 3, and 4) trends 345° and dips 70° northeast. It is up to 4 m thick and consists usually of banded, open space-filling quartz (chalcedony) veins with a sheared and brecciated footwall margin. It is poorly mineralized, predominantly with marcasite. It has a considerable strike length (>800 m), mostly to the north of the mine. It forms the eastern boundary of the workings (but not necessarily of the mineralization) on the Fortune lode (also called the Cusvey lode) of the old Great Consolidated mines, some 475 m (parallel to the strike of the crosscourse) from the Wellington elvan and number 1 lode. If the mineralization itself is stopped, then the early movement on the fault plane of the crosscourse must certainly have predated and controlled the main mineralizations. The adit crosscourse is a single plane in the upper levels of the Wellington mine but splits into two at depth.

The Wellington crosscourse contains sulfides, chlorite, and quartz and varies between 15 cm and 3 m in thickness. It strikes 340° and dips 78° northeast and has a strike length in excess of 500 m. Its continuation appears to form the eastern boundary of workings on the Virgin lode some 675 m (parallel to the strike of the crosscourse) to the north of Wellington elvan and number 1 lode and 274 m north of the Fortune lode. It also forms the western boundary to the workings in the Wheal Andrew lode.

There is then some possible evidence that these faults may be reactivated planes that were present prior to the main mineralization in the area. The point is more fully discussed in the conclusions.

Apart from these two major faults there is a swarm of small-scale gravity faults which displace (by up to 2 m) the Wellington elvan and lodes. These faults are predominantly east-west-striking (070°–090°) but some strike northeast (030°–040°). Both sets dip steeply south from 60° to vertical, averaging 80°. They are unmineralized and usually contain fault clay.

Many of these faults are situated in uneconomic parts of the lodes, but equally many others occur in areas of high-grade ore, and some traverse both areas. The clay-bearing faults may have diluted the tin content of the lodes locally. There is no convincing evidence that these faults have played any significant role in controlling the mineralization of the main lodes.

Mineralization

The mineralization of the three main lodes is so similar that separate descriptions are not required. Following emplacement and cooling of the elvan, extensive fracturing, both along the contacts of the elvan and along steeper fractures, permitted the introduction of mineralizing fluids (phase A). These fluids precipitated considerable amounts of quartz, tourmaline, and cassiterite in fractures between fragments of killas, quartz vein, and chilled elvan (Fig. 5B). This was probably responsible for tourmalinization and sericitization of elvan, killas, and fragments.

The phase A cassiterites are usually bipyramidal, twinned, and zoned and contain rutile inclusions. They are closely associated with the quartz and tourmaline. Minor amounts of wolframite are seen, but sulfides are virtually absent. Phase A material was brecciated by renewed movements in the original fractures which permitted introduction of a second phase, B. Quartz, chlorite, and sulfides of this phase are abundant and replace fragments of phase A (Fig. 5A, B, C). The phase introduced no cassiterite and has therefore resulted in a dilution of the tin grade. The greater dilatancy of the elvan footwall-fracturing permitted better development of phase B in the number 1 lode—hence the thicker lodes but generally lower tin grades of this lode. Phase A cassiterite was fractured and corroded by phase B faulting and the crystals are healed by sulfides. This is the main cause of the very fine grain size and the consequent extraction problems. Chlorite, quartz, pyrrhotite, arsenopyrite, and chalcopyrite were the first minerals precipitated by phase B. These were followed by more quartz with sphalerite (containing an abundance of exsolved chalcopyrite) and rutile. Small grains of gold were probably formed at this stage. Minor amounts of galena were deposited and the phase was terminated by the precipitation of large amounts of pyrite. This developed as euhedral crystals overgrowing earlier minerals and cementing the rock. Secondary marcasite and covellite have been seen in this association, but it is not clear when they formed.

Phases A and B constitute the bulk of the mineralization in all three lodes. In the number 1 lode phase A material is usually concentrated nearer to the elvan. Where the two phases are better separated, it can be seen that there was also wall-rock alteration around phase B—principally chloritization and lesser hematitization.

There have been no major movements on the lode-controlling faults since phase B, but two periods of slight fracturing caused local dilatancies which were filled by phases C and D. Phase C (Fig. 5C) is represented by narrow veinlets cutting earlier material and filled predominantly with quartz, pale green chlorite, and sulfides. The most abundant sulfides are arsenopyrite and pyrite and lesser sphalerite, chalcopyrite, and pyrrhotite. Some cassiterite was deposited with quartz early in this phase and is associated with small amounts of tourmaline and wolframite. Chalcopyrite and pyrite contain stellate exsolution blebs of sphalerite which in turn contain exsolved chalcopyrite and pyrrhotite. The exsolution of sphalerite from pyrite is most uncommon but

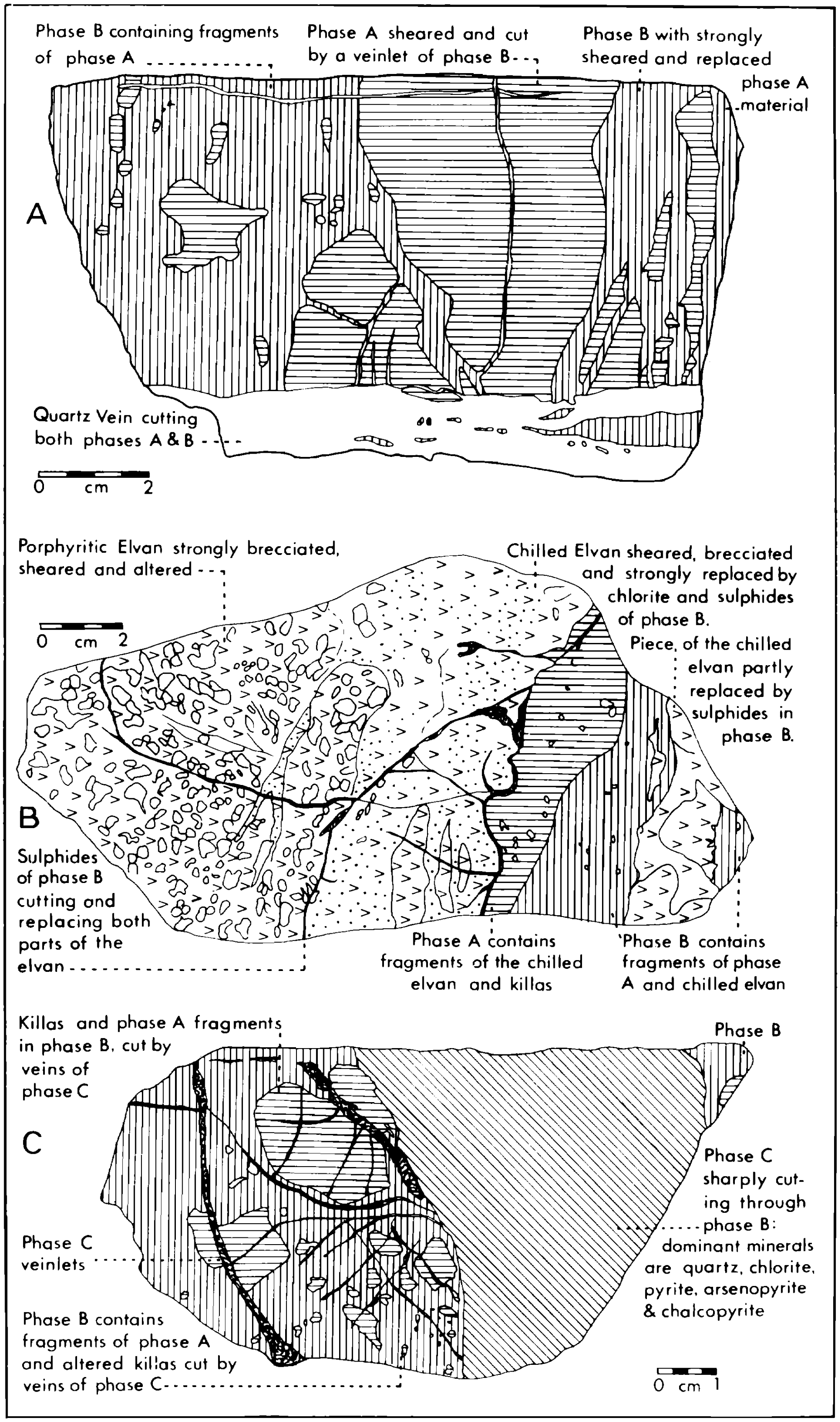

FIG. 5. Camera lucida drawings of lode textures. A. Phase A cut and partly replaced by phase B. Both phases cut by a quartz vein. B. Elvan and its chilled margin brecciated and disrupted by phase A. Both disrupted by phase B. C. Phase C crosscutting phases A and B. Phase D (not shown) has the same crosscutting relation to earlier phases.

is quite clear in these examples. Small intergrowths of silver, gold, galena, and younger bismuth and a series of complex Bi-Pb-Ag-Fe-As sulfosalts occur in the main sulfides. Secondary covellite, marcasite, and neodigenite have also been identified.

Phase D also occurs in small fracture veinlets crosscutting all earlier phases and in many cases filling of the dilatancies was not complete. Vug centers are now filled with a grayish-white clay. The mineralization again consists predominantly of quartz, chlorite, and sulfides and again minor tourmaline and cassiterite (with rutile) were the first minerals deposited. The sulfides are similar to those of phase C but with sphalerite and pyrite predominant. Sphalerite contains pyrrhotite and/or chalcopyrite as the predominant exsolved phases, but also stannite and some as yet unidentified sulfosalts. Galena with minor gold, silver, and Ag-Pb-Sb-Bi-Cu sulfosalts are less important phases. Primary late pyrite in phase D is often distinct in exhibiting gel and spheroidal textures. Pyrite and galena are replaced by marcasite, covellite, and neodigenite

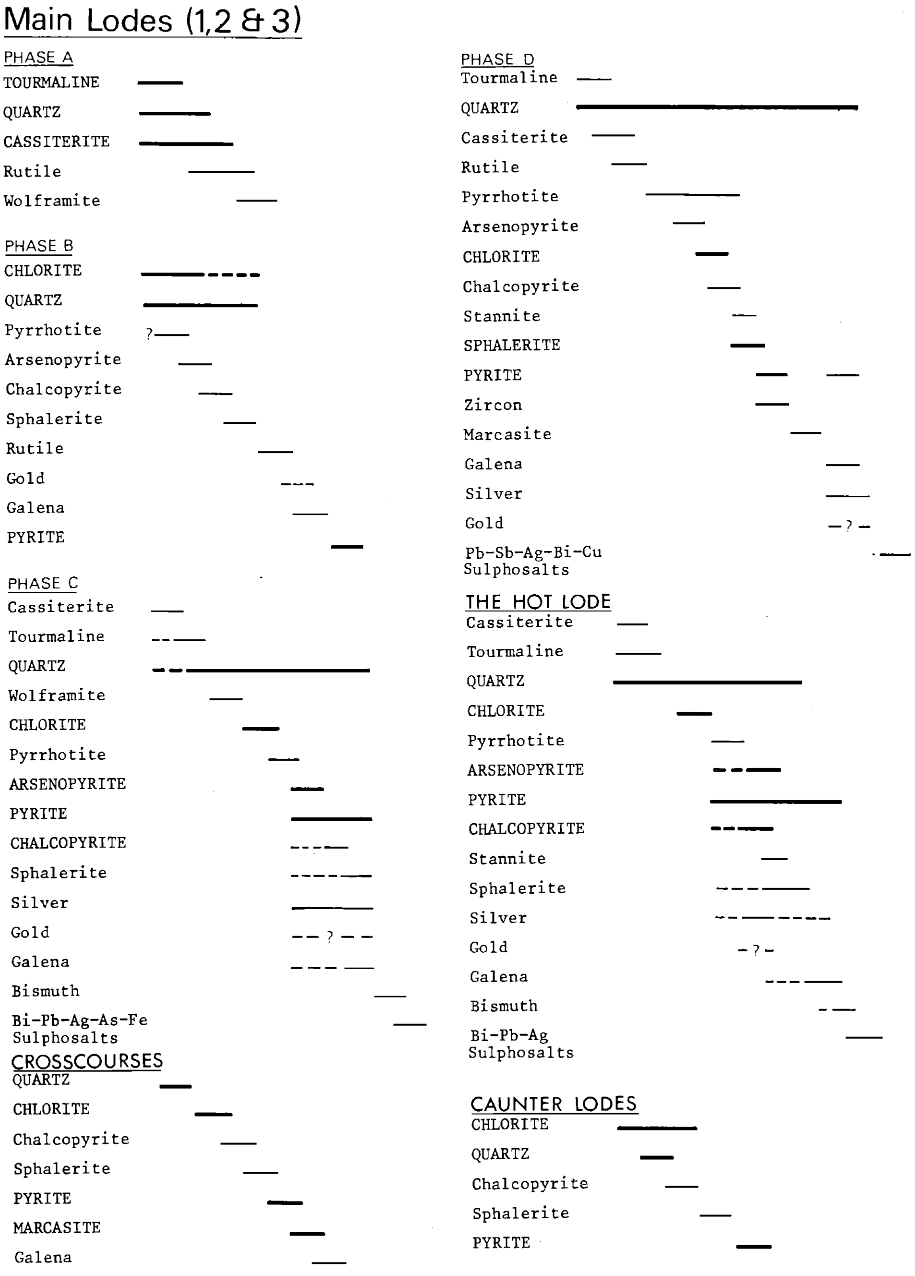

FIG. 6. Mineralogy and paragenesis of the lodes.

which all also show gel textures. Rayment (1974) reported similar textures in pyrite from the B lode at Wheal Jane and suggested that they were formed during replacement of pyrite by marcasite. However Ramdohr (1969) and Oelsner (1966) report gel textures from high temperature hydrothermal pyrite. It is suggested here that the texture is the result of rapid cooling and precipitation from the primary phase D fluid.

The mineralogy and paragenesis of the four phases of mineralization in the three main lodes are summarized in Figure 6. In general the bulk paragenesis is from cassiterite through base metal sulfides to native metals and sulfosalts. It is thought that all the mineralization is hypothermal and that the paragenesis reflects a gradual change in a source fluid (presumably in the granite) which was periodically tapped. These four phases of mineralization were probably emplaced over a short time interval. Textural evidence from the later phases—especially the exsolution of pyrrhotite from sphalerite and of sphalerite stars from pyrite and chalcopyrite—suggests hypothermal deposition in excess of 300°C (Ramdohr, 1969: Edwards, 1954). An investigation of the stable isotopes of sulfur in all phases of mineralization (Rouse and Coleman, 1976) showed general lack of isotopic equilibrium between mineral pairs. Those pairs apparently in equilibrium indicate depositional temperatures in the 300° to 500°C range. Mineralogical and textural evidence (particularly the exsolution of sphalerite in pyrite and chalcopyrite), together with the few invariant temperature points indicated by the stabilities of some of the Pb-Sb-Cu sulfosalts, suggests a similar range.

The Hot lode, which was worked mainly in the old United mine to the west of Mount Wellington, has only been studied in the adit level. It is about 30 cms wide and is mineralogically and paragenetically similar to phase C of the main lodes (Figs. 4 and 6). Although the Hot lode apparently crosscuts the number 1 lode, its relationships to the later phases in the number 1 lode have not been observed. The lode contains early cassiterite, quartz, and tourmaline, followed by chlorite and sulfides. Native metals and sulfosalts occur among the main sulfides and emphasize the similarities with phase C with which they are correlated (Fig. 6).

The caunterlodes crosscut the main and Hot lodes and contain pyrite, sphalerite, and chalcopyrite in a quartz-chlorite gangue. They are only a few tens of centimeters wide. The crosscourses, up to 4 m thick, also crosscut the other lodes and represent open-space filling of considerably younger faults. They are vuggy and have suffered extensively from supergene alteration. Quartz is the dominant mineral, but chlorite and the base metal sulfides are common. An impressive array of supergene minerals can be seen replacing the sulfides. Botryoidal and stalactitic marcasite is particularly common.

Controls of Mineralization

The morphology and telescoped parageneses of the lodes and their complexities in junction areas suggest that the predominant control of the location of mineralization was structural. From the descriptions above it is deduced that two separate sets of fractures moved repeatedly to permit the influxes of mineralizing fluids. The junction areas are morphologically complex, which is only to be expected given the repeated movements and mineralization. It is pertinent that the most complex junction (between numbers 1 and 2 lodes) also coincides with the two main crosscourses (Fig. 2). The number 1 lode is thinner between these crosscourses and thicker to either side of them. However, the number 2 lode is thicker and more complex around and between the crosscourses and is of considerable economic significance in these areas. The grade of tin is no higher than elsewhere but the thickness is economically important (Fig. 3). There is in fact no obvious relationship between lode thickness and tin grade complex areas nor at the junction areas of numbers 1 and 3 lodes.

Rayment et al. (1971) emphasize the importance of embayments in the elvan footwall for the rich and thick mineralization at Wheal Jane. There are no crosscourses coincident with these areas at Wheal Jane and the elvan is thinnest in them. The main embayment at Mount Wellington is between the two crosscourses (Fig. 3). It could be argued from these data that the crosscourses originally predated both elvan and lodes and controlled their irregularities even though their mineralization and major movements postdate the lodes. Equally it could be that irregularities in elvan and lodes predetermined the location of the younger crosscourses. Until there is conclusive evidence that the crosscourses were the original structure, we see no reason to suppose that this is so and prefer the latter argument.

Cotton (1972) suggested that it was not the elvan that was the fundamental control on the location of the mineralization but a set of pre-elvan fractures that controlled emplacement of both elvan and lodes. The following data and conclusions are important in understanding the structural controls of mineralization.

(1) The main lodes are mineralogically similar and coeval.

(2) The hanging wall and footwall contacts of many elvans in the area are mineralized. The

Wellington elvan is the largest in the area of the mine.

(3) The steeper lodes fill fault zones in the killas below the elvan and join the number 1 lode below the elvan.

(4) Lenses of killas may separate lode and elvan.

(5) There are various embayments in the footwall of the elvan. The structures of the lodes are more complex and the mineralization more voluminous in these areas.

It is concluded that the faults, elvans, and mineralizations are intimately related. Two sets of faults were generated in the killas around the rising granite cupolas of the Carnmenellis area. Fracturing at intersections of these faults was more intense and complicated. The faults apparently bear an intimate relation to the emplacement of the granite. Ghosh (1934) has proposed that they developed in response to a regional stress field; Hulin (1945) suggested a more local origin during contractions of the cooling granite; and Emmons (1940) suggested that fluid overpressure from the granites was the cause. The more recent studies of Henley (1974) on elvans have strengthened support for the hypothesis that the elvans were emplaced by gas fluidization.

The conclusions of studies on roof complexes and elvan-pegmatite sheets by Stone (1969, 1975) and of the stress distribution pattern around cooling cupolas (Moore, 1975) can be applied to the Mount Wellington area. It is proposed that the elvans and the later mineralizations escaped through fractures developed in and around the granite hood by fluid overpressure. That the mineralization and elvans were both able separately to escape and to deposit in the same area suggests a rather critical interplay of depth, temperature, fluid overpressure, and rate of evolution of the cooling granite. The lack of distinctive zonation between oxides (cassiterite) and sulfides so common elsewhere in the province emphasizes the uniqueness and effectiveness of the fault zones as a trap. Thus the zonation becomes temporal rather than spatial—a fine example of telescoping.

It is thought that both fault sets are cogenetic but that only the shallower dipping set was used by the elvans. Where the elvans transect the steeper dipping faults, fluctuations in thickness and in dip are only to be expected. The same areas, with their greater dilatancy and complexity, acted as preferential sites for mineralization. Hence the relationship between embayments in the elvan, lode intersections, and locally thicker mineralization. It is possible that tin from earlier phases was preferentially remobilized into these areas during later phases of mineralization: primary cassiterite around the area of junction of lode 1 with lodes 2 and 3 is commonly overgrown by a second generation. Once the elvans had been emplaced, they resisted further fracturing which was preferentially localized at and up to their contacts—so too therefore was the min-

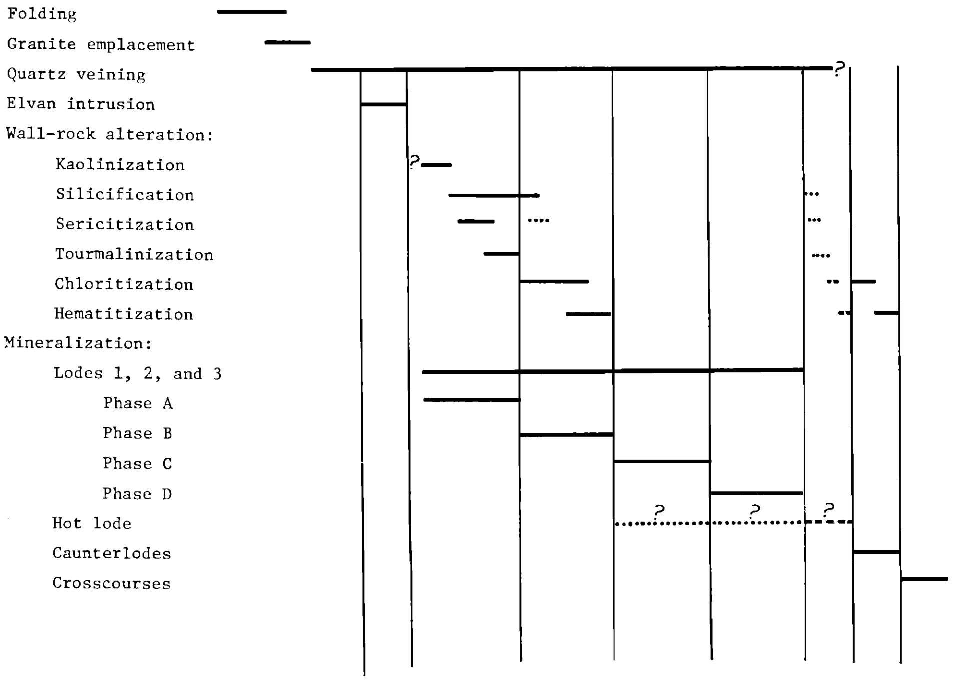

FIG. 7. Paragenesis of events in the Mount Wellington area.

eralization. The elvans thus restricted the mineralization and are the cause of the long and complicated paragenesis. A paragenesis of events in the area is shown in Figure 7.

Conclusions

It is proposed that the distinct mixed oxide-sulfide mineralization at Mount Wellington is coeval and cogenetic in the three main lodes. Four phases of mineralization have been recognized in these lodes and all are primary and hypogene. Quantitative measurements of the depositional temperatures have proved difficult to obtain. However, a temperature range between approximately 300° and 500°C is suggested for the mineral assemblages and textures. Further work is in progress on this problem. A complex mineralogy has been identified. The nature and location of gold and silver in the lodes have been determined. A number of complex sulfosalts have yet to be fully identified and further work is in progress with Mr. J. Bowles at the Institute of Geological Science, London.

Finally the controls of mineralization and elvans have been interpreted as being the same—namely, faults presumably generated by fluid overpressure in and around the granite cupola. Whether or not the various fluids (elvan and mineralizing) actually boiled as they escaped is to be investigated. The efficiency of the faults as deposition sites is suggested by the coincidence of lodes and elvan and by the telescoped paragenesis. In most areas of the Cornish tin province the elvans predated the mineralizations and occupy a different set of fractures. The Mount Wellington area represents a particular coincidence of physical and chemical conditions that is most uncommon. Recognition of these controls may help in identifying similar areas and in reassessing their potential.

Acknowledgments

We are particularly grateful to Malcolm Hooper, Chris Burton, David Kneebone, and all the staff at the Mount Wellington mine for their support and encouragement and for their generosity in giving access to assay information, maps, drill-core, and their development workings. Their free and ready discussion has been most stimulating. However, it should be emphasized that the ideas expressed in this paper may not reflect current ideas of the mine staff and are our responsibility alone. We also thank Max Coleman, Ted Heath, and John Bowles for their most generous help with various stages of the investigation, and the entire staff at Southampton for their excellent, continuing, and invaluable support. These investigations are being supported by the Iraqi Ministry of Oil to whom we are most grateful. The paper is published with the permission of the Manager, Cornwall Tin and Mining Limited.

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September 29, 1977; January 23, 1978

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