



IAEG-50



Irish Association for Economic Geology

(founded 1973)

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A. Poustie & Kucha. H



To cite this article: A. Poustie, A. & Kucha, H. (1986) The geological setting, style and petrology of zinc-lead mineralization in the Moyvoughly area, County Westmeath. *In:* Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M., and Pyne, J.F. '*Geology and Genesis of Mineral Deposits in Ireland*', Irish Association for Economic Geology, Dublin. 305-317. DOI:

To link to this article: <https://>

The geological setting, style and petrology of zinc-lead mineralization in the Moyvoughly area, Co. Westmeath.

Anthony Poustie¹ and Henryk Kucha²

1. Ennex International PLC,
162 Clontarf Road,
Dublin 3.

2. The Stanislaw Staszic Academy of Mining and Metallurgy,
Al Mickiewicza 30,
30-059 Krakow,
Poland.

Abstract

The Zn-Pb mineralization at Moyvoughly is hosted within shallow-water carbonates of Courceyan age which are lithostratigraphically equivalent to those hosting the Navan orebody. Cross-cutting and stratiform mineralization textures are developed. Both types show a close spatial relation to faults and fracture zones. It seems probable that these faults and fracture zones provided the permeability pathways for migrating mineralizing fluids to the host carbonates. The local distribution of metals reflects the relative ability of these carbonates to accept mineralization.

Petrological studies indicate that the distribution of mineralization is controlled by, (i) fracture-fill (40%), (ii) replacement (30%), (iii) infilling of primary porosity (15%) and (iv) infilling of space created by dissolution (15%). Replacement of the carbonate host was facilitated by (i) the conversion of aragonite into low Mg-calcite, (ii) the recrystallization of micritic muds and (iii) the presence of some Zn in Fe-calcite cement. It seems likely that the processes of sedimentation and diagenesis, tectonism and mineralization occurred synchronously over an extended period.

Introduction

The Moyvoughly area is located in the heart of the Irish Midlands 6.4km to the NE of the town of Moate (Fig. 1). Zinc-lead mineralization was first discovered in this area in 1968 by Gortdrum Mines Limited, a subsidiary of Northgate Exploration Limited. Following the definition of a strong Zn-Pb geochemical anomaly by a regional soil geochemical survey, Induced Polarization surveying outlined a target area for drill testing which immediately encountered significant zinc-lead mineralization.

The initial drilling programme defined a deposit of about 125 000t grading 8% Zn-Pb.

The mineralization is hosted within a series of shallow-water carbonates (known locally as the Moyvoughly Beds), the lithostratigraphic equivalent of the Lower Pale Beds of the Navan area which are the hosts to the upper lenses of the Navan orebody (Andrew and Ashton, 1982). It is significant, therefore, that the Moyvoughly deposit represents the first discovery of Zn-Pb mineralization within what has been subsequently proven to be the most economically important stratigraphic horizon of the Irish mineral province.

Stratigraphy

The stratigraphic succession in the Moyvoughly area (Fig. 2) is, in general, analogous to that of the Navan area (Andrew and Ashton, 1982; Andrew and Poustie, this vol.; Ashton et al., this vol.).

The Old Red Sandstone (ORS) facies is much thicker than in the Navan area and probably >200m of terrestrial clastics are developed. They comprise grey-green and red shales, siltstones and sandstones with prominent quartz pebble conglomerates.

The first stages of marine transgression are represented by a series of interbanded and laminated shales and calcareous sandstones forming the shale-dominant Ferbane

Mudstone (30-40m) and the sand-dominant Lower Sandy Unit (23-28m). As in the Navan area these tidal flat and lagoonal siliciclastics are overlain by micritic carbonates indicating a high intertidal to supratidal environment. The Micrite Unit (23-33m) in the Moyvoughly area contains a higher proportion of sand and argillaceous material, particularly in its lower and middle sections. Birdseye textures are typically developed in the upper parts.

The overlying Moyvoughly Beds (40-45m) host the main Zn-Pb mineralization. Together with the Micrite Unit and Middle Sandy Unit (20-25m) they are the lithostratigraphic equivalent of the Navan Pale Beds and represent a shallow sub-tidal sedimentary environment. They comprise alternating micrites, sparites (dominantly oolitic), siltstones and sandstones which pass gradationally into the mudstones, siltstones and sandstones of the Middle Sandy Unit. The sandstones probably represent the build-up of sand bars or channel sands.

The Raheen Silty Calcarenite (33-38m) and the Upper Sandy Unit (15-20m) are the equivalent of the Shaly Pales at Navan. Dark argillaceous pelmicrites grade upwards through bioclastic calcareous sandstones and silty shales which become increasingly sandy and pass into massive sandy calcarenites and argillaceous bioclastic calcarenites.

The succession from the base of the Ferbane Mudstone to the top of the Upper Sandy Unit is collectively known as the Navan Group. As at Navan, this succession is overlain by a thick unit of Argillaceous Bioclastic Calcarenite (~250m), and in turn by up to 300m of Waulsortian mud-bank core and flank facies.

Detailed palynological investigations (Keegan, 1980) of samples collected from the basal siliciclastics (Lower Sandy Unit and Ferbane Mudstone) to the top of the Argillaceous Bioclastic Calcarenite indicate that this succession is characterised by palynoflora of the PC and CM Biozones of the Courceyan. The boundary between these zones is located within the Micrite Unit. Conodont studies (Johnston, 1974) indicate that *Pseudopolygnathus multistriatus* has a range

from the middle of the Moyvoughly Beds to the top of the Raheen Silty Calcarenite and that *Polygnathus mehli* sp. is found in the succeeding Argillaceous Bioclastic Calcarenite and Waulsortian Limestone Units. This assemblage demonstrates an upper Courceyan age for this succession.

Structure

ORS rocks comprise the sub-outcropping core of the Moate inlier (Fig. 1) which is developed along the axis of a NE-trending anticline. The overlying basal clastics and carbonates of the Navan Group dip gently to the SE. To the NW the anticline is truncated by the major NE-striking Moate Inlier Boundary Fault, which brings Waulsortian Limestone into contact with the older rocks. The apparent vertical displacement along this structure can exceed 500m.

The deposit is located where the Moyvoughly Beds sub-outcrop in the immediate footwall of the Moate Inlier Boundary Fault.

The detailed structural interpretation in the area of the deposit (Fig. 3) is based on closely spaced drill hole data. For clarity the Moyvoughly Beds have been subdivided into Upper and Lower sub-units with an intermediate thin, but laterally persistent, micritic stratum (the Upper Micrite).

A series of WNW-trending high-angle faults and fracture zones are developed which have apparent normal displacements of 1m to 75m. A prominent E-trending fault, which appears to post-date the WNW structures, is also inferred.

The distribution of Zn-Pb mineralization as outlined on plan (Fig. 4) and section (Fig. 5) shows a close spatial relationship to these structures.

Mineralization

Distribution and macroscopic textures

The Moyvoughly Beds-hosted mineralization exhibits a clearly defined stratabound control, and little significant Zn-Pb mineralization is developed within either the underlying Micrite Unit, the overlying Middle Sandy Unit or the Raheen Silty Calcarenite.

The distribution of mineralization within the Moyvoughly Beds indicates a large degree of lithofacies control. These beds consist of a series of micrites, grainstones, siltstones and sandstones and while any of these lithotypes can be mineralized, especially close to the faults and fracture zones, mineralization is preferentially developed and laterally most persistent within grainstones. Micrites are most poorly mineralized.

Mineralization exhibits both cross-cutting and stratiform textural relationships with the host carbonates. Six main types are recognized:—

1. Veinlets and veins up to 10cm thick contain sphalerite, barite, pyrite and minor calcite and galena. Barite and calcite are usually zoned. Rarely a mineral assemblage of pyrite, tennantite, arsenopyrite and calcite is developed.
2. Mineralization in micrite sections is characterized by stylolites infilled with sphalerite, barite, pyrite, calcite and minor galena.
3. Sphalerite, pyrite and galena can occur as minor disseminations, irregular blebs and clusters of small grains

in all stratigraphic units from the basal siliciclastics (Lower Sandy Unit and Ferbane Mudstone) to the Raheen Silty Calcarenite.

4. Massive sulphides consisting dominantly of sphalerite and pyrite with minor galena may be up to 1.3m thick. They are typical of the highest grade sections. Texturally they are, at least in part, stratiform but thin sections (Plates 1 to 3) illustrate that they were formed by replacement, with the carbonate host-fabric being preserved. Massive sulphides are most commonly developed as replacements of oolitic limestones (Plate 1) close to their contact with argillaceous and micritic sections.
5. Sphalerite can occur as rim cements either forming continuous rims (Plates 3 and 4) or intermixed with Fe-calcite (Plate 4).
6. Mineralized nodules a few millimetres in diameter are composed of sphalerite cements, mixed sulphides, Fe-calcite and baritocalcite. Pyrite nodules, containing minor sphalerite, may be up to 5cm in diameter. The nodular texture is probably due to replacement of primary carbonate nodules.

Mineralogy

Mineralogical data is based on the examination of 50 polished and thin sections. All thin sections were stained with alizarine red and potassium ferricyanide solution.

Rock-forming minerals

Low Mg-Calcite is the most abundant mineral of the carbonate host occurring as allochems (fossils, micritic muds, ooliths and intraclasts) and cements infilling primary pore space and fractures. Allochems and cements deposited above the oxidation/reduction interface were originally Fe-free.

Fe-Calcite is present as zoned cements, infills and replacements of allochems and older Fe-free cements.

High Fe-Calcite infilled any residual porosity after calcite and Fe-calcite cementation. It was also formed during replacement of Fe-calcite by sphalerite, during which the Fe not incorporated into the ZnS lattice was concentrated as a high Fe-Calcite at the replacement boundary. Carbonate relics left inside replacive sphalerite also consist of high Fe-calcite.

Amorphous calcite was produced during the replacement of calcite by sphalerite or barite (Plate 5). It forms irregular patchy rims up to 100 μ m thick, separating original calcite from the replacing mineral. It is optically isotropic and does not stain.

The first dolomites (D1) formed cements and replaced micritic matrix. They are usually Fe-free unless replacing Fe-calcite. Later D2 Fe-dolomite is usually idiomorphic and often zoned, and is typically developed as well-preserved rhombs. This dolomite is often preferentially replaced by sphalerite, suggesting that it may originally have been Zn-bearing. This contention is supported by examples of zoned dolomite in which Fe-rich zones are well preserved while other zones (lower in Fe and presumably higher in Zn) are replaced by sphalerite. Latest D3 dolomites are coarse, baroque, slightly ferroan replacements which post-date sulphides and may locally replace them.

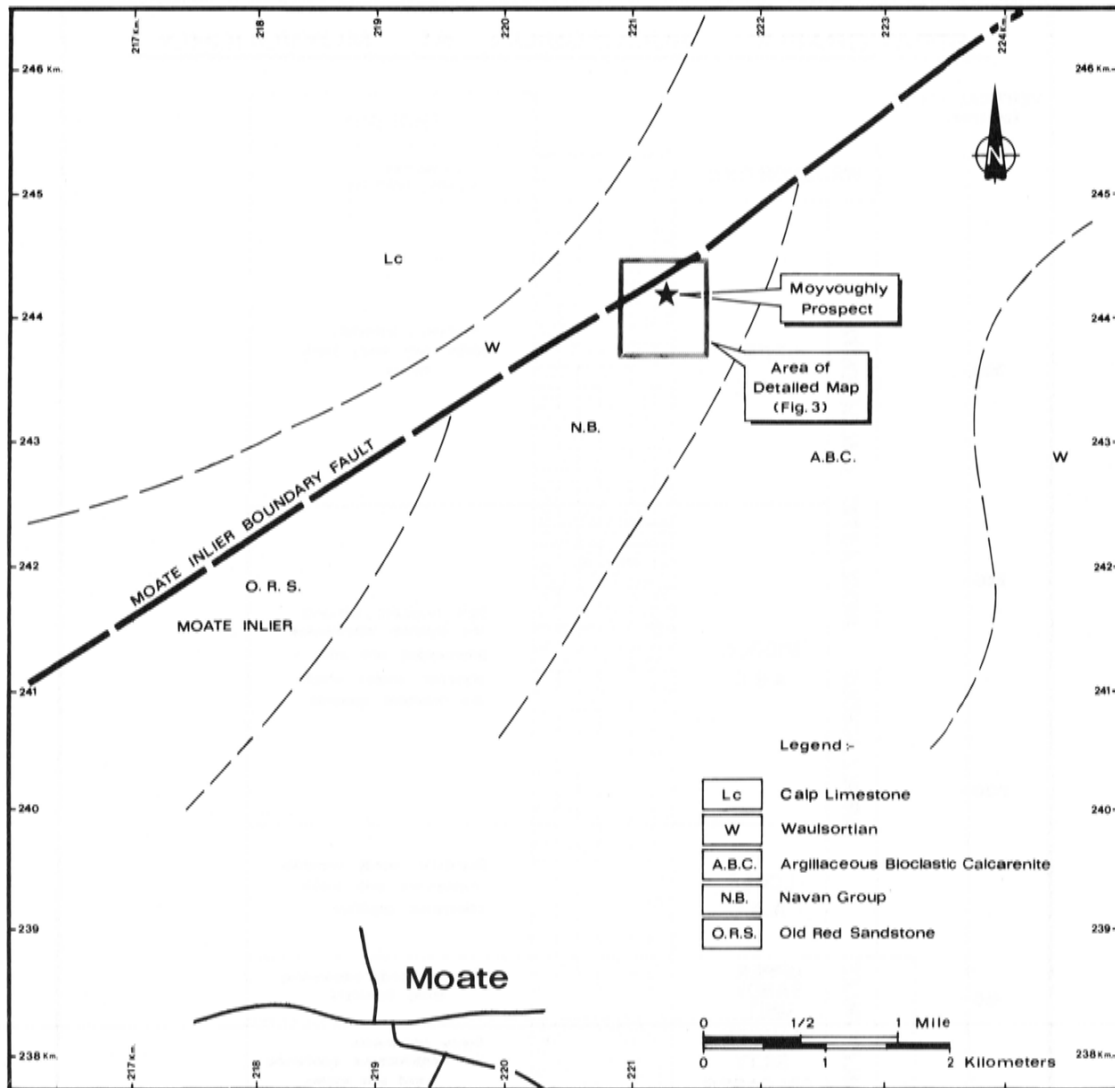


Figure 1. The regional geological setting of the Moyvoughly prospect.

Four separate stages of quartz overgrowths can be distinguished, viz. Q1 containing inclusions of Fe-calcite, Q2 containing inclusions of sericite (Plate 6), Q3 containing inclusions of sphalerite and minor D2 dolomite (Plate 7), and Q4 filling both open spaces generated during the mineralizing process and post-sulphide fractures. In some sandstone sections quartz overgrowths completely seal the rock.

Ore-associated minerals

Sphalerite is by far the most important ore mineral. Four main types of it have been distinguished:—

1. S1 sphalerite is developed as rim cements. It may be pure (Plates 3 and 4) or intergrown with Fe-calcite (Plate 4). Fe-calcite cements and replacements are older than S1 sphalerite indicating that reducing conditions were established prior to sphalerite precipitation. This S1 sphalerite is dark orange in transmitted light.
2. S2 sphalerite forms disseminations and clusters of fine grains, typically together with pyrite, mainly in dark argillaceous sediments. The source of the metal and the sulphur may have been the host sediment itself.
3. The most important type of sphalerite, S3, replaced carbonate allochems and cements and some silica overgrowths. Four different mechanisms of replacement are indicated by microscopic examination:—
 - (a) Sphalerite replacements of Fe-calcite cements are preferentially developed in zones which are inferred to have been originally Zn-bearing. During this replacement surplus Fe was concentrated as inclusions of high Fe-calcite within the replacement sphalerite (Plate 4).
 - (b) Bioclasts consisting originally of metal-free calcite or aragonite were replaced initially by Fe-calcite and then by an irregular zone of amorphous calcite which was finally replaced by sphalerite or barite (Plate 5).

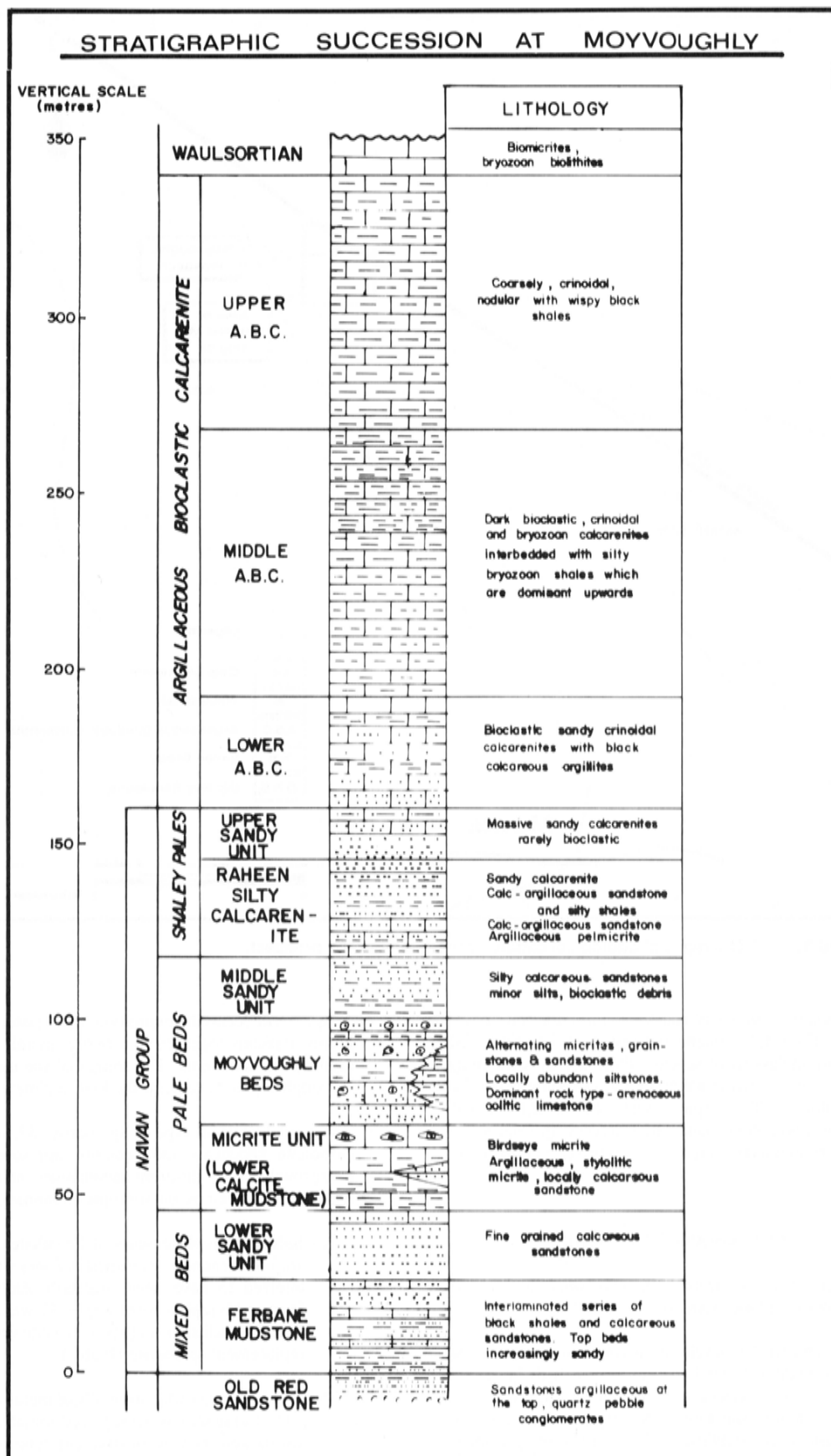


Figure 2. Courcean lithostratigraphy of the Moyvoughly area.

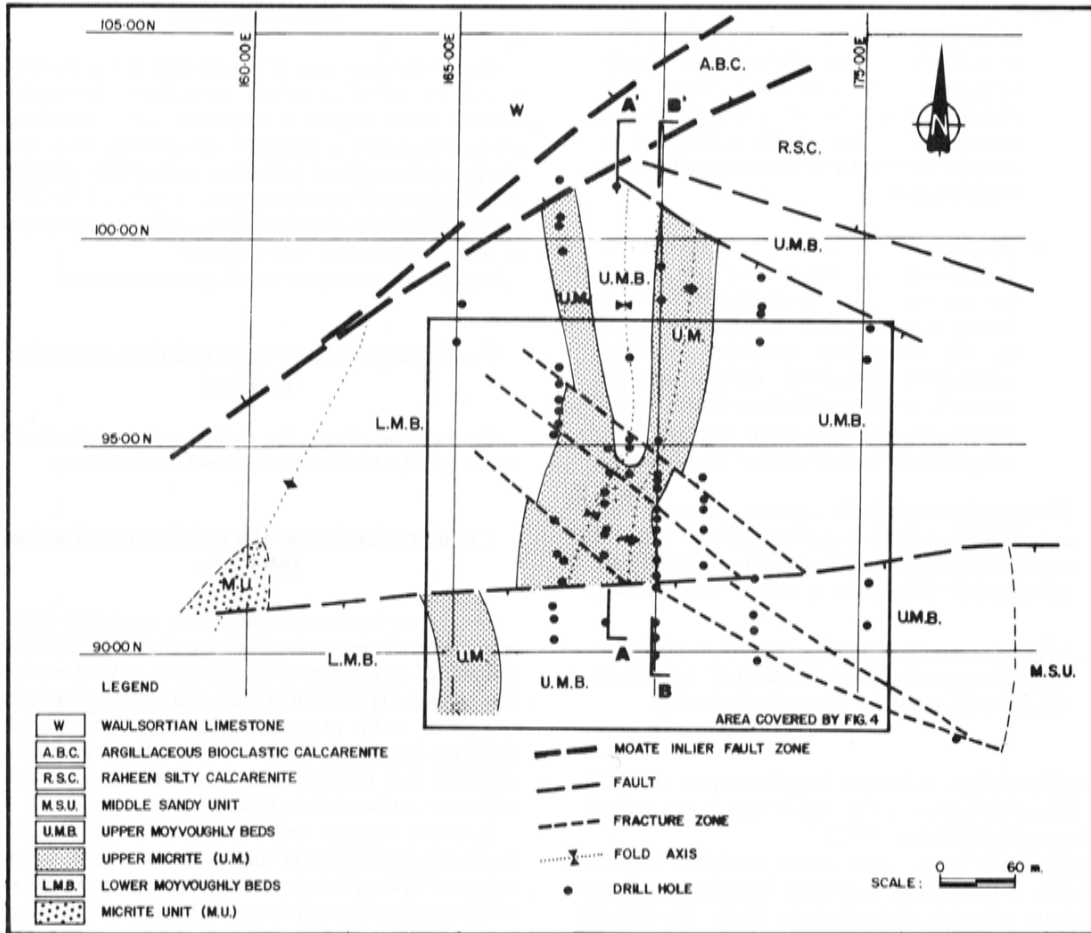


Figure 3. Detail geological setting of the Moyvoughly prospect.

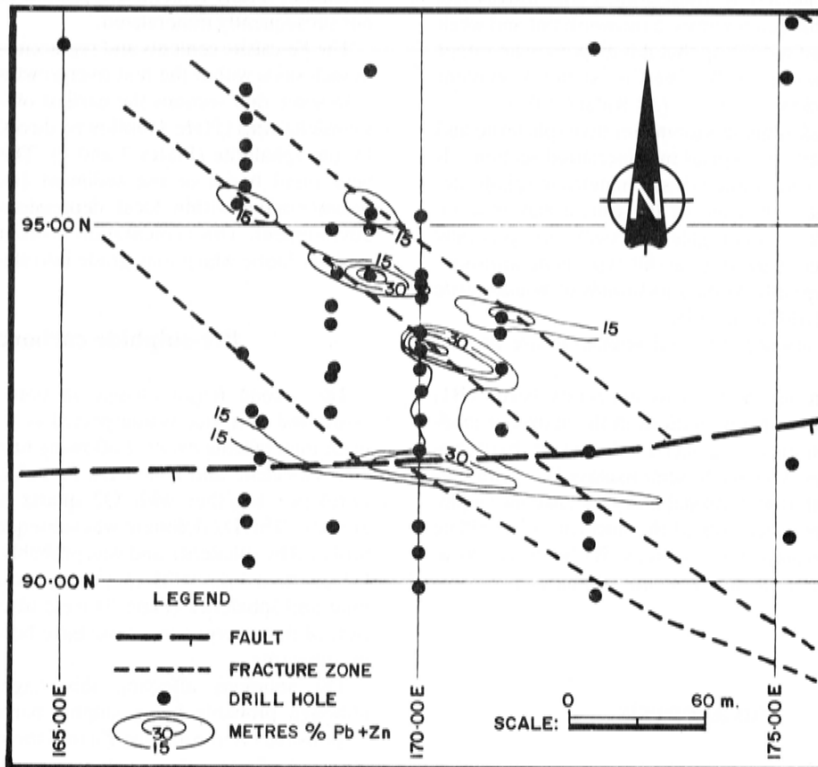


Figure 4. Distribution of Zn-Pb mineralization.

- (c) Conversion of aragonitic oolites into low Mg-calcite polymorphs resulted in a radial texture (Plate 8) which is also exhibited by subsequent replacement. This suggestion is supported by the preservation of low Mg-calcite rim cements around oolites (Plate 8). These preserved rim cements were not subjected to crystallographic transformation.
- (d) Micritic muds are characterized by high primary porosity but low permeability, because the porosity is not geometrically arranged. During recrystallization, however, permeability was temporarily increased, facilitating replacement. Sphalerite crystals replacing micrite have differentiated size (Plate 2) which indicates that the replacement occurred during recrystallization of the original micritic mud.

S3 replacement sphalerite contains numerous voids and inclusions (relics) of carbonate (Plates 1, 2, 3, 6 and 8) which suggest that the replacement process was accompanied by reduction in volume or by leaching.

- 4. S4 sphalerite infilled fractures and open spaces generated during and after replacement of the host carbonate by S3 sphalerite. It is typically banded.

Undifferentiated sphalerite samples contain 0.08-0.41 wt.% Fe, 0.20-0.40 wt.% Cu, 0.17-0.18 wt.% Mn and 0.5-26.6 ppm Hg (Al-Rufaie, 1982).

Pyrite is the second most abundant sulphide mineral. It occurs as fine-grained aggregates organized into larger colloform spheroids, concretions or bands. Idiomorphic pyrite crystals are disseminated within sphalerite, with which it is often intimately intergrown. Pyrite usually has banded or microbanded textures, a brownish tint and weak anisotropy, the last indicating that it is melnikovite rather than pyrite (Ramdohr, 1969). The Co, Ni and As content of the pyrite is below 0.15 wt.% (Al-Rufaie, 1982).

Galena is considerably less abundant than sphalerite and Zn:Pb ratios of 6:1 are typical in mineralized sections. It occurs mainly as fine-grained disseminations in sphalerite. The porous texture of some of the galena may indicate a replacive origin. Larger galena crystals are generally restricted to later stage fracture-fill type mineralization. These crystals typically contain inclusions of boulangerite and bournonite (Al-Rufaie, 1982).

Chalcopyrite, arsenopyrite and tennantite are present but are rare.

Barite is abundant. Some syndimentary barite (B1) may be indicated by disseminations in the matrix of mudstones. This barite may be replaced by Fe-calcite, baritocalcite and sulphides. Massive to semi-massive B2 barite may be developed with or without sulphides and, like the sulphides, formed as replacements of the host carbonate (Plate 5). It may also replace the sulphides. B3 barite occurs as veins and veinlets with calcite, minor sulphides and traces of fluorite.

Paragenesis

An interpreted paragenetic sequence is summarized in Table 1 and described below.

Sedimentation

Most of the carbonate allochems were probably characterized by initial aragonite mineralogy. Aragonite is unstable under diagenetic conditions and is transformed into low Mg-calcite, dolomite or is leached out. This susceptibility of the original carbonate sediment to diagenetic crystallochemical transformations is believed to be an important parameter in defining the ability of such sediment to accept replacement mineralization.

Locally sedimentary barite (B1) was introduced.

Cementation above the oxidation-reduction interface

Cementation above the oxidation-reduction interface introduced Fe-free calcite rims and blocky calcite.

Cementation below the oxidation-reduction interface

The change from an oxygenated to a reducing environment, due to the increasing thickness of overlying sediment, was related to a change in the chemistry of the pore fluids. This change was initiated by the leaching (L1) of carbonates (aragonite) in the presence of CO₂ (HCO₃) produced by oxidation of organic matter. Ca freed from the dissolved aragonite was recycled and reprecipitated as Fe-calcite below the oxidation-reduction interface.

Fe-calcite cements and replacements may have been locally developed until the time of the main sulphide mineralization. The replacements interfinger with D1 dolomite which suggests that replacement of earlier carbonates might have released some Mg. This type of dolomite, though not abundant, locally cemented sandstone sections which were not subsequently mineralized.

The Fe-calcite cements and replacements may be present as inclusions within the first overgrowths of silica (Q1).

In some thin sections the earliest observed cements are Fe-calcite rims (Plate 4) followed directly or accompanied by rim sphalerite (Plates 3 and 4). This suggests either a very rapid burial of the sediment (storm deposits?) or sedimentation within local depressions with a reducing environment. This cementation is often associated with a nodular fabric which may grade into slump textures.

Pre-sulphide carbonates

The second major change in pore-fluid chemistry is associated with what is interpreted as being the start of the main mineralizing event. Following further leaching (L2), high Fe-calcite and zoned D2 Fe-dolomite cements were developed together with Q2 quartz and feldspar overgrowths. This D2 dolomite was subsequently preferentially replaced by sphalerite and was probably Zn-bearing. Later Q3 quartz overgrowths containing inclusions of D2 dolomite and sphalerite (Plate 7) were also developed. Some rims of thin overgrown quartz have been entirely replaced by sphalerite.

The solutions affecting this stage of cementation, although probably being sulphur-barren were therefore responsible for introducing Zn into the structure of carbonates and silicates, thereby having an important influence on the subsequent distribution of Zn sulphide.

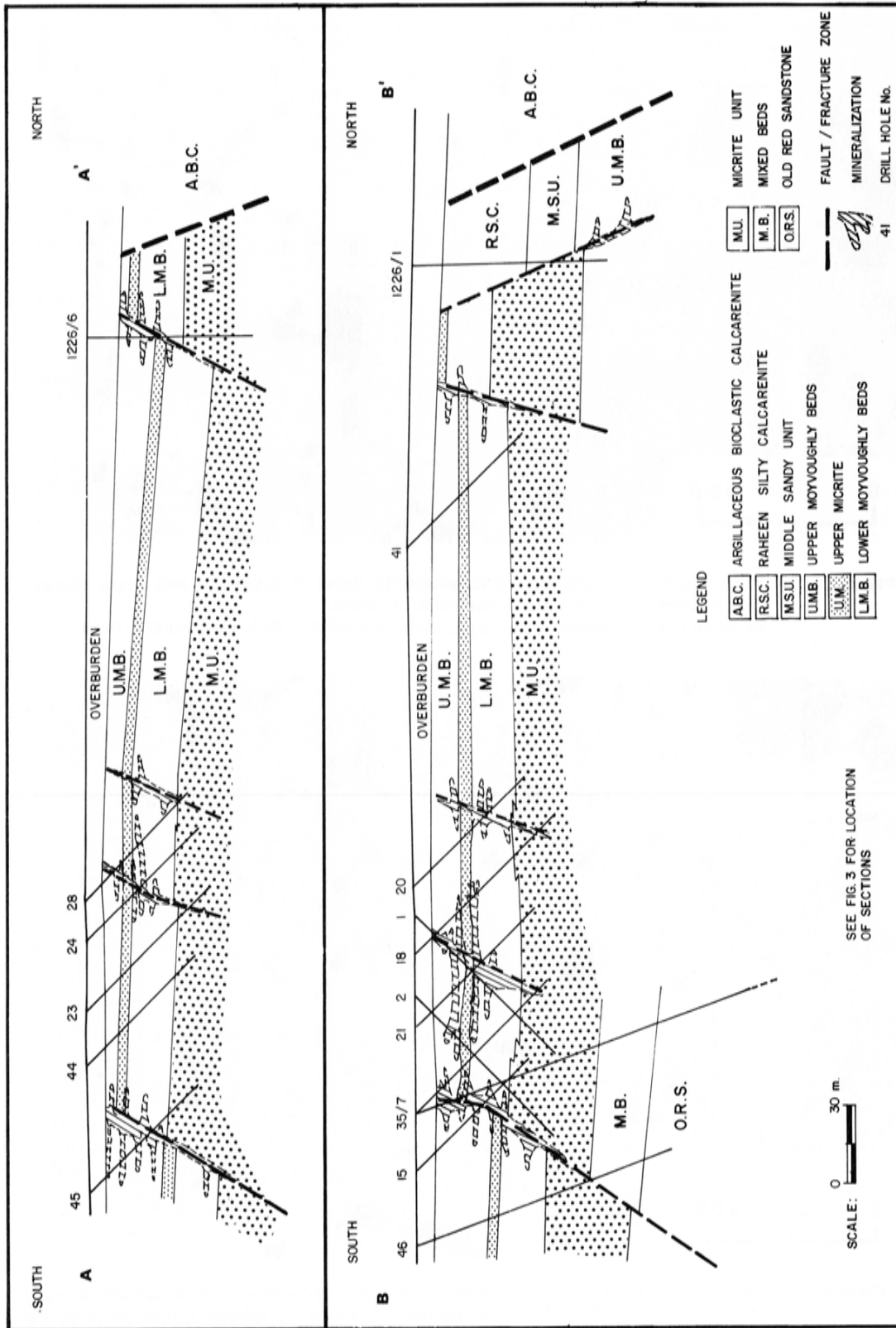


Figure 5. Sectional interpretation of the Moyvoughly mineralization.

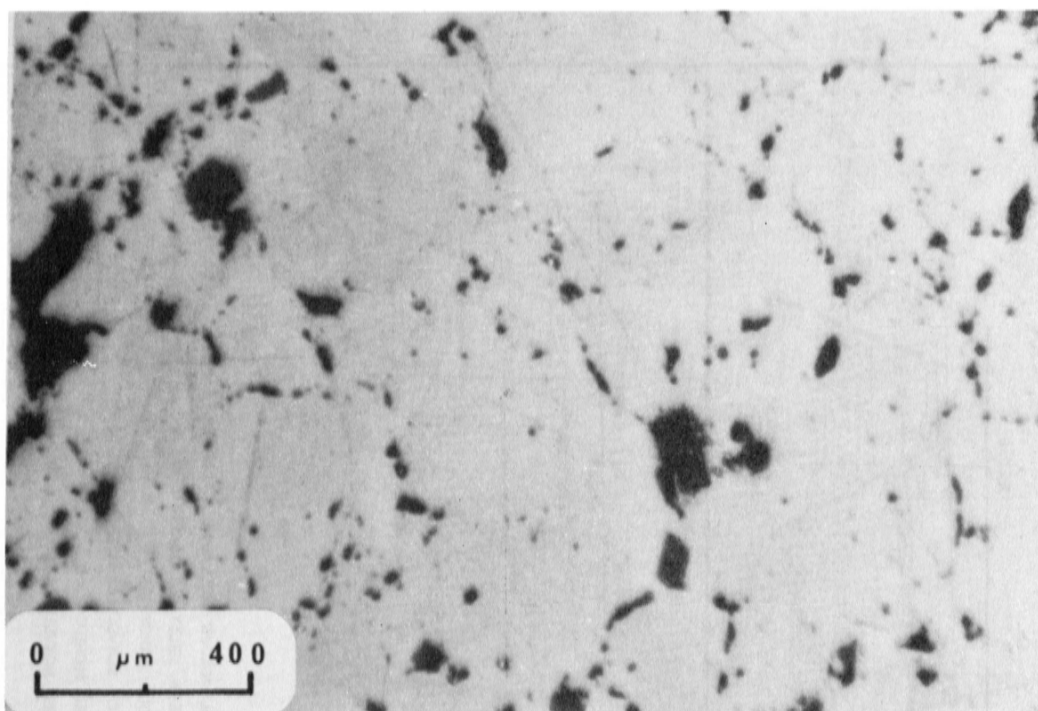


Plate 1. Massive sphalerite replacing oolitic calcarenite. Relics of carbonates and empty spaces form a pattern outlining the original shape of ooliths. Reflected light; sphalerite — light grey, carbonate relics — dark grey, voids — black.

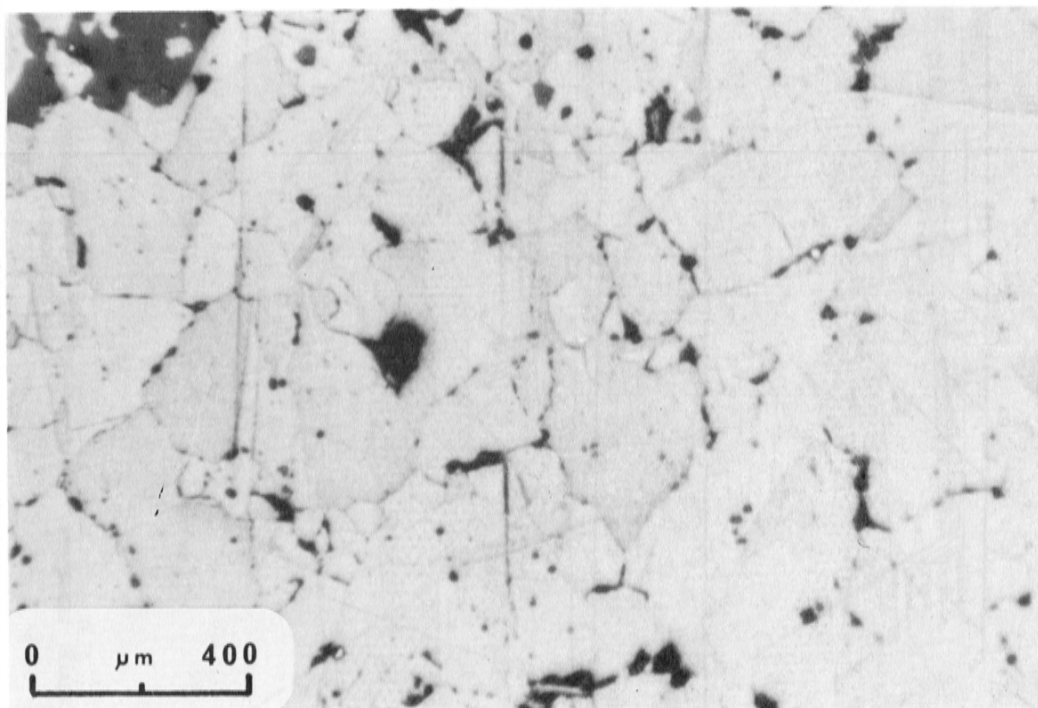


Plate 2. Sphalerite replacing micrite. Differentiated size of sphalerite crystals pseudomorphing carbonates suggests that the replacement of micrite by sphalerite took place during recrystallization of micritic mud. Reflected light; etched sample, sphalerite — light grey, carbonate relics — grey, voids — black.

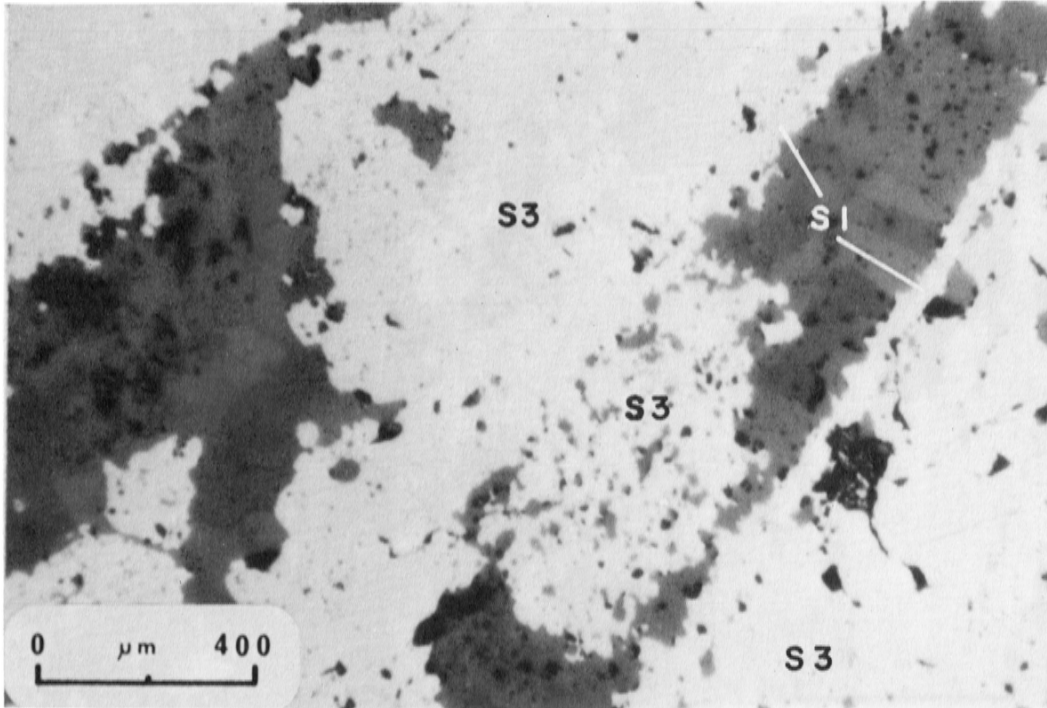


Plate 3. Sphalerite rim cements (S1) around bioclasts. Bioclasts and Fe-calcite spar are also replaced by sphalerite (S3). Rim sphalerite, which probably was precipitated directly from solutions, is practically carbonate relic-free. In contrast, replacive S3 sphalerite contains numerous inclusions (relics) of Fe-calcite and high Fe-calcite, which supports replacive origin. Reflected light; sphalerite — light grey, carbonates — grey, voids — black.

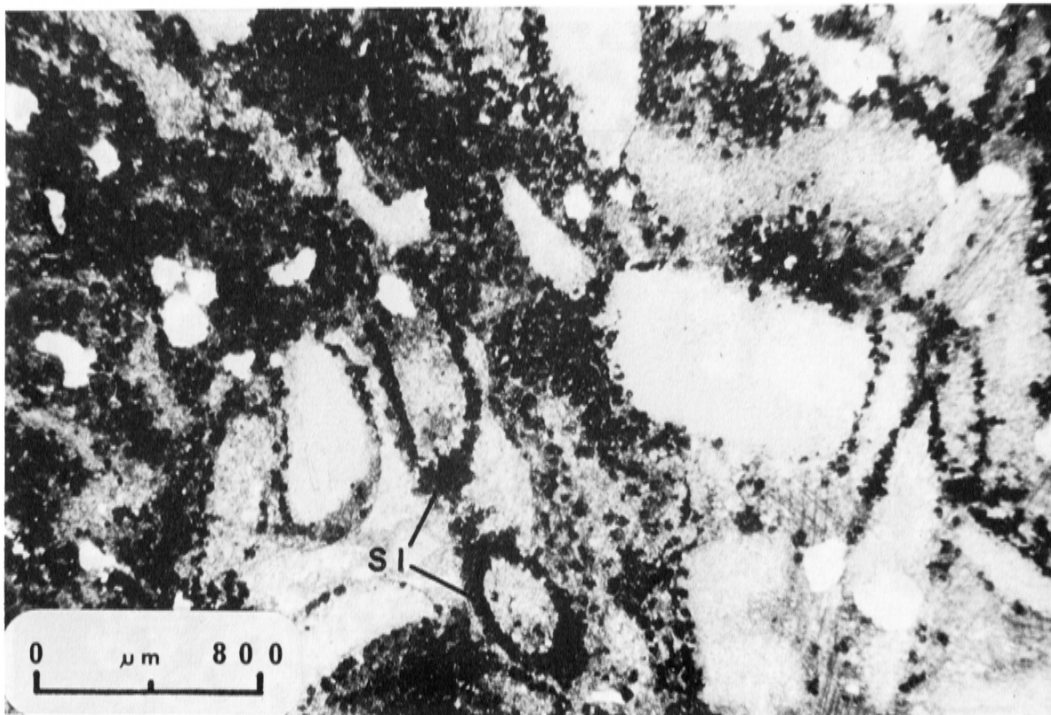


Plate 4. Sphalerite (S1) developed as pure rims or as rims intermixed with Fe-calcite. Fe-calcite also replaces bioclasts and is in turn replaced by sphalerite. During such replacement Fe is reconcentrated as high Fe-calcite intergrowths and relics in the replacive sphalerite. Transmitted light; quartz — white, calcite (bioclasts) — light grey, Fe-calcite cements and replacements — grey, high Fe-calcite (intermixed with sphalerite) — dark grey, sphalerite — black.

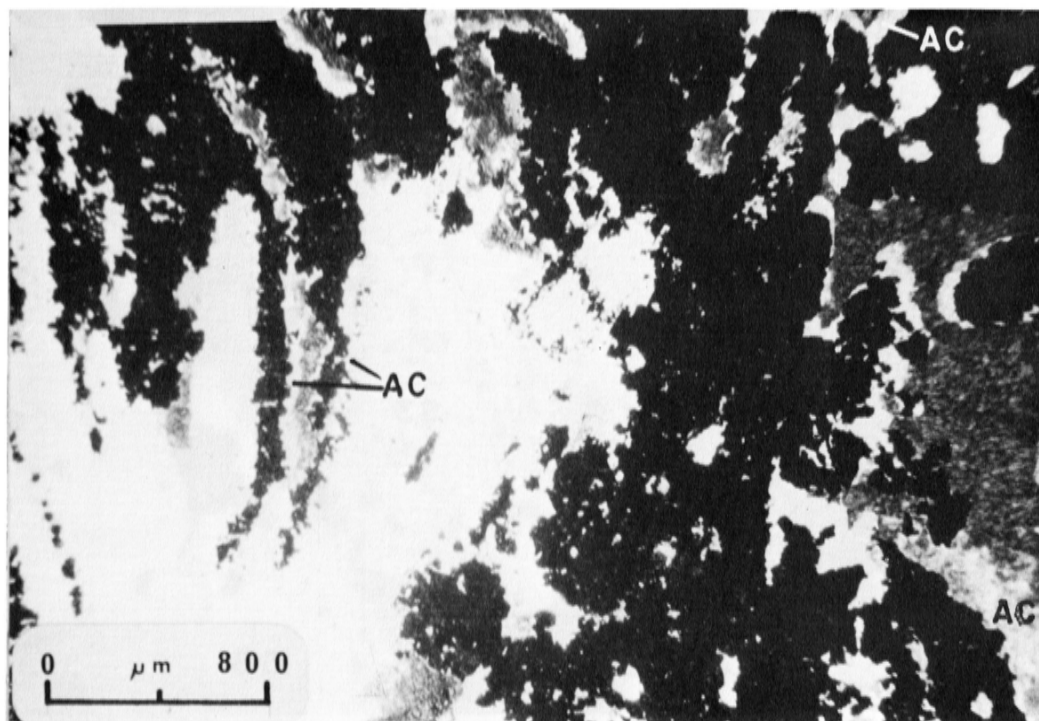


Plate 5. Sphalerite (black) and barite (white) replacing bioclasts and Fe-calcite spar (dark grey). Replace sphalerite and barite are separated from replaced carbonates by a rim of amorphous calcite (AC), which is optically isotropic and does not stain. Transmitted light, stained thin section.

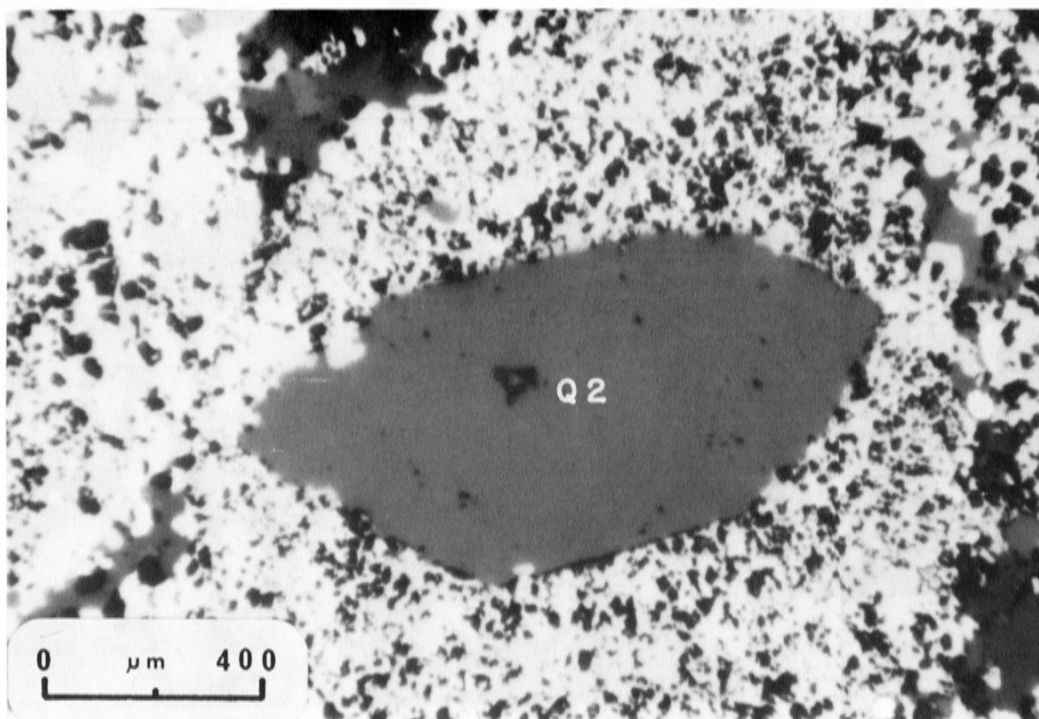


Plate 6. Overgrown quartz (Q2) containing inclusions of sericite. Quartz is present in the matrix of replacive sphalerite. Numerous relics of carbonates (grey) and empty spaces support replacive origin of sphalerite. Reflected light.

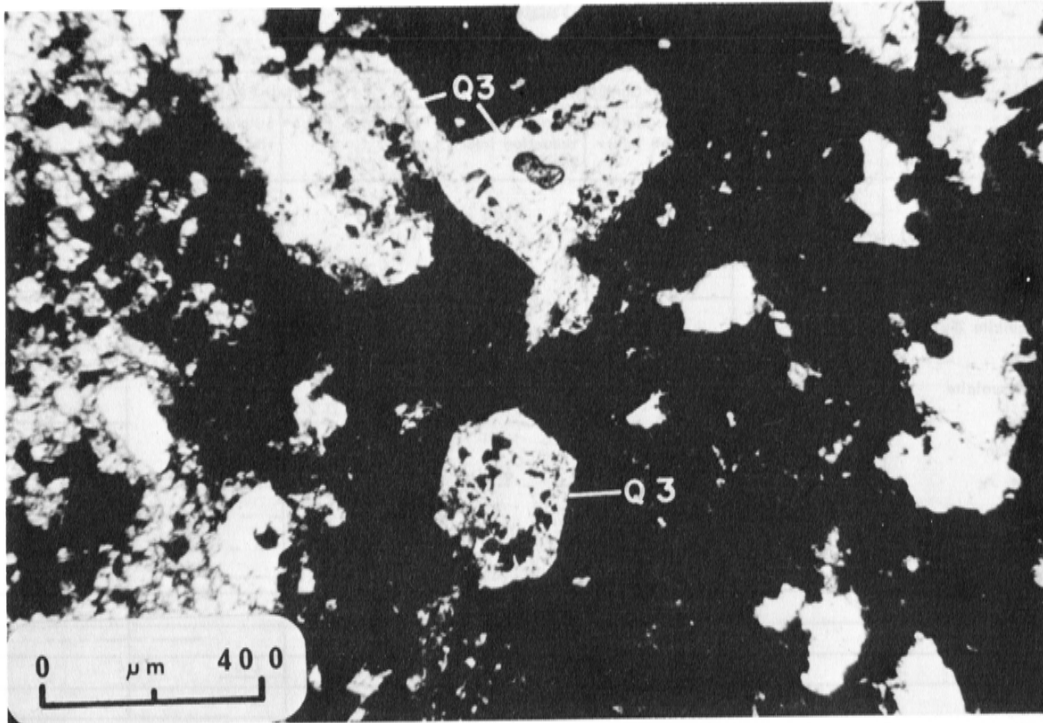


Plate 7. Overgrown quartz (Q3) containing inclusions of sphalerite (black). Transmitted light, stained thin section.

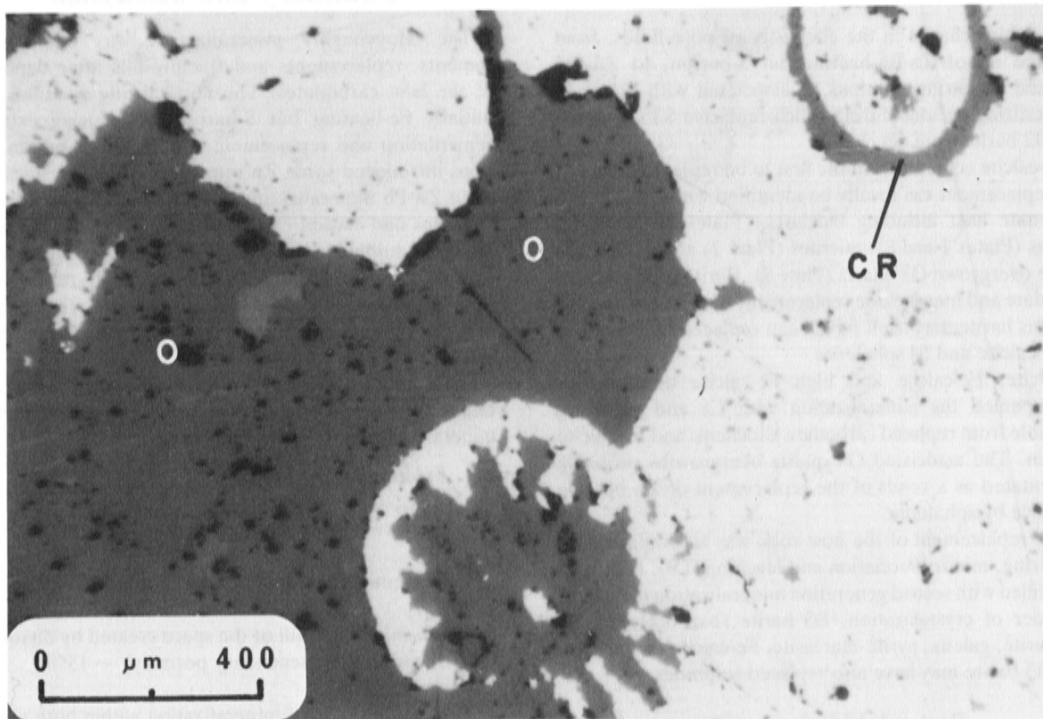


Plate 8. Replacement of oolites by sphalerite. The radial texture suggests that the replacement took place during conversion of the original aragonitic oolite into low Mg-calcite polymorph. Original low Mg-calcite rim cement (CR), not subjected to polymorphic transformation, is preserved. Oolite without radial structure (O) is not replaced. Replacive sphalerite contains numerous relics of carbonates. Reflected light.

Table 1.
A general paragenesis at Moyvoughly.

MINERALS	SEDIMENTATION	CEMENTATION		MINERALIZATION		
		above oxidation-reduction interface	below oxidation-reduction interface	Presulphide carbonates	Sulphides and barite	Postsulphide carbonates
Carbonate grains (aragonite, Mg-calcite)	B 1					
Barite					B 2 B 3	
Calcite rims (Fe-free)						
Blocky calcite (Fe-free)						
Fe-calcite						
Highly Fe-calcite						
Dolomite				D 1	D 2	D 3
Silicification				Q 1	Q 2	Q 3
Sphalerite				S 1 S 2		S 3 S 4
Pyrite				- -		
Galena						
Amorphous calcite						
SLUMPING				-		
FRACTURING				- - -		- - - -
LEACHING			L 1	L 2	L 3 L 4	
BRECCIATION					- -	

cements ————— replacements

Sulphide and barite

The third change in the chemistry of pore fluids, from Fe- and minor Zn-Ba-bearing but S-barren, to Zn-Pb-Ba- and S-bearing solutions, is associated with the main mineralizing episode during which replacive S3 sphalerite and B2 barite were developed.

Fe-calcite cements were the first to be replaced (Plate 4) but replacement can locally be identified within the entire carbonate host including bioclasts, (Plates 3, 4 and 5), oolites (Plates 1 and 8), micrites (Plate 2) and even some of the overgrown Q3 quartz (Plate 7). Barite replacements post-date and may include replacement S3 sphalerite (Plate 5). This barite may itself have been replaced by Fe-calcite baritocalcite and S4 sphalerite.

Calcite, Fe-calcite and high Fe-calcite development accompanied the mineralization with Ca and Fe being available from replaced carbonate allochems and Fe-calcite cement. The associated Q4 quartz overgrowths probably precipitated as a result of the replacement of Zn-bearing Q3 silica by sphalerite.

The replacement of the host rock was accompanied by fracturing, minor brecciation and leaching (L3). Fractures were filled with second generation mineralization including, in order of crystallization, B3 barite (baritocalcite), S4 sphalerite, galena, pyrite-marcasite, Fe-calcite and calcite. The B3 barite may have also replaced sulphides.

Post-sulphide carbonates

Following post-mineralization fracturing, brecciation and leaching (L4), pore solutions were characterized by the disappearance of sulphur and base metals, and the appearance of Mg.

The main mineral introduced during this stage was slightly ferroan baroque dolomite (D3) which infills fractures and extensively replaces unmineralized carbonates. Some Fe-calcite and calcite were also developed.

Summary and discussion

The Moyvoughly mineralization was emplaced as cements, replacements and fracture-fills after deposition of the host carbonates. The mineralizing solutions were initially Fe-bearing but S-barren, introducing extensive cementation and replacement. Later, still S-barren solutions introduced some Zn into carbonates and silica. The main Zn-Pb mineralization was associated with S-bearing solutions and caused extensive replacements and fracture infills by sulphides. This conclusion is consistent with S isotope data (Caulfield et al., this vol.). Mg-rich solutions then introduced extensive baroque dolomite replacements and the mineralizing episode ended with Fe-calcite and calcite.

In the samples studied, which are believed to be representative, the proportional distribution of the various styles of mineralization in the Moyvoughly area is:

1. Fracture infill — 40%.
2. Replacement of the host carbonates — 30%.
3. Cements i.e. infill of primary porosity — 15%.
4. Leaching i.e. infill of the space created by dissolution of carbonates (secondary porosity) — 15%.

The development of mineralization within both primary porosity and space generated by tectonic activity (i.e. 1 and 3 above) probably reflects a normal precipitation process. The remaining 45% of the mineralization is associated with the replacement and leaching of the host carbonates.

Replacement is thought to have been controlled and facilitated by:

- (i) Polymorphic transformation of aragonite into low Mg-calcite.

- (ii) Recrystallization of micritic muds.
- (iii) Presence of some Zn in the carbonate cements.

The replacement of metal-bearing carbonates by sulphides produces volume reduction and releases HCO_3 (Kucha and Crajka, 1984) which causes leaching of the host carbonates, thereby creating additional open space for mineralization.

In the Moyvoughly area the different styles of mineralization are developed together within zones localized adjacent to a series of faults and fracture zones (Figs. 4 and 5) which appear to have been the permeability pathways for the mineralizing solutions to the host carbonates, as well as being the origin of fracture-related space generation. The distribution of mineralization adjacent to these fracture zones reflects the relative ability of the carbonates to accept it.

The ability of carbonates to accept mineralization depends on their initial porosity and permeability, which also control secondary porosity and permeability and thus replacement potential. It is not surprising, therefore, that the mineralization is developed within the Moyvoughly Beds intertidal sediments which are characterized by high initial porosities and permeabilities. It is significant that the sections of birdseye micrite which represent supratidal truncations within these intertidal deposits have low permeability and are generally poorly mineralized. These supratidal deposits, however, typically have a high Mg content (Shinn, 1983) which probably explains why the development of post-ore baroque dolomite is preferentially developed within micrites or within other sediments modified in a supratidal environment.

Mineralization in the Moyvoughly area is epigenetic in so far as it was developed after the deposition of the host carbonates. The mineralization process, however, was clearly active during diagenetic cementation and recrystallization as well as post-dating episodes of tectonic fracturing. It has been estimated (Bathurst, 1971) that the time required for the complete cementation of carbonates is about 100 000 years. It seems likely that the processes of sedimentation and diagenesis, tectonism and mineralization occurred synchronously over such a period.

Acknowledgements

The authors acknowledge the work of present and former colleagues who have been involved with the exploration of the Moyvoughly area. Special thanks are due to Prof. P. Mohr, Dept. of Geology, University College Galway for

granting access to the Department's facilities for petrological research work, and to Dr. G. Steed, Dept. of Mineral Exploitation, Cardiff University, who provided polished sections used in an earlier study. The authors also thank the management of Ennex International PLC for permission to publish this paper.

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