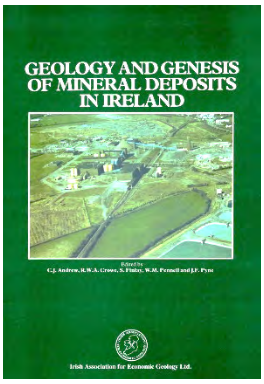

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A review of metal deposits associated with the Leinster Granite, SE Ireland and a model for their genesis.

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Abstract

Small vein-type Pb-Zn sulphide deposits, which have been mined intermittently in the past, are an important feature of the eastern margin of the Caledonian Leinster Granite in SE Ireland. An equally important feature revealed by the renewed exploration of recent years is the presence on the same margin of potentially valuable deposits of lithium and tungsten. These are located in conformable granite sheets and pegmatites within the granite envelope.

A decade ago, the origin of the Pb-Zn deposits was seen as involving residual hydrothermal fluids of essentially magmatic origin. More recent models have favoured an external source for at least a proportion of the mineralizing fluids involved and the scavenging of the necessary metals from the envelope rocks.

This change of view has served to focus attention on that part of the local Cambrian-Ordovician succession that contains coticule (spessartine-quartzite) and tourmalinite — very distinctive lithologies which are associated with mineralization elsewhere. That association is not confined to lead, zinc and copper; it also includes deposits of tungsten, lithium, gold and tin. It is proposed that Cambrian-Ordovician sediments acted as a source for many of the metals now located in deposits of various types that are associated with the Leinster Granite.

Introduction

A variety of mineral deposits are associated with the eastern flank of the Caledonian Leinster Granite (Fig. 1). Towards the northeast a series of vein-type lead-zinc deposits occur in the Granite between Glendalough and Ballycorus. Further southwest, in the Aughrim-Tinahely area, a zone of tungsten-tin mineralization is associated with a swarm of microgranite sheets. A group of lithium-bearing pegmatites is associated with the margin of the Leinster Granite to the west and southwest of Shillelagh, and is best developed in minor sheets of granite emplaced in the metamorphic aureole of the main pluton.

The Glendalough-Ballycorus group of deposits has enjoyed a long history of exploration and exploitation (1750-1957) although the latter has always been on a small scale (Cole, 1922; O Brien, 1958). Serious development of these deposits commenced in the early years of the nineteenth century. The most intensive activity occurred in the thirty years following 1850 when the mines at Glendalough were reported to employ over 200 persons (Smyth, 1853). Mining in Ireland entered a general decline in the early 1880s and this group of mines ceased working. Between 1943 and 1957 some of the adits at Glendalough area were re-opened intermittently. It is estimated that over 60,000t of galena ore, all hand sorted, was produced from this mine in the period 1751-1958 (O Brien 1958).

The Aughrim-Tinahely tungsten mineralization represents the largest example of its type in Ireland. It was discovered by Irish Base Metals Ltd. in the early 1970s after scheelite was identified in stream sediment pan concentrates. The exploration history of the mineralized zone has been described by Steiger (1977), Steiger and Poustie (1979) and Steiger and Bowden (1982). The zone has not been developed for production to date.

The lithium pegmatites were discovered about 1970 during research mapping based at University College Dublin. Irish Base Metals Ltd. subsequently undertook an extensive and continuing programme of prospecting which has confirmed the existence of significant lithium deposits. However none has been sufficiently attractive to warrant development. The discovery and exploration of these deposits is discussed in a number of papers (Steiger and von Knorring, 1974; Steiger, 1977; Luecke, 1981; Moore-Lewy, 1983).

Stratigraphy

The Lower Palaeozoic sequence of SE Ireland has been divided into four lithostratigraphic groups (Brück et al., 1979 and Fig. 1) as follows:

Bray Group: This is composed of greywackes and quartz arenites of lower to middle Cambrian age.

Ribband Group: This succession of distal turbidites comprises slates, siltstones and sandstones as well as local volcanic rocks of intermediate to basic composition. The group ranges in age from middle Cambrian to Llandeilo.

Duncannon Group: Mainly Caradoc in age, this group consists of acid, intermediate and basic volcanic rocks. It contains some sediments including, locally, calcareous beds at its base.

Kilcullen Group: This is a greywacke sequence of lower Ordovician to Wenlock age.

It is in rocks of the Ribband Group flanking the Leinster Granite on its eastern margin that all of the deposits described in this paper occur (Fig. 1). In NE Wicklow, the lead-zinc vein deposits are spatially associated with the Maulin Formation (Brück et al., 1979). To the south, the tungsten deposits are spatially associated with rocks of the Ballybeg Pelitic Formation, and the lithium deposits with rocks of the Kilcarry Volcanic Formation (McArdle, 1981 and

1984). In all instances, these Formations belong to the lower part of the Ribband Group and are late Cambrian to Llandeilo in age.

In the area between Aughrim and Borris, a sequence of four formations has been defined (McArdle, 1981). The sequence youngs to the northwest and has been correlated with part of the Ribband and Bray Groups. The succession is as follows (Fig. 2):

Ballybeg Greywacke Formation: This is correlated with the top of the Bray Group and is over 400m thick. It consists of fine-grained greywacke units up to 0.3m thick, which are interbanded with lesser amounts of laminated siltstones and coarse-grained greywacke.

Ballybeg Pelitic Formation: This unit represents the basal formation of the Ribband Group in the area. Its thickness is estimated as 2.0-2.5km. It is characterized by thinly bedded siltstones. Towards the base of the formation a significant proportion of coticule, i.e. spessartine-rich quartzite, is interbedded in the sequence, while the top of the Formation is characterized by the occurrence of tourmalinites. Beds of greywacke, quartzite and dacitic tuffs also occur.

Kilcarry Volcanic Formation: This is 500m thick and is composed of andesitic lavas, with minor dacitic tuffs near its base.

Monaughrim Semi-Pelite Formation: This, the youngest Formation, belongs to the Ribband Group. It consists of over 250m of semi-pelitic schists and hornfelses with several horizons of finely banded calcareous sandstones.

The sequence in NE Wicklow has been summarized by Brück et al. (1979). The Bray Group (Fig. 2) consists of two formations as follows:—

Bray Head Formation: This Formation (+2500m) is the younger formation and is composed of fine- to coarse-grained greywackes which may be green or purple in colour. Quartz arenite beds and sedimentary structures are common.

Devil's Glen Formation: This older Formation is 2000m thick and comprises fine- to coarse-grained greywackes. Sedimentary structures are not common.

The Ribband Group has been divided into three formations (Brück et al., 1979) as follows (Fig. 2):

Maulin Formation: The oldest of the three formations, this consists of 900m of mainly grey slates, phyllites and quartzites with abundant coticule laminae.

Sleamaine Formation: This Formation is 650m thick and comprises a sequence of grey laminated siltstones and slates.

Glencullen River Formation: This Formation is 500m thick, it is composed mainly of acid tuffs and has been dated as Upper Cambrian to Arenig in age. This is the youngest of the three Formations.

Lithological comparison allows a partial correlation of the two sequences (McArdle, 1981 and Fig. 2). The Ballybeg Pelitic Formation is here correlated with the Maulin and Sleamaine Formations, and the Glencullen River Formation is regarded as the correlative of the Kilcarry Volcanic Formation. The Ballybeg Greywacke Formation is correlated with the Bray Head Formation. It has not been possible to establish a correlative of the Monaughrim Semi-Pelite Formation elsewhere in this region.

Structure and plutonism

During the Caledonian orogeny the rocks of this region suffered polyphase deformation. The overall structural pattern as now displayed was determined during the two (D1 and D2) initial phases. During the D1 phase, a slaty cleavage was developed as were associated minor structures typical of the Caledonides of SE Ireland (e.g. see Sanderson et al., 1980). A major structural zone of intense strain, here called the East Carlow Deformation Zone (Fig. 1) formed during the D2 phase, and is considered to be a major geotectonic element in SE Ireland. Later deformation phases (D3 and D4) include outcrop-scale fold structures and large scale faults which had a less significant impact on the structural development of the region.

The structural geometry of the Caledonides of SE Ireland has been described as being controlled by large scale fold structures (e.g. Gardiner, 1970). An antiformal axis, northwest of the area under consideration, is postulated to lie along the crest-line of the Leinster Granite (Brück et al., 1979). The axis of the Wicklow Syncline (Gardiner, 1970) is considered to pass to the southeast of the same area. Both postulated structures trend northeasterly and on a regional scale would be approximately parallel to the regional D1 cleavage. However there is noticeable divergence between cleavage trend and the postulated fold axes in many areas. In NE Wicklow, the contact between the Ribband and Bray Groups is marked by an extensive thrust which formed in the earliest phase of deformation (Brindley and Millan, 1973; Brück and Reeves, 1976).

The East Carlow Deformation Zone, a newly recognized tectonic zone (McArdle, 1984), is developed along the eastern margin of Unit 4 of the Leinster Granite, and extends for at least 40km (Fig. 1). It is a ductile zone which cuts across both metamorphic and intrusive rocks. Deformation along the zone occurred mainly during D2 and coincided broadly with the emplacement of the Leinster Granite. The zone has a simple curvilinear morphology and is up to 3km wide. Within it, the S1 cleavage was thoroughly reworked. Synkinematic growth of amphibolite facies minerals within the contact aureole of the Leinster Granite occurred during the development of a second cleavage.

A suite of minor granitic intrusions was emplaced along the line of the Deformation Zone immediately prior to its development. These intrusions comprise coarse-grained equigranular Type 2 granite (Brindley, 1954; Brück and O'Connor, 1977) in the area SW of Shillelagh, and fine-grained Type 1 granite in the Aughrim-Tinahely area. At approximately the same time a swarm of appinites and lamprophyres, centred on the Deformation Zone, were emplaced (Brindley, 1970; McArdle, 1974).

The main Leinster Granite (e.g. Brindley, 1973) is a multiple intrusion which consists of five broadly contemporaneous dome-like plutons which are aligned in a NNE direction. Their western contacts are steep in contrast to the moderate dips along the eastern margin. Individual plutons are concordant with the country rocks along the flanks but are sharply discordant at the terminations. The batholith is late Silurian to early Devonian in age (O'Connor and Brück, 1978) and may have been emplaced in a major shear zone (Brindley, 1973; Cooper and Brück, 1983).

Veins in the Leinster Granite

Galena-sphalerite bearing veins occur along the eastern margin of Units 1, 3 and 5 of the Leinster Granite (Williams

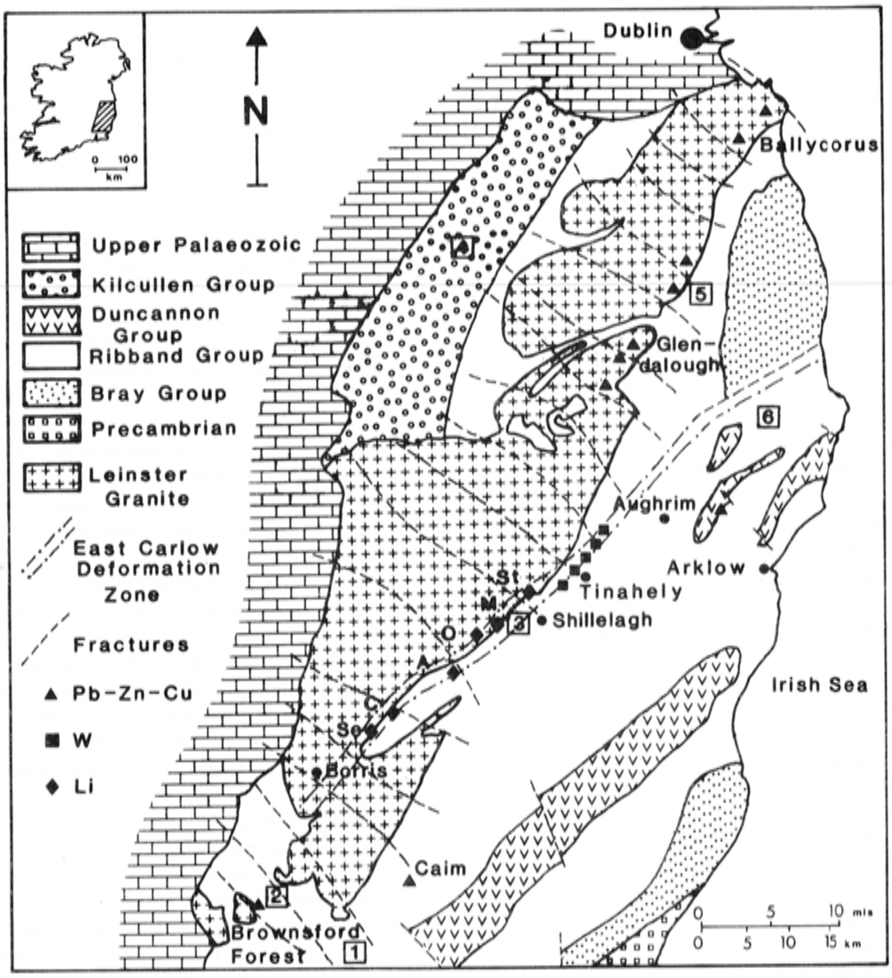

Figure 1. Geological setting of mineralization associated with the Leinster Granite. Individual granite units are numbered as in Brindley (1973). Fractures transecting the granite are shown as in Brück and O'Connor (1980). St=Stranakelly; M=Moylisha; O=Orchard; A=Aclare House; C=Coolasnaghta; S=Seskinamadra. Numbers in square frames indicate generalized locations for sections shown in Figure 2.

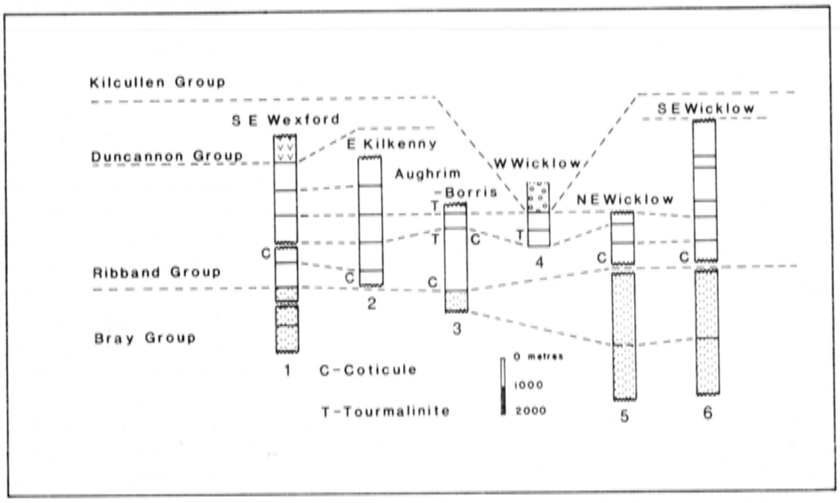

Figure 2. A correlation of the Ribband and Bray Group successions in the region of the Leinster Granite. The stratigraphic positions of coticule- and tourmalinite-bearing horizons are indicated. The stratigraphic columns and the thicknesses of the various formations here not named are based on those given in Brück et al. (1979) and McArdle (1981). The numbers below each section refer to the numbered locations shown in Figure 1.

and Kennan, 1983 and Fig. 1). They are found only in areas where coticule (Fig. 4) and/or tourmalinite rocks occur in the aureole rocks.

The veins on the Unit 1 margin are broadly similar in nature, in orientation and in thickness (maximum 1.8m). The best examples are at Ballycorus where two veins were worked. Both veins strike NW but one dips to the NE while the other dips to the SW. They are hosted mostly by granite but extend some metres into mica schist beyond the contact.

A large number of galena-sphalerite veins were worked in the Glendalough area of Unit 3 (Fig. 1). The orientations of veins and the scale of their development are shown in Figure 3. The Rupla Lode at Glendasan has a strike length of 3km and a width of 1m. Other veins have thicknesses of up to 12m but are less extensive. The single lode at Brownsford Forest, SW of Unit 5, is 1.5m thick.

Deposition of the sulphide minerals in all areas occurred during and following several episodes of explosive brecciation (Williams, 1984). Sulphide veins often formed on re-opened fractures originally filled by aplite and pegmatite. The major sulphides are galena and sphalerite, and they have undergone both ductile and brittle deformation. Quartz, calcite and barytes form the gangue minerals, and chalcopyrite and pyrite occur in minor amounts. Sericitic alteration preceded deposition of sphalerite and galena; argillic alteration occurred after ore deposition, and alteration is more extensive in the hangingwall in every case.

Sulphur, carbon and oxygen isotopic studies of the ore minerals indicate that the sulphides in Unit 1 were deposited at a temperature of about 500°C, those of Unit 3 at about 250°C and those of Unit 5 at probably less than 200°C (Williams and Kennan, 1983; Williams 1984). Carbon and oxygen isotope data suggest the involvement of formation or meteoric water derived from the aureole rocks in the hydrothermal mineralizing system (Williams, 1984). A component of magmatically equilibrated carbon or oxygen would not be incompatible with the data.

In Unit 5, a low temperature of deposition for the single vein at Brownsford is suggested by the absence both of wall rock alteration and of significant quantities of quartz. On the other hand replacement of wall rock in Unit 1 and of sulphides in Unit 3 is consistent with deposition above 250°C; this is compatible with the isotopic data.

Mineralization is restricted to areas of the Granite margin which are tongued and shallow-dipping. The vein mineralization is associated with hydrothermal explosion breccias which developed along the Granite margin as it cooled. Brecciation is attributed to hydraulic fracturing followed by collapse brecciation in some veins (Williams, 1984). Breccias may have developed from altered minor shear zones as water was channelled by convective circulation into the Granite.

Tungsten mineralization

Scheelite mineralization is associated with a swarm of Type 1 granite sheets in the Aughrim-Tinahely area. These narrow granite sheets, emplaced along the S1 cleavage of the country rocks, are concentrated within a zone which is 1km wide and which follows the cleavage trend for approximately 10km. Significant scheelite is confined within, or adjacent to quartz veinlets in greisened parts of these granite sheets.

The dominant wallrock lithology consists of laminated siltstones from the base of the Ballybeg Pelitic Formation. Significant amounts of coticule are present in the local sequence. Greywacke bands are present in the hanging wall rocks, and some psammitic bands occur in the footwall. Coarse-grained pyrrhotite and arsenopyrite are conspicuously developed in the siltstones and semi-pelites. These sulphides occur as minor disseminations controlled by bedding laminae or by the S1 cleavage. Scheelite is locally present and, in metasediments near Tinahely, occurs in quartz segregations which are probably D1 in age.

Significant mineralization at Ballinglen is hosted in a microgranite complex which is no more than 100m wide and can be followed along strike for 5km. Scheelite occurs as grains in quartz veinlets with borders of muscovite greisen or as fine disseminations in the bleached sericitized zones immediately adjacent to these veinlets. The mineralization is characterized by a fluorite-arsenopyrite-pyrrhotite-scheelite assemblage. No consistent pattern of distribution of ore minerals in the mineralized granite has been observed. There is one area of enhanced tin values which Steiger and Bowden (1982) consider to be coincident with an apparent thinning of the main sheet. The mineralogy of the deposit is described in detail by Steiger and Bowden (1982).

There are three regional influences on the siting of the tungsten mineralization. The stratigraphic setting of the wallrocks, belonging to the base of the Ribband Group and containing coticule bands, is the most important. The East Carlow Deformation Zone is another significant control. The presence of granitic sheets is the third influence.

Though traces of scheelite occur in a number of microgranite scheets, significant concentrations are confined to a single zone of sheets. This zone extends parallel to the strike of the local lithostratigraphy, and appears to be confined to a particular part of the Ribband Group sequence. Scheelite mineralization is not known to occur in the main body of the Leinster Granite or in sheets of granite lying closer to the Leinster Granite. The sulphides and the scheelite in the wallrocks are at least partly of D1 or earlier age, and therefore pre-date granite emplacement. These observations suggest that the mineralization originated with the deposition of the host-rock sediments and that subsequent deformation and igneous activity has resulted in some remobilization and concentration.

Lithium mineralization

An extensive development of lithium-bearing (spodumene) pegmatites occurs in the Borris-Shillelagh area (Steiger and von Knorring, 1974; Steiger, 1977; Luecke 1981). The pegmatites occur along the eastern flank of the Granite (Fig. 1) and constitute the only known significant development of lithium minerals in Ireland. Only six of the thirteen recorded occurrences are regarded as significant bedrock deposits, namely those at Stranakelly, Moylisha, Orchard, Aclare House, Coolasnaghta and Seskinnamadra (Fig. 1).

The pegmatites are confined to that part of the East Carlow Deformation Zone which abuts Unit 4 of the Granite (Fig. 1) and which is an along-strike extension of the area which contains the tungsten mineralization described above. The pegmatities are spatially related to aureole granite sheets or to the very margin of the main Granite; no spodumene pegmatities have been recorded within the interior of the batholith in this area. Some small spodumene occurrences hosted in lithium-enriched granite occur near Dublin (Moore-Lewy, 1983).

In the south, the major pegmatities all occur within wallrocks that lie stratigraphically within a few hundred metres of the Kilcarry Volcanic Formation (Fig. 2). In the case of the Stranakelly, Aclare House and Coolasnaghta

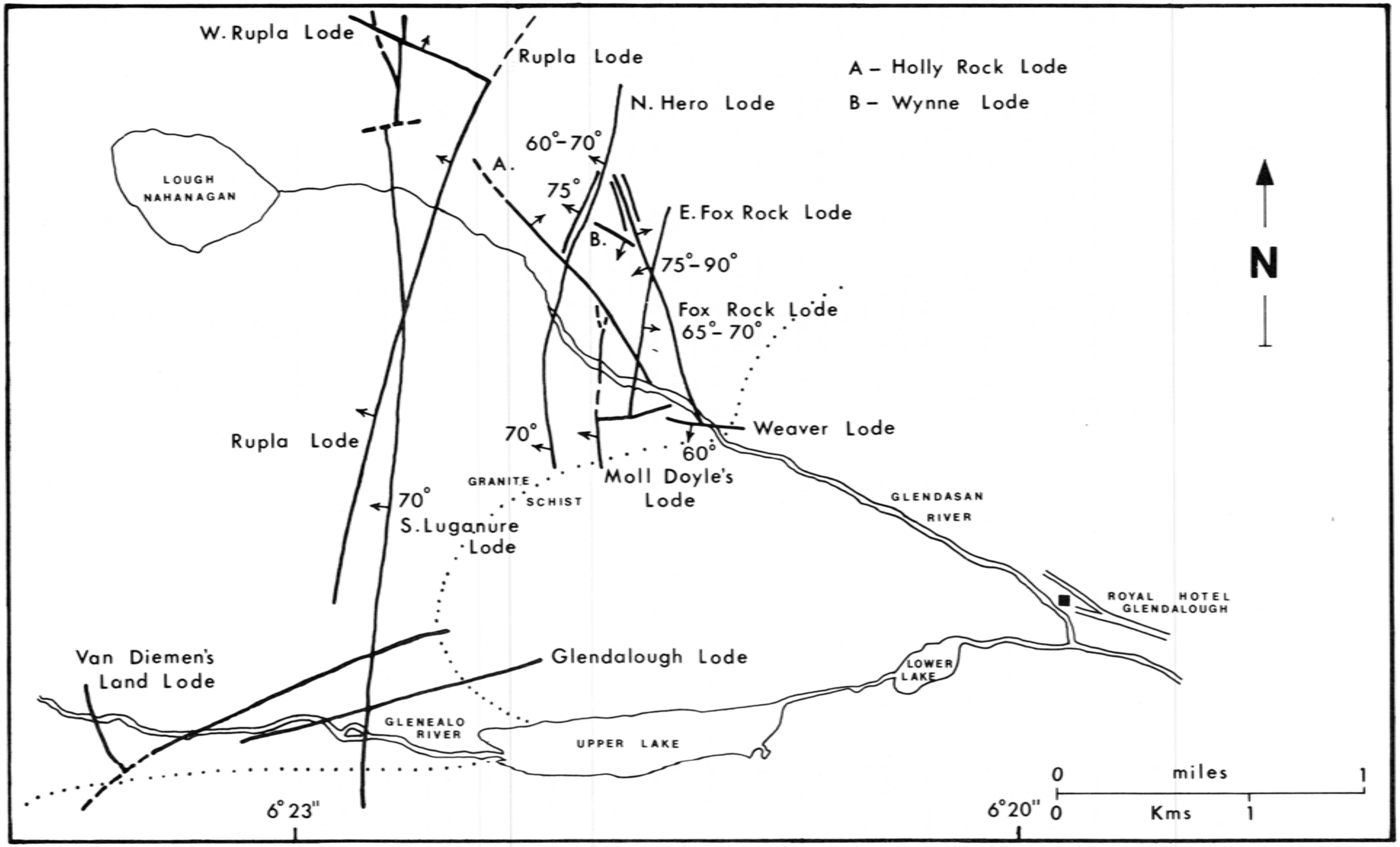

Figure 3. The disposition and scale of worked lead-zinc veins in the Leinster Granite at Glendasan and Glendalough, Co. Wicklow. Partly from Geological Survey records.

deposits, the wallrocks belong to the Ballybeg Pelitic Formation and there is an obvious spatial association with tourmalinites. At Aclare House, laminae and veinlets of pyrite, pyrrhotite and chalcopyrite also occur. At Moylisha, the tourmalinite-bearing wallrocks belong to the Monaughrim Semi-Pelite Formation and lie about 200m above the top of the Kilcarry Volcanic Formation. At Seskinnamadra, the mineralization is at least partly hosted in lavas of the Kilcarry Volcanic Formation near the junction with the schists of the Ballybeg Pelitic Formation.

The spodumene pegmatites are up to 20m thick and individual veins may be traced for up to 400m. Typically the spodumene occurs in a matrix of quartz, albite and microcline. Tin and niobium-tantalum minerals are common accessories (Steiger and von Knorring, 1974). The pegmatites have a grade of 1.6% lithium which is comparable with the pegmatites of other lithium mining districts (Stewart, 1978).

There is a clear spatial association between the spodumene pegmatites and tourmalinites. The latter are typically tourmaline-quartz rocks interbanded with tourmaline-rich mica schist. There is also a clear spatial association of the pegmatites with the Kilcarry Volcanic Formation. The pegmatites are confined to that part of the East Carlow Deformation Zone that falls within the Granite aureole. Surprisingly however, the main Granite itself does not appear to be the essential or dominant control; the lithium pegmatites are confined to one segment of the Granite margin only, are very rare in the Granite interior and the largest and richest examples occur at some distance from the Granite contact.

Age of the mineralization

There is little problem with dating the tungsten and lithium mineralization as being of Caledonian age. The processes involved in their development, such as the development of the Deformation Zone, major pegmatite formation and the emplacement and alteration of microgranite sheets, form integral parts of the Caledonian orogeny.

A Caledonian age for the Pb-Zn veins on the granite margin is implicit in all of the models proposing hydrothermal metal-leaching convection systems initiated by granite intrusion in the aureole (Kennan, 1978; Brück and O'Connor, 1980 and 1982; Williams and Kennan, 1983). Independent objective evidence for a Caledonian age and for the close relation between granite emplacement and mineralization proposed by Tremlett (1959) has proved elusive. Pb isotope model ages (Pockley 1961; Moorbath, 1962) seemed to support the earlier view of Finlayson (1910) that the vein mineralization was Hercynian. The model used to interpret the Pb isotope data makes the ages obtained very uncertain. The possibility of crustal contamination leading to apparent (and erroneous) young ages requires consideration (Wheatley, 1971). The oldest of the spread of calculated Pb ages (that of 390Ma for vein lead from Brownsford Forest at the southern end of the Granite) may be considered a minimum age for the mineralization. Kennan (1974 and 1978) related Pb-Zn-Cu mineral occurrences in the Granite to a suite of hydrothermal alterations in the Granite and, in turn, to a suite of pegmatites identified by their red haematized feldspars. Brück and O'Connor (1980 and 1982) recognized a suite of photo-linears traversing the Granite (Fig. 1) which they interpreted as fracture zones that acted as the plumbing for the hydrothermal mineralizing solutions. Brück and O'Connor (1980) concluded that this fracture system developed primarily during Caledonian times, but that reactivation during Hercynian and/or Tertiary times had also occurred. The possibility that the mineralization was a Hercynian event was resurrected by Halliday and Mitchell (1983, p.12) who noted that, if mineralization was associated with late Caledonian granite emplacement in Ireland, they had not been able to date it using K-Ar methods on clays from ore-gangue-wallrock associations. They obtained ages in the range 248-304Ma which should, as the authors themselves note, be treated as minima for the timing of the ore deposition. Perhaps by relating the haematized pegmatites to undoubted Caledonian structures, e.g. the Granite fabrics and the aureole schistosity, any uncertainty about the age of mineralization can be dispelled. Elsdon and Kennan (1982), using structural observations of the type made by Brindley (1954) and some preliminary probe analyses, concluded that metals, e.g. Zn, became available for incorporation into pegmatite feldspars late in the Granite cooling history and that it would be prudent to treat with caution data which suggest a younger than Caledonian age for the mineralization.

Microprobe analyses (Doyle, 1985) reveal the presence of zinc in aureole minerals, e.g. staurolite and the outer rims of zoned garnets. No zinc has been detected in the cores of these garnets or in garnet that developed prior to granite emplacement. Zinc was mobile in the aureole rocks at the time of intrusion.

Brindley (1957) recognized a series of mineral alterations in the aureole that followed immediately after granite intrusion. These include the replacement of biotite by muscovite, sericite and fibrolite and, by implication, the release of iron, magnesium and any other metals contained in the biotite. Brindley (1957) correlated these alterations with the development of pegmatite dykes within the Granite. Elsdon and Kennan (1982) recognized, in the feldspars of one particular suite of pegmatites, a significant enrichment in manganese, iron, nickel and zinc. Brück and O'Connor (1980 and 1982) regarded those very haematized pegmatites as characteristic of major fractures cutting the intrusion (Fig. 1) and which seem also to be coincident with sites of base metal deposition. The nickel content of the pegmatite feldspars may indicate that these fractures in fact acted as channelways for mineralizing fluids; enhanced nickel is a common feature of the aureole rocks.

Discussion of genesis

The metal deposits associated with the Leinster Granite occur in a number of diverse ways. However, there is a pattern to their development that indicates a common thread if not a genetic relation between them all. That pattern involves three interrelated elements or controls.

The first element is stratigraphical and involves the recurring association between the metal deposits and very distinctive coticule and tourmalinite lithologies which are confined to formations in the lower part of the Ribband Group. The association of base metals with manganese has often been recorded (e.g. Moore, 1971; Freyer and Hutchinson, 1976; Stanton, 1976; Plimer, 1980; Solomon, 1980). The association of sulphide deposits with boron-enriched sediments or tourmalinites is of more recent recognition (e.g. Ethier and Campbell, 1977; Slack 1980 and 1982). Kennan (1978), Slack (1980 and 1982), Williams and Kennan (1983) and Slack and Plimer (1983), among others, have recognised that tourmalinite and/or coticule might be a useful guide to mineralization. The widely recognized spatial association between metals and coticule/

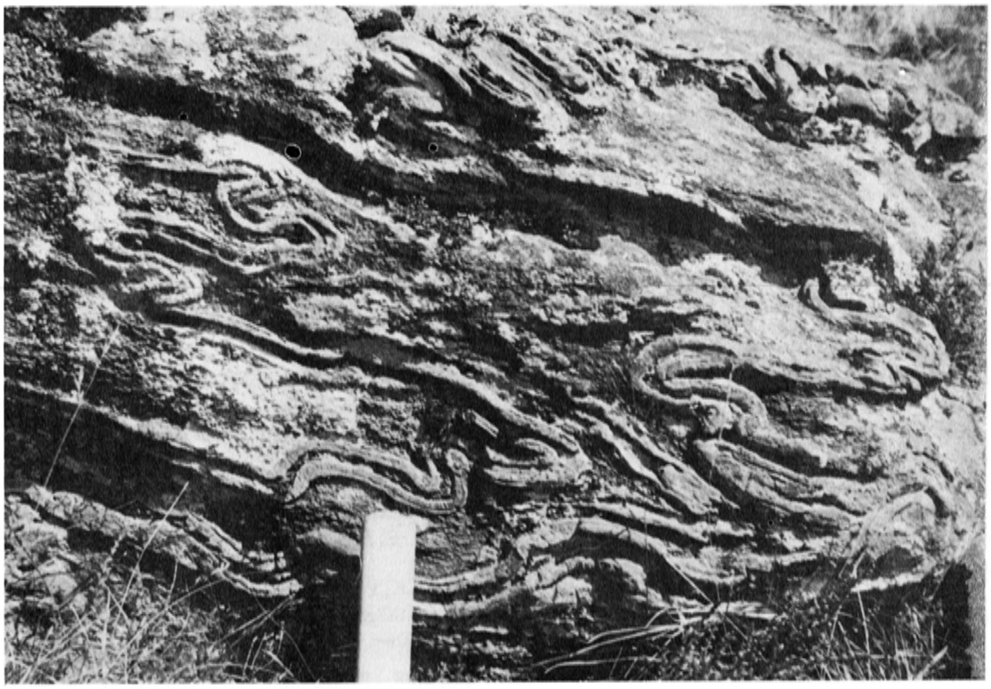

Figure 4. Folded coticule beds; Glendasan, Co. Wicklow.

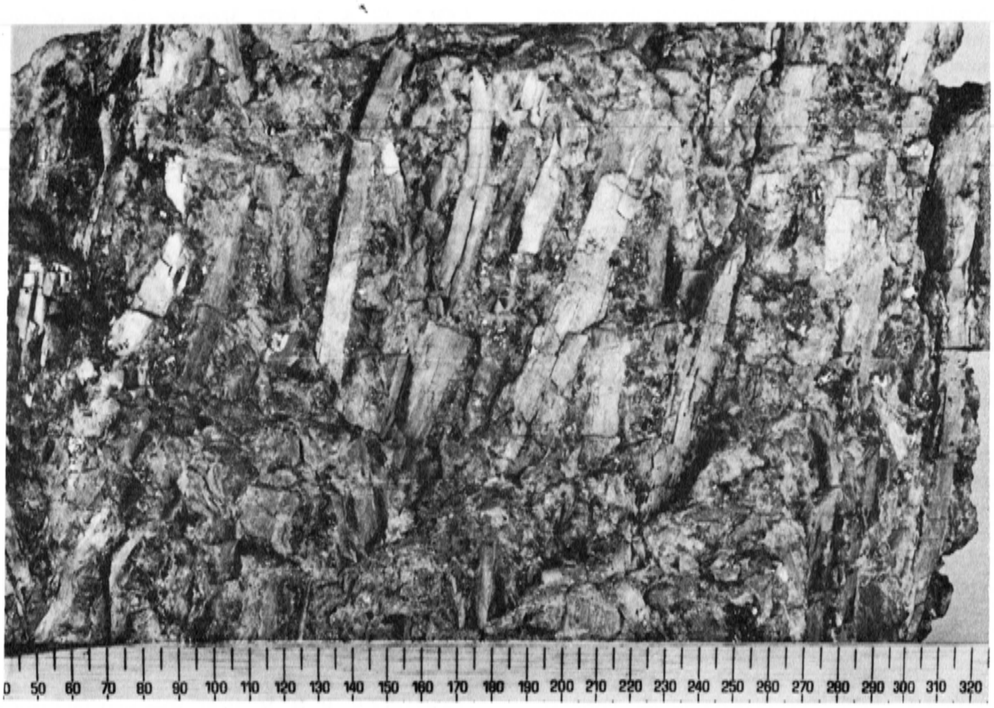

Figure 5. Spodumene pegmatite showing strongly aligned spodumene crystals in a matrix of quartz, mica and K-feldspar. Aclare House, Co. Carlow.

tourmalinite-bearing sequences, an association which is demonstrated by the Ribband Group rocks of Leinster, suggests that there is a close genetic link between the presence of metal and the deposition of the host-sediments.

The second element controlling the siting of mineralization in the Leinster Granite and its aureole is the intrusion of the Granite itself. The Granite did not provide the metals, but rather acted as the source of heat to produce metamorphic reaction and to drive a convective metal-leaching hydrothermal system in the envelope rocks. The base-metal and tungsten deposits are thought to have developed in this way. Base metals transported inwards towards the Granite only penetrated significantly into the Granite where marginal jointing and explosive brecciation occurred, or where major fractures provided deep-going channelways. Only base-metal bearing fluids appear to be moved into and along these fractures. The lithium pegmatites may well have originated in the manner proposed by Stewart (1978) for similar deposits in the Appalachians, i.e. the partial melting of a lithium-rich sedimentary protolith.

The third control, which applied especially in the case of the tungsten and lithium deposits, is tectonic. These tungsten and lithium deposits are all sited along the line of a major zone of deformation where it intersects the granite aureole. The fact that tungsten and lithium occurrences of the same type are not to be found elsewhere along the Granite margin in similar lithologies strongly suggests a causal relationship with this major zone of deformation.

Though research is continuing to improve our understanding of the origin of the various metal deposits, it seems certain that the most significant common factor is a lithological and stratigraphical one. In every instance it can be argued that the metals were originally located in envelope sediments prior to granite emplacement. An exhalative, possibly volcanogenic exhalative, origin for this primary mineralization would also explain the association with coticule (chert?) and tourmalinite. One of us (E.D.) favours a sedimentary exhalative origin.

Thus, a model involving the concentration of dispersed metals contained within Ribband Group sediments by processes related to stress and plutonism is proposed for the deposits associated with the Leinster Granite. The sediments and volcanic host rocks all belong to the lower part of the Ribband Group. The model provides a conceptual basis within which exploration for a wide range of metals in addition to those mentioned explicitly above, e.g. gold and tin, might be pursued.

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Discussion

MARK BENNETT (Dept. of Earth Sciences, The University, Leeds) commented:

1. You have isotopic data indicating the aureole of the Leinster Granite as a potential source of the ore and gangue minerals found in the veins. Is it not more likely that these minerals were derived, to a large extent, from the schists hosting the coticule horizons rather than from the coticules?

2. If, alternatively, one considers the coticules to be metamorphosed manganiferous carbonate-clay mineral sediments, altered tuffs, or even hydrothermal exhalites, would they not provide a more suitable source of metals than the cherty sediment proposed by the authors as the most likely precursor?

REPLY:

1. The aureole rocks do appear to be the source for the ore and gangue minerals found in the veins. The coticule

rock is merely the most distinctive lithology in these aureole rocks. It is the entire package of aureole metasediments that we perceive as a source for the metals at this stage. The mica schists would be especially important in this regard.

2. There is evidence to support all of the options mentioned as possible precursor lithologies for the rocks now identified as coticule. The coticule is but a minor, if very distinctive, lithology in the package of sediments recognized as the likely source of the ore metals. Whatever its exact origin(s), this lithology by itself is unlikely to be the significant source rock — rather it is an indicator.

DR. R. STEIGER (Ennex International PLC) asked:

1. What data is available on the trace element content of coticule rocks of SE Leinster? Can a depletion halo be demonstrated with respect to Pb, Zn, Cu, Li, Sn, Ta, Nb, W and Au?

2. At Ballinglen all granite sheets are mineralized and coticule rocks at best are a minor constituent of the sedimentary pile intruded by these sheets.

3. There is no evidence for NW-trending fractures having any bearing on the emplacement enrichment of either Li or W mineralization.

REPLY:

1. Coticule rocks have been analysed for Sr, Ga, Ba, Nb, Co, Zn, Pb, Ni, Y and Zr. There is evidence that rocks adjacent to the Pb-Zn vein deposits are depleted in Zn and Cu as well as some major and minor elements.

2. Tungsten mineralization is widespread in trace amounts at Ballinglen. However, the most significant mineralization is confined to the vicinity of a single zone of granite sheets. This zone is not the closest to the Leinster Granite contact, and it is parallel to the strike of the local lithostratigraphy.

3. We agree that NW-trending fractures do not appear to have a direct bearing on the occurrence of either Li or W mineralization. However, until proved otherwise, these fractures remain as potential controls on the Pb-Zn mineralization as Brück and O'Connor (1980) originally proposed.