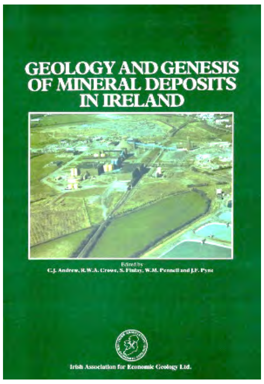

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Controls on mineralization in the Dalradian of Ireland.

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Abstract

The Dalradian Supergroup, a belt of metasedimentary and metaigneous rocks of late Pre-Cambrian to early Palaeozoic age, outcrops in NW Ireland. The sequence is considered to have been deposited in an ensialic basin, marginal to an ocean to the south. The rocks were subjected to polyphase deformation during the Grampian orogeny, with the intrusion of late orogenic granites at the end of the Silurian. Base-metal, tungsten and barite mineralization is mainly hosted in metasedimentary and metavolcanic rocks with known examples occurring at particular stratigraphic horizons.

In Connemara, three styles of mineralization are recognised: (1) stratiform iron-sulphide lenses and disseminations ±Cu ±W ±Mo; (2) granite-associated skarn- and vein-hosted base-metal +W ±Mo; (3) vein-hosted and replacement-type base-metal and barite. Stratiform mineralization in Connemara is mainly confined to the Lakes Marble Formation and is spatially associated with amphibolites. An early volcanic-associated origin is proposed for the iron-rich bodies. Later skarn mineralization adjacent to the granite plutons shows some stratigraphic control and locally is superimposed on the iron-rich bodies. Late post-deformational Pb–Zn veins are the products of the last mineralizing event seen in Connemara.

In Donegal the mineralization is less variable, with Pb+Zn ±Ba occurring either as disseminations and stratiform lenses or as cross-cutting veins. Both styles of mineralization occur predominantly in carbonate facies at particular levels in the stratigraphy. The stratabound Pb–Zn bodies may have been deposited prior to lithification, with vein deposits formed by the remobilization of earlier stratiform concentrations.

While some deposits were worked in the past, all are subeconomic today but genetic models and exploration results from Scotland confirm the attractiveness of Dalradian terrains for base metals and barite, particularly for sediment-hosted deposits.

Introduction

The Dalradian Supergroup (Harris and Pitcher, 1975) consists of metasedimentary and metaigneous rocks of late Pre-Cambrian to early Palaeozoic age. It crops out in extensive tracts of scenic country in Connemara, West Mayo, the Ox Mountains, Donegal, the Sperrin Mountains, Derry, and NE Antrim (Fig. 1). The Dalradian rocks were deformed and metamorphosed during the Grampian Orogeny. Later they were intruded by a variety of plutonic rocks, notably by suites of granites in Donegal and Connemara.

Base-metal, barite and tungsten mineralization is predominantly hosted in metasediments and metavolcanic rocks of the Dalradian, although it frequently shows a spatial relation to granite plutons. This mineralization is the major type known in the Dalradian of Ireland. A variety of lesser deposit types also occur. Porphyry-style mineralization is associated with granite plutons e.g. molybdenum deposits in Connemara (Max and Talbot, this vol.) and greisen-style mineralization such as beryl in Donegal (Burke et al., 1964). Minor chromite occurrences are known from layered ultrabasic rocks in Connemara (Rothstein, 1957) and minor chalcopyrite is present as a common constituent in metabasic intrusive rocks in Donegal. Uranium has recently been discovered in pegmatites in the Main Donegal Granite (O'Connor, this vol.). Finally, gold placers and epigenetic vein-type gold occur within Dalradian terrain (Reeves, 1971; Clifford, this vol.).

Several of the deposits discussed in this paper were mined on a small scale during the last century and the early years of the twentieth century. Mining operations generally concentrated on coarse-grained mineralization, often vein-style, which could be cobbed by hand to give a saleable product. It is unlikely that more than 10 000t of mineralized rock were extracted from any one deposit.

Regional geology

The Dalradian sedimentary and volcanic rocks accumulated in a complex linear basin extending at least 700km from Connemara to the Shetland Islands (Harris and Pitcher, 1975; Harris et al., 1978). This basin is generally considered to have been an essentially ensialic one, marginal to the developing Iapetus Ocean (Harris et al., 1978; Phillips, 1978) but there is evidence for the presence of oceanic crust in the later stages of basin development (Kennedy, 1980; Ryan et al., 1983). Although palaeontological evidence is sparse,lithostratigraphical correlations can be made along the entire belt (Fig.2). A further correlation has been suggested with the Fleur de Lys Supergroup in Newfoundland (Kennedy, 1975).

The basin developed above a stretching and thinning area of continental crust, representing an early phase of Iapetus rifting (Anderton, 1979; Soper and Anderton, 1984). Initially, in Grampian and Appin Group times, basin infilling kept pace with slow subsidence and largely shallow marine sequences were preserved with locally evaporitic conditions.The basin became increasingly unstable during Argyll Group times due to increased stretching rates and heat flow, resulting in synsedimentary growth faulting and the development of second-order basins (Anderton, 1979).

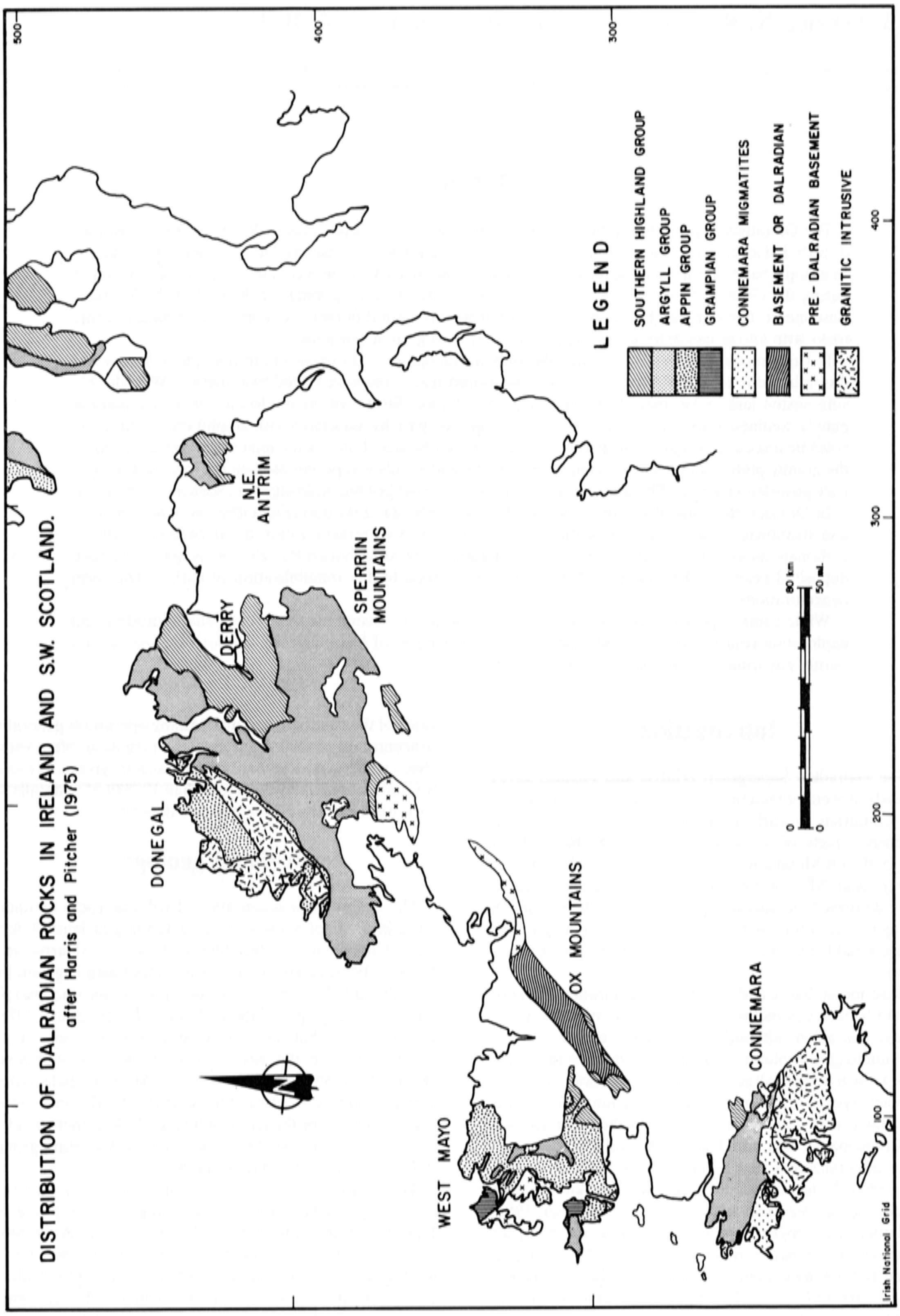


Figure 1. Distribution of Dalradian rocks in Ireland. After Harris and Pitcher (1975).

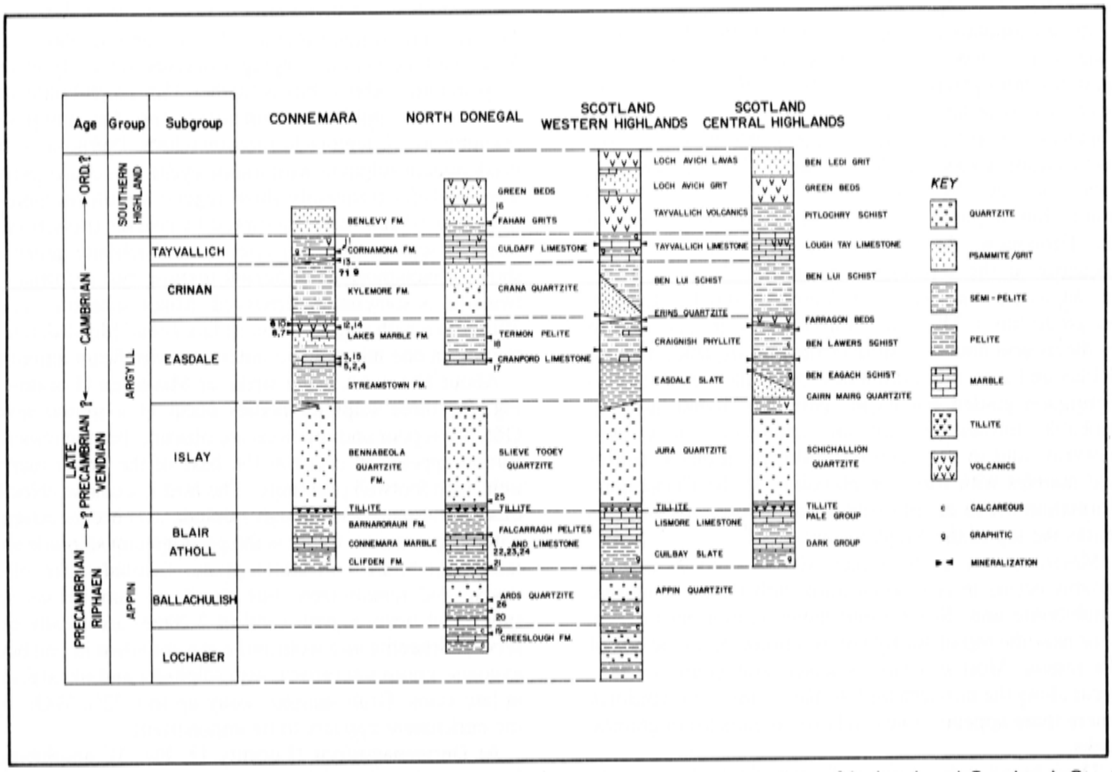


Figure 2. Stratigraphic correlation of mineralized horizons in the Dalradian of Ireland and Scotland. Stratigraphic columns are from Harris and Pitcher (1975) and Harris et al. (1978). The Scottish mineralized localities and their stratigraphic positions are taken from Willan (1980). Stratigraphic thicknesses are not drawn to scale.

Clastic wedges adjacent to rises passed laterally into distal basinal deposits (Harris et al., 1978; Anderton, 1980). By Easdale Subgroup times, hydrothermal systems had developed in Scotland giving rise to exhalative base metal and barite mineralization (Coats et al., 1980; Willan, 1980). This was followed by tholeiitic volcanism and the intrusion of tholeitic sills in the Dalradian pile (Evans and Leake, 1960; Graham, 1976). Basin rifting stopped in early Southern Highland Group times and cooling-related subsidence led to the deposition of a thick greywacke succession (Soper and Anderton, 1984).

Most of the Connemara succession has been correlated with the Argyll Group of Scotland (Fig. 2). In Donegal the Dalradian rocks are disposed in three separate successions whose stratigraphic relations are obscured by tectonism. The Creeslough succession in NW Donegal is structurally overlain by the Kilmacrenan Succession of central Donegal, which in turn is overlain by the northern Lough Foyle Succession. Based on large scale lithological correlations these are broadly assigned to the Appin, Argyll and Southern Highland Groups respectively (Pitcher and Berger, 1972) and these are the subdivisions used in Figures 2 and 4.

The Dalradian pile suffered polyphase deformation and metamorphism in the Cambro-Ordovician Grampian Orogeny (Phillips, 1978). In Donegal the metamorphic grade increases from greenschist facies in the north to amphibolite facies in the south (Pitcher and Berger, 1972). Grade was higher in Connemara with greenschist facies rocks only in the extreme north (Tanner and Shackleton, 1979). The rocks show the effects of intensive stress and generally contain at least one penetrative fabric. Tectonic slides subparallel to bedding and complex refolding patterns are commonly observed (Pitcher and Berger, 1972; Tanner and Shackleton, 1979). Synorogenic basic intrusions were emplaced into Upper Argyll Group sediments at mid-crustal levels. A major episode of late orogenic granite emplacement occurred at the end of the Silurian with relatively high level plutons emplaced in Donegal and Connemara (Leake, 1978).

At a later stage a series of transcurrent faults developed. Examples are the Maam Valley Fault in Connemara and the Leannan Fault in Donegal. Movement along these Faults took place during the Caledonian orogeny. The Faults were probably reactivated in post-Caledonian times.

This paper will discuss examples of mineralization from Connemara and Donegal only, although mineralization is known to be present elsewhere, e.g., in the Grampian Group rocks of West Mayo.

Mineralization

Connemara

Significant known mineralization in Connemara is confined to the Middle Dalradian Argyll Group, the majority of deposits being hosted in the Lakes Marble Formation of the Easdale Subgroup (see Figs. 2 and 3). The Lakes Marble Formation overlies the more monotonous psammites, semipelites and graphitic pelites of the Streamstown Formation. Its base is defined by a widespread thick marble and calc-psammite unit which passes upwards into a sequence with psammites, quartzites and minor thin pelites. A second thinner and less widely developed marble horizon occurs near the top of the Formation and is overlain by a striped amphibolite unit. Several amphibolitic bands, ranging up to 10m thick, are interbanded with marble and quartzite throughout the Formation. Field relations,chemistry, and correlation with similar rocks in the Central Highlands of Scotland (Fig. 2) suggest that these are basic metavolcanic rocks of tholeiitic affinity (Evans and Leake, 1960; Graham, 1976; Max and Long, 1979). Although minor thin amphibolite horizons occur at lower levels in the Formation, the development of a thick persistent sequence at the top, especially in the NE part of the region, suggests a significant volcanic event in late Easdale Subgroup times. The Lakes Marble Formation is overlain by the monotonous Kylemore Formation sequence of semipelites and rare thin psammites. At higher levels in this Formation graded and locally pebbly psammite units of probable turbiditic origin are abundant. These pass upwards, and in part laterally, into the graphitic pelites and marbles with minor amphibolites of the Cornamona Formation which are of probable deep water origin. This marks the top of the Argyll Group.

Mineralization in the Lakes Marble Formation most notably occurs in close association with the metavolcanic amphibolite unit. Stratabound mineralization also occurs at or near the top of the Kylemore Formation in the NE of the region. Most deposits, whether stratabound or not, occur along the northern limb of the Connemara Antiform where there appears to be a relative abundance of granitic rocks.

Three broad styles of mineralization can be recognised:

Type I — Iron sulphide-dominated stratabound sulphide lenses and disseminations with low grade copper mineralization, and locally with tungsten and molybdenum enrichment,

Type II — Granite-associated skarn and vein-hosted base metal and tungsten mineralization,

Type III — Vein-hosted and replacement-type base metal and barite mineralization.

Type I: Pyrrhotite/pyrite-dominated sulphide lenses and disseminations occur stratabound near the top of the Lakes Marble Formation over a strike length of at least 30km in the region west of the NW part of Lough Corrib. Similar bodies occur near the top of the Kylemore Formation on the Doorus peninsula on the north side of Lough Corrib (Fig. 3). They were mined at several localities for pyrite and copper. Although many occur in close proximity to the Oughterard Granite and are affected by it, there is no primary spatial or genetic relation between them.

The Lakes Marble Formation deposits are closely associated with the metavolcanic amphibolite unit. The bodies are stratabound, up to 200m long and 6m wide, and appear to be lensoid. Elsewhere the horizon is often marked by abundant disseminated and locally laminated iron sulphides within metasediments or, with minor chalcopyrite, in amphibolite. Sulphide forms up to 80% of the more massive bodies, pyrrhotite generally being dominant over pyrite, though locally the converse is true. Magnetite and haematite are occasionally abundant; chalcopyrite is ubiquitous in small amounts, with copper generally grading less than 1%. Scheelite, wolframite and molybdenite are present at some localities in small amounts. The sulphide host is generally a calc-silicate, amphibolite or chloritic quartz-feldspar lithology.

At Teernakill (Locality 10, Fig. 3), psammites pass up into a thick 10m amphibolite unit forming the footwall to the sulphide rock which varies in thickness from10m to less than 1m, and contains thin interbedded amphibolites. A 2-3m amphibolite in the hanging wall gives way to about 15m of psammite. Above this a further 15m amphibolite unit has a thinner sulphide horizon near its top. This unit passes abruptly into Kylemore Formation schists. Pyrrhotite is the predominant sulphide with minor pyrite and chalcopyrite. The sulphides frequently show regular stratiform lamination on a 1-5mm scale, disrupted by coarser transgressive sulphide segregations and late veins. Pyrrhotite generally shows a metamorphic annealed texture, but deformation twinning is sometimes preserved. Minor scheelite occurs intergrown with sulphide and in late veins. Molybdenite is present in one mineralized outcrop in significant amounts.

About 6km west along strike at Maumeen (Locality 7, Fig. 3), three sulphide bodies occur at a similar level. Outcrop is poor and relations are obscure, but the mineralization appears to occur at the base of the upper marble unit, with footwall psammite. The host is a coarse chloritic quartz-feldspar rock, though sulphide also occurs disseminated in psammite. Pyrite is the predominant sulphide with minor pyrrhotite and chalcopyrite. Sulphides are often coarse and remobilized, but stratiform laminations and spheroidal textures with radii of 2-20mm are locally preserved. Scheelite and wolframite are abundant in one body as coarse grains intergrown with sulphides and silicates and in late veins. Grab samples assay up to 0.72% WO_3, but the enrichment appears to be impersistent.

At Derreenagusfoor (Locality 12, Fig. 3), amphibolite forms the hanging and footwalls to the sulphide body. Pyrrhotite appears to be the principal sulphide phase but is largely replaced by pyrite. This may be a granite-related alteration associated with the development of coarse garnet-diopside skarn in regional fine-grained calc-psammite and amphibolite.

In NE Connemara on the Doorus peninsula, pyrrhotite-amphibolite pods outcrop over a strike length of 3km, near the top of the Kylemore Formation. Regionally the footwall sequence contains a distinctive banded quartzite horizon (4-12m thick), consisting of quartz laminae and beds 4-5mm thick, interbedded with garnet-rich pelitic schist. It is overlain by about 80m of mica schist before it passes abruptly into the amphibolite-pyrrhotite rock. At Doorus (Locality 13, Fig.3), where the unit is best exposed and where 4 drillholes provide additional information, pyrrhotite-pyrite represents 50-80% of the rock and contains minor chalcopyrite (copper grades in general do not exceed 0.5%). No tungsten or molybdenum minerals have been recorded. The rock is generally coarse-grained and recrystallized with no original texture preserved. A crude banding parallel to the schistosity can be recognized.

The mineralization decreases towards the top of the amphibolite, and the unit is succeeded by thin marbles and black to dark grey graphitic schist, although marbles are sometimes present within the amphibolite. The marble varies from a white crystalline medium-grained equigranular marble to a massive fine-grained light green chloritic calcareous rock. Minor sulphides (less than 20%) occur as disseminations in the marbles and graphitic schists.

Structurally the sequence is complicated by two intense deformation phases which have resulted in large-scale boudinage of the pyrrhotite-amphibolite bodies. The graphitic schist is generally sheared but the overall sequence is preserved wherever the contacts are seen in the drillhole section. This graphitic schist is overlain by mica schists of the Kylemore Formation and these pass up into the graphitic schists of the Cornamona Formation.

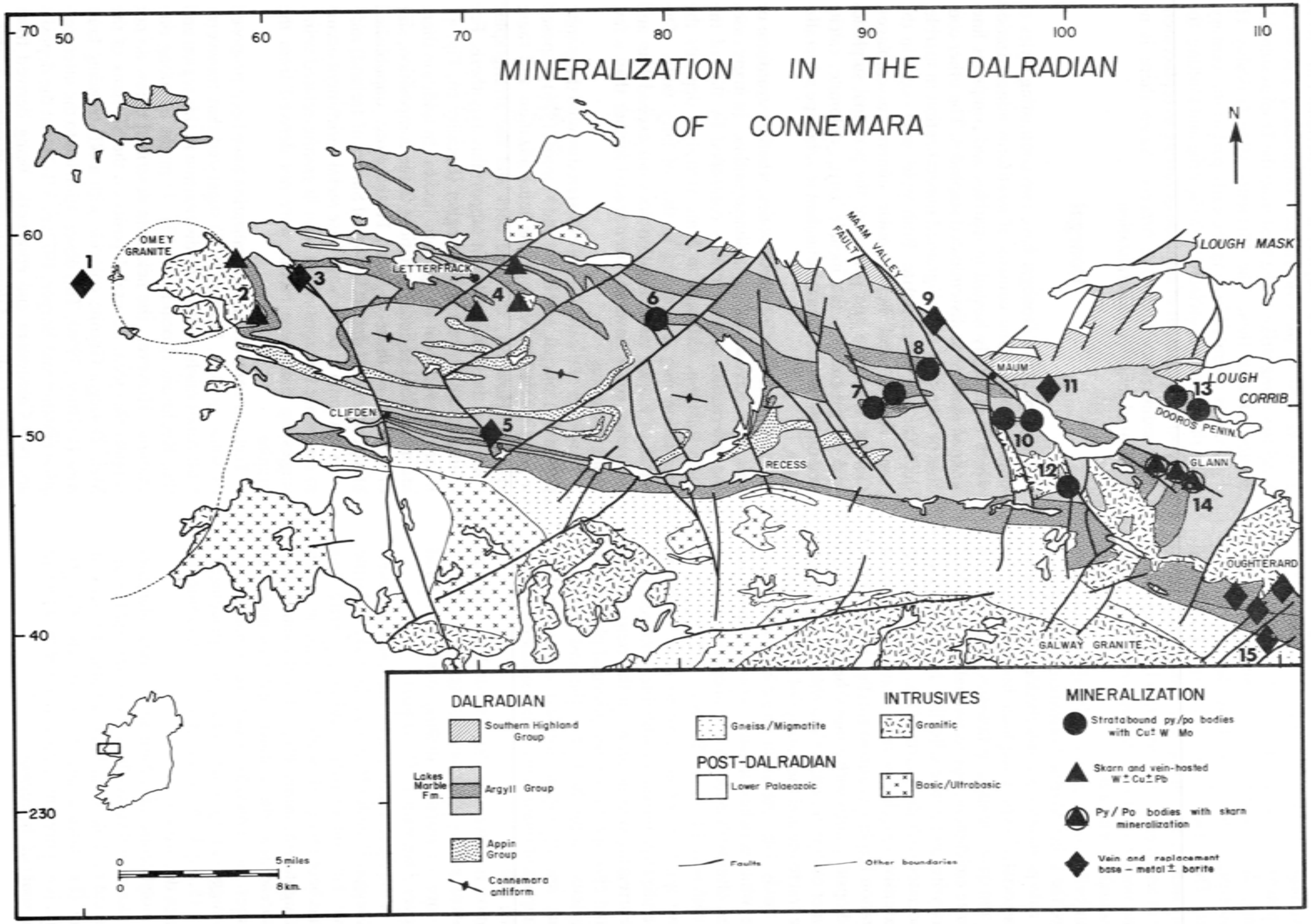


Figure 3. Distribution of Dalradian-hosted deposits in Connemara. The numbered localities are as follows (grid references in brackets): 1. High Island (L 507575). 2. Omey Granite deposits. 3. Cleggan (L 614575). 4. Letterfrack Granite deposits. 5. Derrylea Lough (L 714495). 6. Benbaun (L 785539). 7. Maumean (L 907505). 8. Cur (L 935533). 9. Kilmeelickin (L 933554). 10. Teernakill (L 985505 — L 971505). 11. Clements Mine (L 993518). 12. Dereenagusfoor (M 004471). 13. Doorus (M 049520 — M 078505). 14. Glan area (M 035485 — M 090467). 15. Oughterard area (M 074416 — M 113427).

Type II: Skarn and vein-hosted base metal/scheelite mineralization occurs for approximately 3km along strike in the Lakes Marble Formation of the Glan area (Locality 14, Fig. 3), south of the west end of Lough Corrib. The main area of the Oughterard Granite outcrop lies about 2km to the south, but several smaller granite pods occur in the intervening area. The Oughterard Granite has a remarkably patchy and irregular outcrop pattern in the metasediments, down to the scale of small veins and patches. It is typically fine-grained and leucocratic, and locally aplitic. These factors, together with geophysical data, probably indicate that the present outcrop represents the exposure of an irregular roof zone to a larger and more regular granite body at depth, extending northwards under the Glan area and Lough Corrib.

In the Glan belt, massive granite-related quartz veining cuts the top of the Lakes Marble Formation where impure marbles and calc-psammites are interbedded with amphibolites. An associated Type I sulphidic horizon occurs in amphibolitic and quartz-feldspar lithologies, generally with only weak pyrite enrichment, but occasionally with massive pyrite, chalcopyrite, and minor scheelite. Intense metasomatism is associated with the quartz dykes, with the development of extensive scheelite-bearing skarns. In areas of greatest alteration bedding is almost totally obscured. Primary garnet-diopside skarns with minor scheelite are partly replaced by later carbonate, quartz and chlorite associated with intensive fracturing and the passage of lower temperature hydrous fluids. This alteration phase has more abundant scheelite, which is richest in late coarse carbonate and quartz patches, often with associated chalcopyrite. Fluorite is associated with scheelite at one locality.

The massive quartz veins are host to more extensive sulphide mineralization and minor scheelite, both generally richest at the irregular vein margins. In the centre of the belt, pyrite and chalcopyrite are the principal phases with very minor galena. Along the belt to the east and west, where veining and alteration are less intense, galena becomes an important phase. Very minor sphalerite occurs throughout the belt.

Mineralization in outcrop is characterized by irregular and impersistent grades. Maximum tungsten grades of 1.19% WO_3 are recorded in drilling over 1.5m, and 1950ppm W over 3.6m with 1.55% copper.

Elsewhere in the Oughterard granite area, skarns developed in the Cleggan Boulder Bed, and the Lakes Marble Formation may have minor pyrite and chalcopyrite, but no scheelite has been recorded. South of the granite, south and west of Oughterard, minor Pb-Zn-Cu-Ba mineralization is widespread near the contact, and was mined at several localities. No mineralized outcrop remains, but spoil samples suggest an epigenetic vein- and replacement-style (Locality 15, Fig.3). No associated tungsten mineralization has been discovered.

Scheelite, molybdenite and base metal mineralization also occurs in skarns and veins where the Omey and Letterfrack Granites cut the Lakes Marble Formation in the west of Connemara (Localities 2 and 4 respectively, Fig. 3). Minor scheelite is also present in the contact of the Galway Granite in the south of the region.

Type III: Small-scale vein-hosted mineralization apparently unrelated to igneous intrusion is widespread on a small scale in the Connemara region, and is often fault-related. The most interesting locality is the Ba-Pb-Zn mineralization at Derrylea Lough, east of Clifden (Locality 5, Fig. 3). Here, conformable barite veins with minor galena are stratabound over 200m of strike in a weakly barium-enriched felsic psammite unit at the base of the Lakes Marble Formation. The mineralization is cut by faults but there is no apparent genetic relation with faulting. There is no associated tungsten mineralization.

Pb-Zn-Cu vein and replacement mineralization occurs near the base of the Cornamona Formation at a series of localities along strike to the west from the Doorus sulphide bodies. One of these, the Clements Mine (Locality 11, Fig.3), was operated here in the early part of this century. Mineralization is associated with shearing and faulting, the greatest development of sulphide occurring as replacement of a sedimentary limestone breccia. Again there is no associated tungsten mineralization.

Donegal

The deposits in Donegal have two contrasting styles of mineralization. One consists of stratiform mineralization which is generally hosted in marbles and comprises fine-grained massive or disseminated sulphides. The other consists of vein-type coarse-grained mineralization in marble, quartzite and metadolerite. Both styles may occur in the same deposit and have similar mineral assemblages. Galena, sphalerite and pyrite are the principal sulphides and the gangue minerals include barite, dolomite, calcite and quartz. Barite is more abundant in vein-type mineralization.

All the known mineralized zones, whether stratiform or vein-style, have a simple planilinear outline. In many cases the orientation of the zone is controlled by that of the main foliation, although in some vein-style deposits the orientation may be related to that of later faults. The width of known mineralization does not exceed 10m and individual zones have not been traced further than a few hundred metres.

A number of the deposits are clustered around the granite plutons in Donegal, and Evans and Maroof (1976) proposed a genetic relation between the mineralization and these granites. However, the field data and the stratigraphic control on the deposits do not support this hypothesis. For example, the deposit at Glentogher (Locality 16, Fig. 4), is far removed from any granitic bodies. In addition there are no obvious regional variations in the composition, size or textures of these deposits. Furthermore, unpublished lithogeochemical data (Geological Survey of Ireland) indicates that on a regional scale base metal enrichment occurs in carbonate horizons rather than in granite-related veins, suggesting that these metals were not derived from the granite.

Tectonic controls on mineralization have been proposed by some authors. Horne (1975) suggested that transverse fault zones might control the distribution in this region and that Keeldrum (Locality 26, Fig. 4) might lie along one example. However, the field data described below do not support this idea. Several deposits on the SE flank of the Main Donegal Granite coincide with a NE-trending fault zone (O Brien, 1958). This observation led to the interpretation (Pitcher and Berger, 1972; p. 371-2) that the deposits are post-Caledonian and epigenetic, being derived from depth along faults and deposited preferentially in marbles. The interpretation was supported by the presence of vein-style mineralization and their apparently Hercynian age as indicated by lead-isotope studies (Pockley, 1961). However the preference of mineralization for marbles of specific lithostratigraphic levels, the presence of stratiform sulphides and the relative absence of epigenetic mineralization

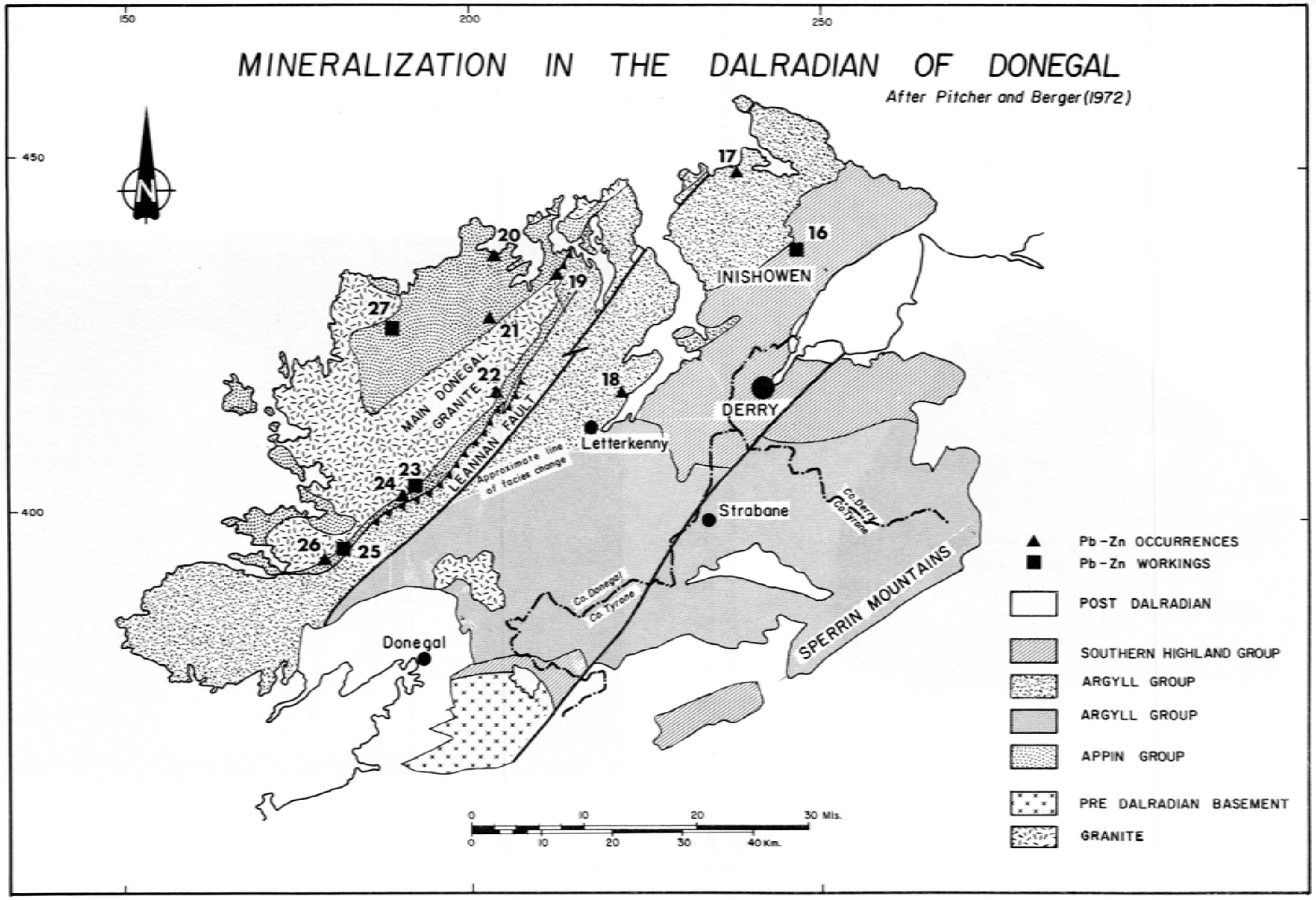
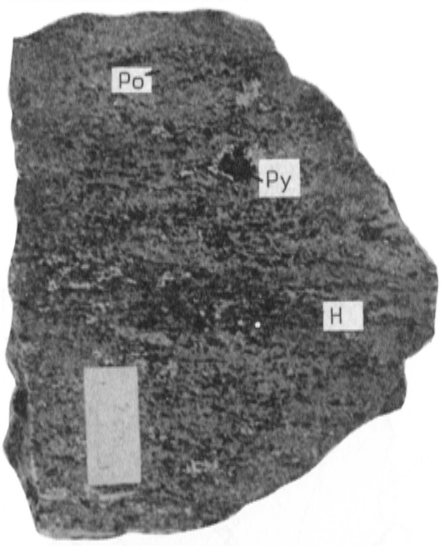
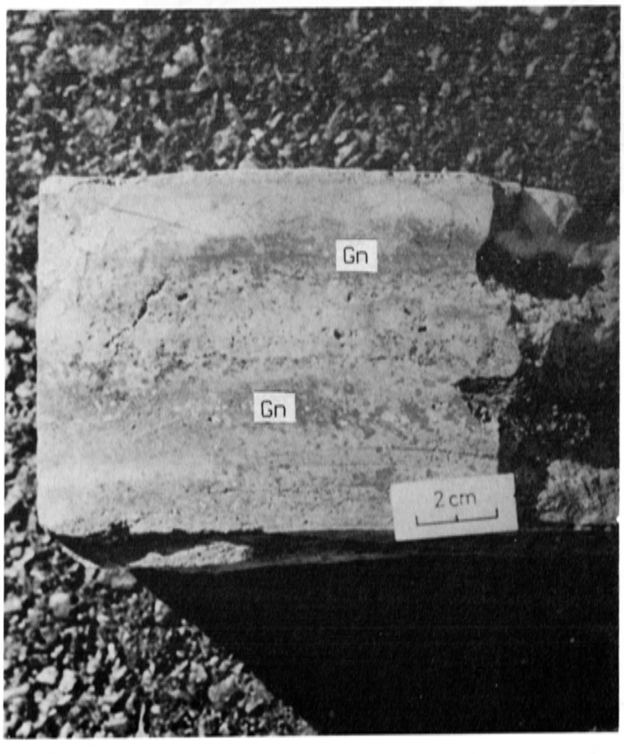


Figure 4. Distribution of Dalradian-hosted deposits in Donegal. The numbered localities are as follows (grid references in brackets): 16. Glentogher (C 478378). 17. Pollan Bay (C 395505). 18. Castlegrove and Knockybrin (C 225155, C 189160). 19. Drumreen (C 136343). 20. Tullaghobegley (B 936276). 21. Ardaturr (C 042159). 22. Glenaboghil (B 923036). 23. Loughnambraddan (B 911023). 24. Kilrean and Mullantiboyle (G 776917, G 807939). 25. Cronkeeran (G 757886). 26. Keeldrum (B 903262).

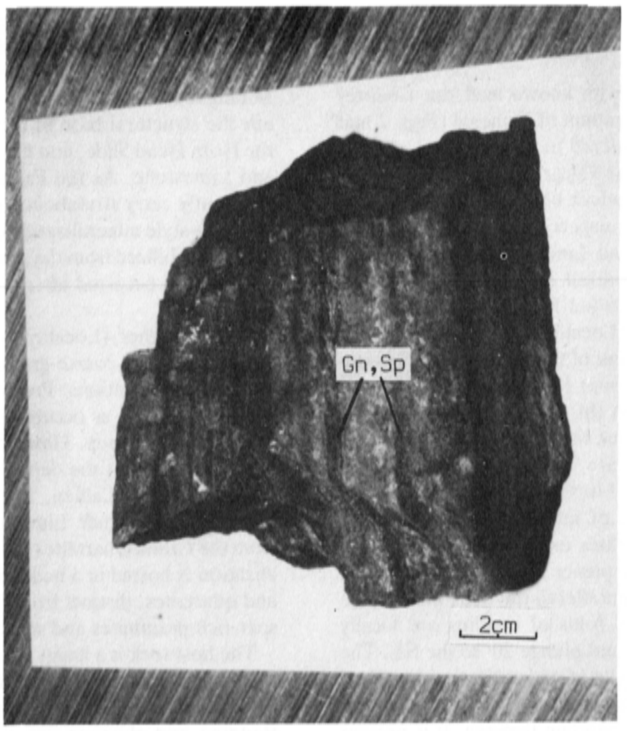


(a) Pyrrhotite-pyrite mineralization from Doorus, Connemara. Massive pyrrhotite (Po) and porphyoblasts of pyrite (Py) set in a foliated matrix of pyrite and hornblende (H).

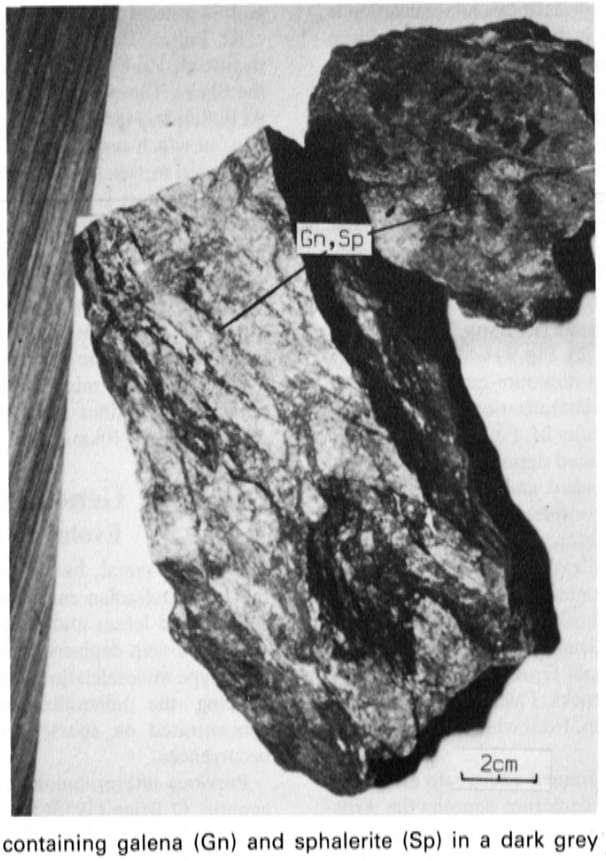


(b) Massive calc-silicate lithology with two bands of coarsely crystalline galena (Gn), Glentogher, Donegal.

Figure 5. Examples of mineralization hosted in the Dalradian.



(c) Stratiform laminae of galena (Gn) and sphalerite (Sp) set in a bedded marble unit. Glenaboghil, Donegal.



(d) Brecciated quartzite containing galena (Gn) and sphalerite (Sp) in a dark grey quartz matrix. Glenaboghil, Donegal.

except in association with stratiform sulphides, all suggest that stratigraphic controls on mineralization were very important.

There are four horizons with known lead-zinc (-barite) mineral deposits in the Dalradian of Donegal (Figs. 2 and 4). Of these, two are considered more important and are described here. These are the Falcarragh Pelites and Limestone and the Fahan Grits, which belong to the Appin and Southern Highland Groups respectively.

The Falcarragh Pelites and Limestone is the principal and most commonly mineralized unit, with a total of at least 10 deposits being recorded in it. The best exposed example is at Glenaboghil (Locality 22, Fig. 4) where the deposit occurs on the SE flank of the Main Donegal Granite. Mineralization occurs about 100m from the contact of the Granite. The Granite at this locality forms a sheeted complex; enclaves of wallrock lithologies, as well as appinite and pegmatite sheets, are interbanded with foliated granite and disposed parallel to the Granite contact. Host rocks comprise a sequence of interbanded calc-silicates, marbles, quartzites, semipelites and amphibolites. These rocks form a concordant sequence along the flank of the Granite and bedding is subparallel to the main penetrative fabric in the rock. Isoclinal folds of bedding are locally present in carbonate bands and plunge 20° to the NE. The deposit illustrates the two styles of mineralization described above. Stratiform mineralization is fine-grained and controlled by cleavage-parallel bedding laminae. It is present in a narrow zone of marble which is 1m wide and can be followed for a few hundred metres. The sulphides are sphalerite and galena, but very little pyrite is present. Veinlets are rare. The hangingwall of this mineralization is a 0.3m quartzite band in which the coarse-grained style of mineralization is well developed. This quartzite contains vein-type sulphide mineralization along cross-joints and in irregular breccia networks. The marked difference in competence between marble and quartzite is here illustrated by the different tectonic styles; the latter form boudins within the ductile, folded marble.

Several other deposits (Fig. 4) have a broadly similar geological setting. Although no mineralization is exposed, it can be seen in debris and shows the same two contrasting styles as at Glenaboghil. The banded marble has sphalerite and galena-rich laminae at Kilrean (Locality 24, Fig. 4) and Loughnambraddan, (Locality 23, Fig. 4) while quartzite at Kilrean has sphalerite-galena-dolomite-quartz vein-style mineralization. Vein-style mineralization in marble is present at Mullantiboyle (Locality 24, Fig. 4). A prominent feature of these carbonate-hosted deposits is that dolomitization is not strongly developed and dolomite is often confined to minor veins. It is considered that the vein-style mineralization, hosted in fracture systems in competent lithologies, formed by remobilization from original stratabound mineralization in carbonates.

The Keeldrum deposit (Locality 26, Fig. 4), situated north of the Main Donegal Granite, occurs at the top of the Ards Quartzite in the Appin Group (Fig.2). This unit structurally overlies younger rocks, Falcarragh Pelites and Limestone of the Appin Group, from which it is separated by a tectonic slide.

The Ards Quartzite is fine-grained and cream or buff in colour. In the vicinity of the Keeldrum deposits the Ards Quartzite is rather massive, and there is a spaced cleavage which is weakly marked and dips gently eastwards. The mineralization is preferentially hosted in fractured quartzite, as well as in metadolerite. Galena-pyrite-barite-quartz is the typical mineral assemblage of the deposit. It consists of two veins occupying steeply disposed fractures which trend easterly. There is considerable jointing, often limonite-stained, and minor quartz veinlets which are often vuggy. Mining records indicate that mineralization extended beneath the structural base of the Ards Quartzite, marked by the Horn Head Slide, into the underlying Falcarragh Pelites and Limestone. As the Falcarragh Pelites and Limestone frequently carry stratabound mineralization, the cross-cutting vein-style mineralization could be interpreted as having been remobilized from the stratabound host along late stage faults which occurred after movement ceased on the Horn Head Slide.

At Glentogher, (Locality 16, Fig. 4) sphalerite and galena occur as massive coarse-grained bands and irregular cross-cutting disseminations. Previously this mineralization had been interpreted as occurring within the Crana Quartzite of the Argyll Group. However, from regional evidence it is more likely that the deposit is hosted at the base of the Fahan Grits (McCallien, 1935) of the Southern Highland Group. The Culdaff Limestone separates this lithology from the Crana Quartzite (Fig. 2) further north. The mineralization is hosted in a bedded sequence of calc-psammites and quartzites, distinct from the main coarse-grained feldspar-rich psammites and wackes of the Fahan Grits.

The host rock is a flaggy, finely laminated quartzite. Two sheets of metadolerite are interbanded with the quartzite, one of which occurs 1m below the mineralized horizon. Bedding and cleavage are parallel to each other at this locality and they dip steeply either NW or SE. However there are strong variations in trend adjacent to the deposit, presumably due to large-scale folding, and a major cross-fault is present nearby.

At Pollan Bay, (Locality 17, Fig. 4), on Inishowen, stratiform Zn-Fe-Pb has recently been discovered. Here the Slieve Tooey Quartzite is overlain by Termon Pelite. At Pollan Bay this contact is an important zone of deformation, in which remnants of Cranford Limestone facies are preserved as thin lenses of sheared metasediment. Further NE the contact is mylonitized and this facies is not preserved. Within this zone, lenses of calcareous and dolomitic marbles and pelites are mineralized. Weak disseminations and massive bands of sphalerite, galena and pyrite are present. Exposure is sporadic but two localities near the foreshore show massive stratiform sphalerite and pyrite interbanded with the dolomitic marble over 0.5m. Mineralization, including minor barite veins, has been found at a number of localities along this contact to the SW over a strike length of 10km.

Genetic discussion

Evolution of concepts

The base-metal, barite and tungsten mineralization in the Irish Dalradian can be separated into three types — stratabound lenses and disseminations, granite-associated skarn and vein deposits, and epigenetic vein and replacement type mineralization. Most earlier workers, when considering the mineralization in the Dalradian, have concentrated on coarse-grained vein-type deposits and occurrences.

Previous interpretations explained the deposits as epigenetic. O Brien (1958) for example, considered that the deposits SE of the Main Donegal Granite were controlled by a NE-trending late Caledonian fault. Pitcher and Berger (1972) regarded the mineralization as related to post-Carboniferous reactivation of faults, although they recognized the importance of a tectonic slide in controlling mineralization at Keeldrum. Evans and Maroof (1976) argued that the distribution of occurrences in both Connemara and Donegal indicated a relation with the Caledonian granites. Isotopic dating by Pockley (1961) and Moorbath (1962) indicated post-Caledonian ages, but these are likely to be anomalous and as such are unreliable indicators of the age of mineralization (see, for example, Kennan et al., this vol.). McArdle (1978) suggested that the mineralization in Donegal is stratabound at particular levels in the Appin and Argyll Groups of the Dalradian. Williams and McArdle (1978) suggested that many of the Connemara deposits were similarly controlled and that in both areas these could be correlatives of mineralized horizons in Scotland. This correlation has been strengthened by the discovery of the Aberfeldy base-metal and barite deposit in Scotland (Coats et al., 1980) in Argyll Group rocks.

While the stratabound nature of these occurrences has been recognized, very little applied research has been carried out. This compilation reviews previous work and, by reference to specific Dalradian-hosted deposits, it attempts to provide a framework for further research and exploration. Despite the paucity of geological data some general conclusions can be drawn which point to a number of unifying models for the various styles of mineralization.

Stratabound mineralization

Two broad styles of mineralization have been recognized in the Dalradian of Ireland.These are (i) stratabound mineralization in metasediments and metavolcanic rocks, and (ii) skarn-hosted, vein-hosted and replacement style mineralization. In this section the first category, which developed prior to the Grampian orogeny, is discussed.

In Connemara several small stratabound deposits are present in the Lakes Marble and Kylemore Formations. The sulphides occur in, or show a close spatial relation to, metavolcanic amphibolite units. It is considered that these amphibolites are a major control on the occurrence of sulphide deposits in this setting. Although several deposits are closely associated with calcareous horizons, this is not regarded as the primary lithological control; many deposits have no associated marble horizons and at the same time, several carbonate units (including that at the base of the Lakes Marble Formation) do not contain mineralization.

The volcanic association suggests that the mineralization was related to a mid-Argyll Group tholeiitic volcanic event. No volcanic centres have been recognised in Connemara, but the mineralization is interpreted as being associated with localized hydrothermal activity related to volcanism. The sulphides, displaying laminated and colloform textures, seem to have developed on or near the seafloor. Given the predominance of sediments over volcanic rocks, these deposits show similarities to many stratiform Proterozoic sulphide deposits elsewhere in the world (Hutchison, 1983).

The Guaymas Basin in the Gulf of California is an extensional rift-controlled basin which contains a thick sedimentary sequence with some basic lavas and intrusions. In its broad setting it may have some similarities with the Dalradian Basin (Soper and Anderton,1980). It is possible that some of the Dalradian mineral deposits are metamorphosed versions of those found in the Guaymas Basin(e.g. Lonsdale et al.,1984). Recently Höll (1977), Plimer (1980) and others have described a worldwide occurrence of stratabound exhalative deposits which are characterized by tin-tungsten and tungsten-antimony-mercury. The Connemara mineralization shows a number of similarities with many of these deposits.

The stratabound mineral deposits in Donegal are sediment-hosted. Most of the stratiform mineralization occurs in carbonates; the only exception is at Glentogher and here the mineralization is stratigraphically very close to a major marble unit. It is interpreted that these carbonate-hosted lead-zinc deposits are pre-Grampian in age for a number of reasons. Mineralization is largely stratabound at certain stratigraphic horizons over a wide area. Also, many of the deposits have undergone deformation and metamorphism along with their host rocks. Accordingly, the deposits are regarded as having formed during the sedimentary evolution of the Dalradian Basin. Palaeogeographic reconstructions, such as that of Pitcher and Berger (1972, Fig. 1.7) suggest that the deposits developed in a near-shore setting and often in association with facies changes, with turbidite sediments being deposited distal to platform carbonates, particularly during Argyll Group times.

It is suggested that these deposits may represent minor examples of sediment-hosted massive sulphide lead-zinc deposits, as described by Large (1983). These are tabular orebodies with simple sulphide mineralogy and often containing associated barite. They developed in marginal to extensional ensialic sedimentary basins, often with growth faults and tenuous links to volcanic activity. However, it is not possible to characterize the evolution of the Donegal deposits in any more precise way; the possibility of pre-deformational replacement of the host rocks cannot be ruled out as a mechanism of formation for some of the deposits.

The mineralized horizons in Connemara and Donegal can be correlated within a broader stratigraphic framework (Fig. 2). The Easdale Subgroup contains most of the deposits known in the Dalradian, including a major barium-zinc-lead deposit at Aberfeldy in Perthshire. This deposit has been interpreted as sediment-hosted exhalative mineralization, deposited in a local fault-controlled basin (Coats et al., 1980). Only one of the Irish occurrences, Pollan Bay (Locality 17, Fig. 4), is found at about the same stratigraphic level. However, higher in the succession the Lakes Marble Formation in Connemara is at a similar stratigraphic level to the pyritic horizon in Scotland (Willan, 1980). Mineralization in the Lakes Marble Formation is related to volcanic lithologies, while in Scotland the volcanic Farragon Beds overlie an important pyritic horizon associated with minor base-metal concentrations. Thus both mineralized areas show similarities in their geological setting. In addition both contain pyrrhotite and pyrite predominant over base-metal sulphides. Molybdenum is a minor constituent in Scotland, molybdenum and tungsten in Ireland.

Higher in the Argyll Group, in the Tayvallich Subgroup, another mineralized horizon seems to be widespread. However the style varies from an iron-copper-rich mineralization in Connemara to a lead-zinc one in Donegal and Scotland. This contrast in metal composition may suggest a basement control on the evolution of the mineralization, as originally suggested by Williams and McArdle (1978). Alternatively the relatively greater influence of volcanism at this stratigraphic level in Connemara, with its higher heat flow, may have favoured the deposition of iron-copper mineralization.

Facies changes have been identified and related to exhalative deposition of sulphides at Aberfeldy (Coats et al., 1980). Barite is found in shallow-water quartzites and pelites close to the site of exhalation, while galena, sphalerite and pyrite occur in black graphitic pelites in more distal and deeper water. In Donegal, facies changes are also well documented in Easdale Subgroup lithologies (Pitcher and Berger, 1972) and these may be related to growth faulting. In Connemara, the thin volcanic rocks are associated with mineralization. For example the pyrrhotite body at Doorus (Locality 13, Fig. 3) is associated with a restricted amphibolite horizon. Similar deposits could have been generated where intra-basinal faults tapped magma at depth. It may be that such faulting sustained volcanism over a relatively short period which effectively limited the amount of exhalation possible. This could account for the small size of these deposits.

Skarn-hosted and vein-type mineralization

The skarn-hosted and vein-type Dalradian mineralization is largely stratabound at those same stratigraphic horizons which host stratiform mineralization. There is frequently a strong spatial and genetic relation to known early mineralization. It is interpreted that skarn-hosted and vein-type mineralization have developed during Grampian and post-Grampian times through remobilization of the metals present in the original stratiform deposits. The hydrothermal processes responsible for this redistribution are associated with metamorphism, granite emplacement and faulting.

Granite-associated skarn-type tungsten mineralization is best developed around the Oughterard and Omey Granites in Connemara. In the Glan region (Fig. 3) mineralized skarns have formed in a stratabound belt, genetically related to the late-orogenic Oughterard Granite, and confined to the top of the Lakes Marble Formation. The skarn is a typical calcic exoskarn of intermediate copper-tungsten type (Einaudi et al., 1981). The richest mineralization formed in the later lower temperature hydrous stages of skarn development, possibly coinciding with the evolution of a more extensive hydrothermal system around the Granite. The skarns are confined to the same stratigraphic level which shows tungsten enrichment elsewhere in Connemara. This suggests that the granite-related skarn development may have resulted in the redistribution and enrichment of an earlier mineralization, without a significant metalliferous contribution from the granite.

The vein-hosted and replacement-type deposits include veins of any orientation. They usually contain lead,zinc and barium, and are noted for their high silver content. They are found at many stratigraphic levels but are particularly associated with deposits hosted in the Falcarragh Pelites and Limestone in Donegal and the Lakes Marble Formation in Connemara. While the evidence points to a late development for these deposits, their preference for horizons which host stratabound mineralization is notable. Other carbonate horizons in the Dalradian stratigraphy (Fig. 2) do not host this type of mineralization. Southeast of the Main Donegal Granite (Fig. 4), a series of deposits are aligned parallel to NE-trending faults, suggesting an epigenetic development unrelated to the host rocks of the mineralization. However, the geometric relation is not a sufficient line of argument in itself. These faults, now seen as late- or post-orogenic structures, may have developed along growth faults which were active during Dalradian sedimentation.

The authors consider that the controls on mineralization in Dalradian terrain are best discerned through analyses of the sedimentary and orogenic evolution of the Dalradian basin. The early stratiform deposits developed during the sedimentary evolution of the basin and in Scotland seem to have been controlled by palaeotopographic features (Coats et al., 1980). There is evidence that synsedimentary growth faults may have been a significant influence on the location of these features and, given their possible relation to later tectonic events (Soper and Anderton, 1984), may well form a link between the development of stratiform deposits and the processes which subsequently reconstituted them during their Grampian and post-Grampian development.

Conclusions

Although the deformational history of the Dalradian has received considerable attention in recent times, relatively little sedimentological work and basin analysis has been focussed on the complex lithostratigraphic sequences of the Supergroup. The recognition of deep-seated fault controls on Dalradian sedimentation in Scotland is supported at present in Ireland only by indirect evidence.Consequently this review, which attempts to explain the context of the stratabound mineralization in terms of an extensional basin model, is tentative. However, a study of the mineralization may contribute to generating a basin model; for example, exploration at Aberfeldy has provided a sufficiently detailed stratigraphy for a basin model to be constructed (Coats et al., 1980; Willan, 1980).

An important conclusion of this review is the recognition that the Dalradian basin forms a metallogenic province.Exhalative and syndiagenetic mineralization is characteristic of certain units which are regarded as favourable for future discoveries. Optimistically, further exploration in the terrain should show the truth of this model with the discovery of significant sediment-hosted mineralization, as has been discovered in Scotland.

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