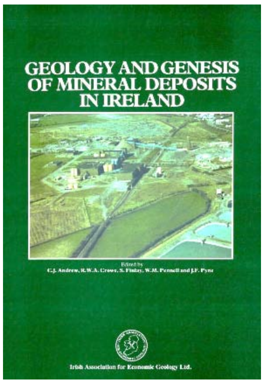


Irish Association for Economic Geology

(founded 1973)

Home Page: https://www.iaeg.ie

Geology of the Abbeytown Mine, County Sligo, Ireland.

M.W. Hitzman

To cite this article: M.W. Hitzman. (1986) Geology of the Abbeytown Mine, County Sligo, Ireland. *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. 341-353. DOI:

To link to this article: https://

Geology of the Abbeytown mine, Co. Sligo, Ireland.

Murray W. Hitzman

Chevron Resources Co.,
P.O. Box 7147
San Francisco,
California, 94120-7147
USA.

Abstract

The Abbeytown mine is situated in County Sligo, approximately 500m west of the village of Ballysodare. The mine was worked intermittently from 1785 to 1961. Total production from the area is estimated to have been approximately 1.1Mt of nearly 1.5% Pb, 3.8% Zn, and 40-45g/t Ag. The mineralization is hosted in a transgressive carbonate sequence of Visean age (Lower to Middle Carboniferous) unconformably overlying Precambrian to Cambrian metasedimentary basement. Three major mineralizing events are recognized. The first resulted in dolomitization of the host rocks and precipitation of minor pyrrhotite in two NNE-trending fracture zones. The second mineralizing event produced dedolomitization and precipitation of pyrite, sphalerite and galena. These sulphides occur as stratabound replacements, veins and internal sediments and are best developed either in highly permeable rocks, such as calcareous sandstones, or adjacent to impermeable shale beds. Mineral textures indicate a complex sequence of precipitation and dissolution. Fluid inclusions in sphalerite suggest trapping temperatures of 88°-170°C. Calcite-pyrite breccias were formed during the last major mineralizing event, and the calcite in these breccias yields fluid inclusion trapping temperatures of 140°-175°C. The dolomitized and mineralized zones display a characteristic oval shape in plan view. These zones formed as extensional structures related to Visean movement on two sinistral faults which terminated in the Abbeytown area. The textures, temperatures and late timing of the mineralization relative to host-rock deposition suggest that Abbeytown should be classified as a replacement-style, Mississippi Valley-type deposit.

Introduction

Mineralization in the Abbeytown area was first recognized in the 1700s. Mining from the 1700s to the late 1950s exploited the eastern orebody which initially cropped out on the shore of Ballysodare Bay. In the late 1950s diamond drilling by Johannesburg Consolidated Investments (JCI) resulted in the discovery of the concealed western orebody. Between 1950 and 1961 JCI produced nearly 1Mt of 5% combined lead and zinc from the two orebodies. Mining ceased in 1961 due to exhaustion of reserves and low base-metal prices. The mine area is currently a limestone quarry operated by Spollen Concrete.

There is little published information on the Abbeytown deposit. Except for brief summaries by Dennison and Varvill (1952), O Brien (1959), Schultz (1971) and Williams and McArdle (1978), references on the Irish deposits generally ignore Abbeytown. The best description of the mineralization is contained in an unpublished thesis by Fernandez (1957), and the present study utilized this thesis for detailed petrographic descriptions of the sulphides. Geological maps, plans, and cross-sections were constructed from drill hole and underground data held by the Geological Survey of Ireland in Dublin and from fieldwork in both the Spollen quarry and the surrounding area.

Stratigraphy

The Carboniferous section in northwestern Ireland has been described by Oswald (1955), Sheridan (1972), and George et al. (1976). It is grossly divisible into a clastic-dominated sequence to the north in Donegal and a more carbonate-rich sequence in the Sligo area (Table 1). The Abbeytown mine is located on the southern margin of the Sligo area (Fig. 1).

The Carboniferous section in the Abbeytown area is underlain by Precambrian metasedimentary rocks. Both in the Ox Mountains immediately south of Abbeytown and in scattered, fault-bounded blocks to the east of the mine, these metasedimentary rocks are micaceous quartzites and banded feldspathic psammites containing small metabasite and serpentinite pods. The metasediments are dominated by granoblastic quartz which generally comprises up to 80% of the rocks. Other constituents are microcline, oligoclase, biotite and muscovite. Grain size is generally coarse. The grade of metamorphism observed in these rocks is variable. Petrographic studies by Molloy and Sanders (1983) indicate that the commonly seen, amphibolite grade assemblages were derived from granulite facies assemblages during retrograde metamorphism. Phillips et al. (1975) considered these rocks Moinian (late Pre-Cambrian, pre-Dalradian)

Table 1

General stratigraphic succession of Carboniferous sediments in the Sligo area

Age	Local nomenclature	Thickness (m)	Lithology
Late Asbian	Mennymore Formation	0-30m	Laminated calcarenite/evaporites/minor argillaceous calcarenite, calcsiltite and shale).
Asbian	Dartry and Glencar Limestone	200-300m	Bioclastic calcarenite/massive calcarenite ('reef')/argillaceous calcarenite/cherty limestone.
Asbian to Holkerian	Benbulben Shale	90-120m	Shale/calcareous shale.
Holkerian to Arundian	Mullaghmore Sandstone	0-200m	Sandstone/calcareous sandstone/micaceous shale and siltstone/oolitic limestone.
Arundian	Bundoran Shale	10-125m	Shale/calcareous shale/calcarenite, often bioclastic.
Arundian to Chadian	Ballyshannon Limestone	250-300m	Calcarenite/bioclastic calcarenite/cherty calcarenite/minor calcareous sandstones.
Chadian	Ballysodare Limestone	10-180m	Calcareous shale/calcarenite/sandstone/quartz-pebble conglomerate.

in age, whereas Long and Max (1977) suggested they were of Dalradian (late Pre-Cambrian to late Cambrian) age.

The metamorphic basement in the Sligo region is overlain by Lower Carboniferous rocks of Chadian age; both the Upper Devonian Old Red Sandstone and Courceyan (lowest Carboniferous) rocks are absent (Sheridan, 1972). Exposures around Ballysodare contain no evidence of deep erosion on the unconformity surface. The lowest Carboniferous unit at Abbeytown, informally designated the Ballysodare Formation, consists of a heterogeneous, transgressive sequence of shales, sandstones, quartz-pebble conglomerates and limestones (Fig. 1).

Overlaying the Ballysodare Formation is the Ballyshannon Limestone, the base of which, in the mine area, is placed at the top of Lower Grit Unit, a 0.5 to 1.5m thick calcareous sandstone. Above the Lower Grit Unit the basal Ballyshannon Limestone is composed of 30 to 35m of crinoidal calcarenite. This calcarenite is overlain by 2 to 8m of medium-grey, poorly fossiliferous calcarenite and calcilutite which is, in turn, capped by the 5 to 8m thick Index Bed. The Index Bed is a well-developed marker horizon composed of calcareous sandstone and calcite-cemented, fine-grained, quartz-pebble conglomerate. Both the sandstones and conglomerates contain minor detrital feldspar. The Index Bed displays planar-laminated beds and large- to small-scale cross-beds. Thin, discontinuous, argillaceous layers are also present, especially at the top of the unit. The textures and stratigraphic position of the Index Bed are suggestive of deposition as a barrier bar. The Index Bed has a sharp upper contact with dark grey calcarenites and biocalcarenites. The lower 40m of limestone succeeding the Index Bed contains centimetre-thick shale beds. Approximately 100m above the Index Bed the Ballyshannon Limestone grades vertically into a cherty limestone which contains thin, sandy and bioclastic intervals. None of the units in the lower Carboniferous section contain significant dolomite outside the mine area.

Although not preserved in the immediate mine area, the Ballyshannon Limestone is overlain elsewhere in the Sligo region by the Arundian Bundoran Shale which is often highly fossiliferous. The Bundoran Shale is overlain by the late Arundian to Holkerian Mullaghmore Sandstone which blanketed the entire Sligo region north of the Ox Mountains and was derived from the NW (Sevastopulo, pers. comm., 1984). The Mullaghmore Sandstone is covered by the Benbulben Shale which grades vertically into the Asbian Dartry and Glencar Limestones. The intertidal Meenymore Formation overlies the Glencar Limestone (Brandon, 1977).

The Ballysodare Limestone and the lower part of the Ballyshannon Limestone represent a northwards prograding sequence of local barrier bars and lagoonal environments. The overlying sequence records the establishment of a carbonate shelf (upper Ballyshannon Limestone), subsequent burial of these carbonates by a southward prograding, deltaic wedge (Bundoran Shale-Mullaghmore Sandstone), and a return to shelf conditions (Benbulben Shale-Dartry and Glencar Limestones). The presence of conglomerate beds and the abundance of coarse mica flakes in the Ballysodare-Ballyshannon and Mullaghmore sequences indicate a proximal source area. The Carboniferous succession in the Sligo region also displays rapid lateral changes in both thickness and facies. These may be due, in part, to deposition within actively subsiding, fault-controlled basins (Sevastopulo, pers. comm., 1984).

Structure

The structure of the Sligo region is dominated by NNE to nearly easterly striking, high-angle faults between which the Carboniferous section is broadly folded. In the Abbeytown area the rocks generally dip 1-10°S. Further south, along the border of the Ox Mountains, equivalent strata dip steeply northwards. The apparent absence of extremely coarse clastics immediately adjacent to the Ox Mountains and its bounding fault indicate that this fault was not a palaeogeographic feature during the period in which the sediments which host the Abbeytown mineralization were deposited. However, pebble-filled channels within the middle Ballyshannon Limestone suggest the fault may have been active later in the Chadian (Philcox, pers. comm., 1984).

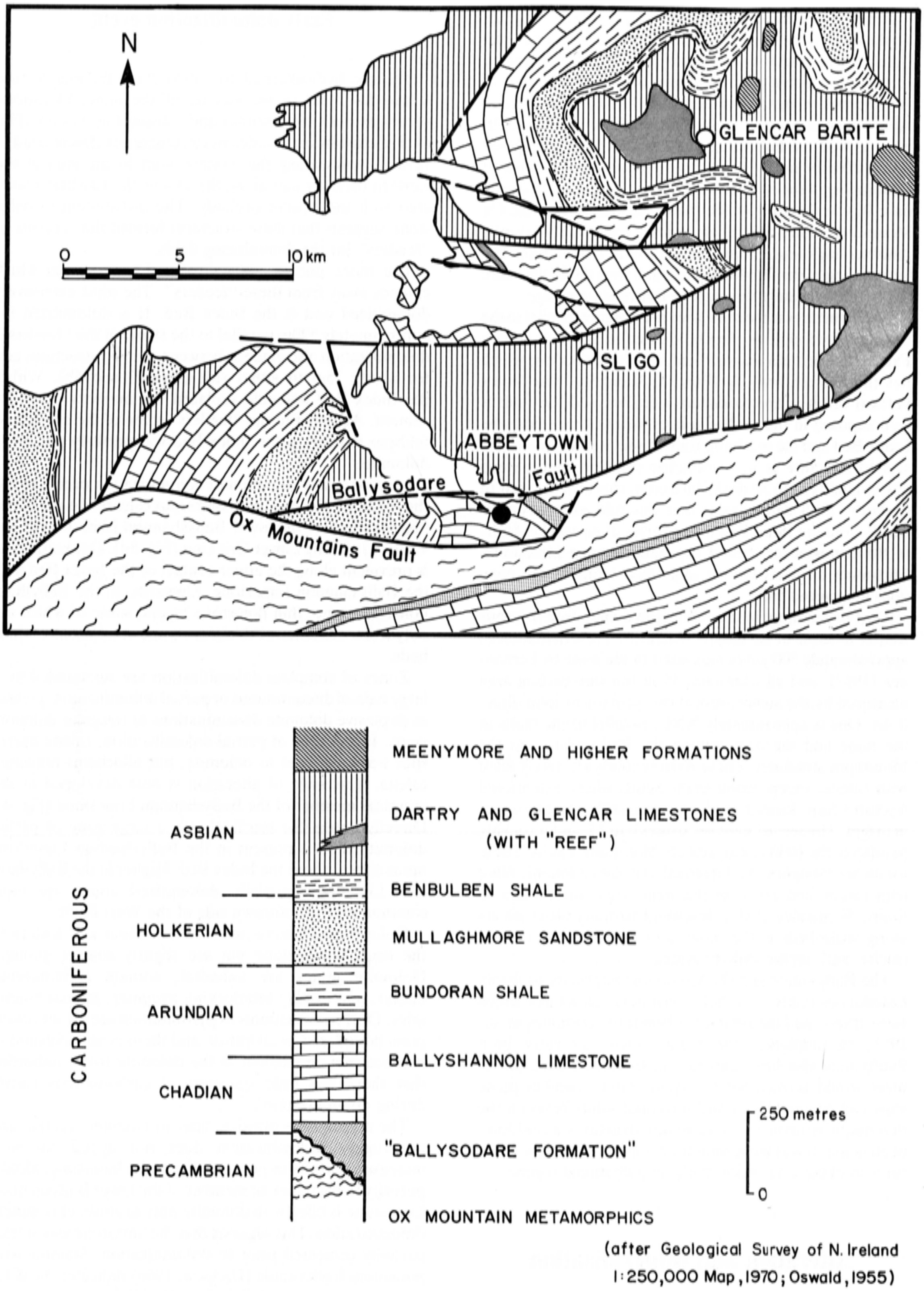


Figure 1. Geological map of the Sligo area.

Abbeytown is located between two major faults (Fig. 1). To the south is the Ox Mountains Fault which separates Pre-Cambrian metasedimentary rocks from the Carboniferous section. This Fault terminates approximately 2.5km SE of Abbeytown in metasedimentary rocks. To the north of Abbeytown is another high-angle, easterly striking fault, here termed the Ballysodare Fault. This Fault juxtaposes Asbian Dartry and Glencar Limestones to the north against Chadian-aged rocks to the south. It extends under Ballysodare Bay to the north of the mine and merges with the Ox Mountains Fault approximately 20km west of Abbeytown. Another high-angle fault, with a NNE strike, joins the termination of the Ox Mountains Fault with the Ballysodare Fault approximately 4km east of Ballysodare village.

Two structures in the mine area are roughly parallel to the NNE fault which joins the Ox Mountains and Ballysodare Faults. The first is a near-vertical, reverse fault along which lies the western orebody (Figs. 2, 3 and 5a). The fault's vertical offset is approximately 4 to 7m, and the fault is well exposed in the Spollen quarry where it cuts both the Index Bed and the overlying Ballyshannon Limestone. The second structure is an asymmetric syncline with a steep eastern limb (up to 30° dip) which coincides with the eastern orebody. Drill data suggest that this fold extends downwards from the Index Bed into a series of *en échelon* faults in the crinoidal member of the Ballyshannon Limestone. Maximum displacement on individual faults in this zone does not exceed 5m.

Joint orientations in the Abbeytown area display trends similar to those of the major structures. The orientation of approximately 500 joints measured in the mine by Fernandez (1957), and an additional 45 in the surrounding area measured by the author, reveal two prominent joint directions. One is approximately NNE, parallel to the faults in the mine and the fault joining the Ballysodare and Ox Mountains structures. These narrow joints are rarely filled with calcite, except along slight bends where extensional fractures have formed, and are apparently compressional in origin. The second joint set strikes 0 to 13° and is roughly parallel to the Ballysodare and Ox Mountains Faults. These joints are thought to be tensional and are commonly filled with calcite and pyrite in the mine area. In addition to joints, Fernandez (1957) described bedding-plane shears along shale beds in the mine area which locally contain calcite- and sulphide-filled cavities.

The Ballysodare and Ox Mountains Faults are probably Caledonian (early to middle Devonian) structures which were reactivated during the Carboniferous (Phillips et al., 1976). In addition to "north-side down" geometry, both Faults may also have sinistral displacement. Such movement would account for the minor faults, bedding-plane slips and compressional and tensional joints between the two major structures. These minor structures would have been generated at the termination zone of the major structures as oblique extension faults in a dilational regime.

Alteration and mineralization

Alteration and mineralization at Abbeytown can be divided on the basis of crosscutting relations into four events, each of which produced distinctive mineral suites. The events are: (1) an early dolomitization event, (2) the main sulphide event, (3) the calcite-pyrite breccia event, and (4) the formation of late mineralized vugs (Table 2).

Early dolomitization event

The first hydrothermal alteration event dolomitized the calcareous rocks in the vicinity of the mine. Dolostone occurs as both stratabound and crosscutting bodies (Fig. 4). Pre-existing carbonates were completely dolomitized in vertical zones along the western fault in the area of the western orebody and along the axis of the syncline associated with the eastern orebody. The distribution of dolostone suggests that these structures formed the conduits or "feeders" for the dolomitizing fluids.

The more porous units display dolomitization which extends away from these "feeders". The most extensively dolomitized unit is the Index Bed. It is dolomitized for approximately 520m parallel to the strike of the "feeders"; dolomitization also extends between the two structures and for nearly 75m to either side (Figs. 2 and 5b). Within the Index Bed dolomite replaced the majority of calcite cement. Adjacent to the "feeders" some of the quartz and feldspar detritus in the Index Bed was partially altered to dolomite.

Less extensive stratabound dolomitization occurs below the Index Bed in the non-fossiliferous calcarenite and crinoidal members of the lower Ballyshannon Limestone (Figs. 4 and 5c) and the Lower Grit Unit (Fig. 5d). Dolomitization is prevalent along the upper contact of the Index Bed with the Ballyshannon Limestone. Upwards, in the Ballyshannon Limestone, thin dolostone layers, some of which are only a few centimetres thick, are present adjacent to shale beds.

Zones of complete dolomitization are surrounded by a large halo of discontinuous or partial dolomitization present as pervasive dolomite disseminations or irregular dolomite veins. In the zone of partial dolomitization, calcite microspar was converted to dolomite, but allochems remained calcite. This style of alteration is best developed in the crinoidal member of the Ballyshannon Limestone (Fig. 4). Directly above the synclinal axis a large zone of partial dolomitization is present in the Ballyshannon Limestone immediately above the Index Bed. Higher in the Ballyshannon Limestone partially dolomitized zones are most common on the upthrown side of the West Fault.

Dolostones preserve much of the colour and texture of the original limestone but are slightly coarser grained. Dolomite grains are anhedral, contain carbonaceous matter, and display interlocking irregular, mutual boundaries. Only trace amounts of pyrobitumen are present along grain boundaries or stylolites, and there is no indication of hydrocarbon enrichment at the dolomite front, indicating that there was little transport of carbonaceous matter during dolomitization.

The dolostone is massive, fine- to medium-grained, and non-vuggy. Dolomitization does not appear to have increased porosity or permeability of the limestone. Moldic porosity in the crinoidal member of the lower Ballyshannon Limestone is filled with dolomite only in zones of complete dolomitization. This suggests that the limestone was at least partially cemented prior to dolomitization. Staining with potassium ferricyanide (Dickson, 1966) indicates the dolomite is nonferroan to mildly ferroan. Highest iron contents are present in dolostone closest to the "feeders". Dolomite in partially dolomitized zones is invariably nonferroan.

Diagenetic framboidal pyrite, which is a ubiquitous minor constituent of the Ballyshannon Limestone, is not preserved in dolomitized zones. Pyrrhotite, precipitated within dolostone as intragranular grains, was idiomorphic-

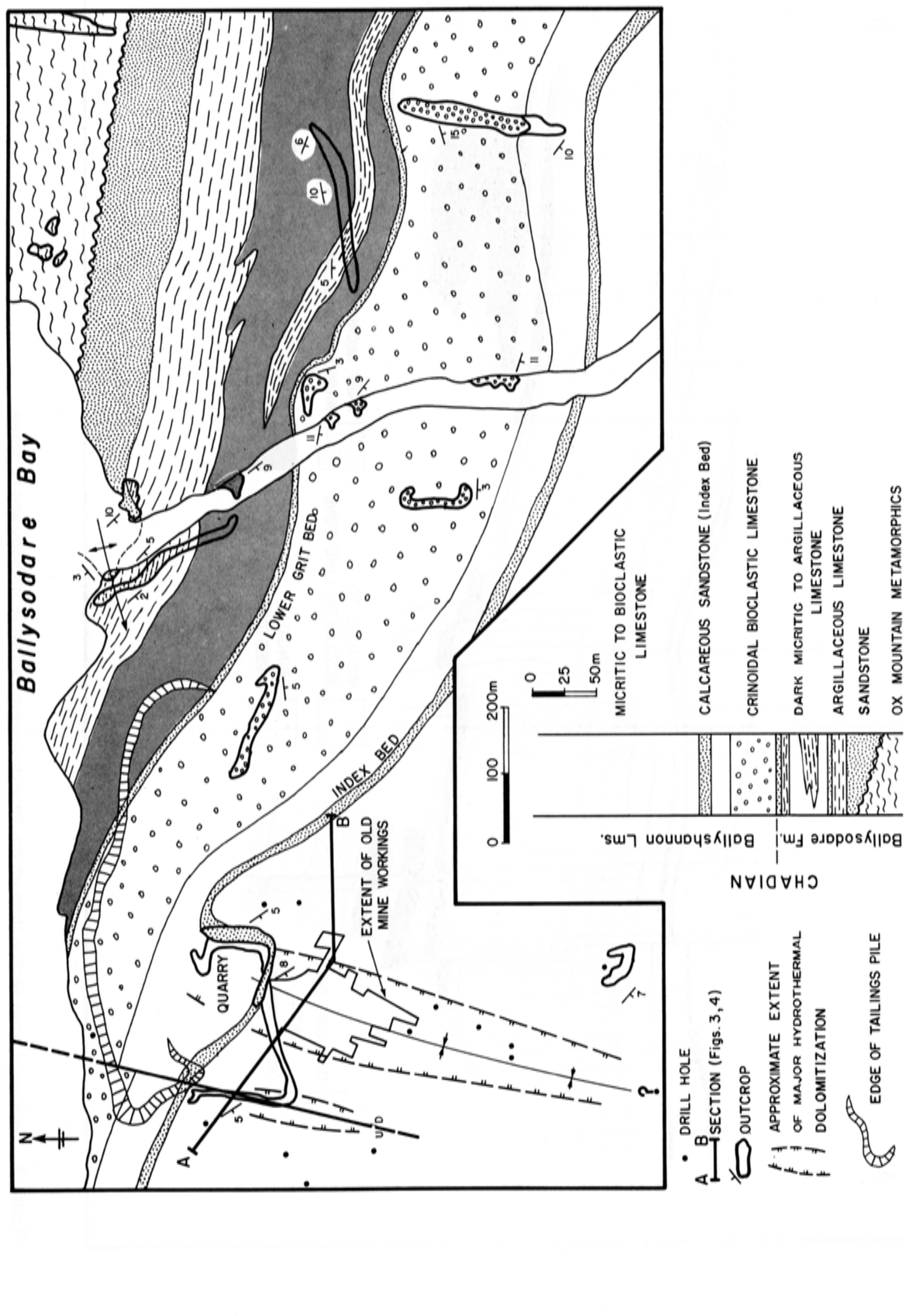


Figure 2. Geological map of the Abbeytown mine area.

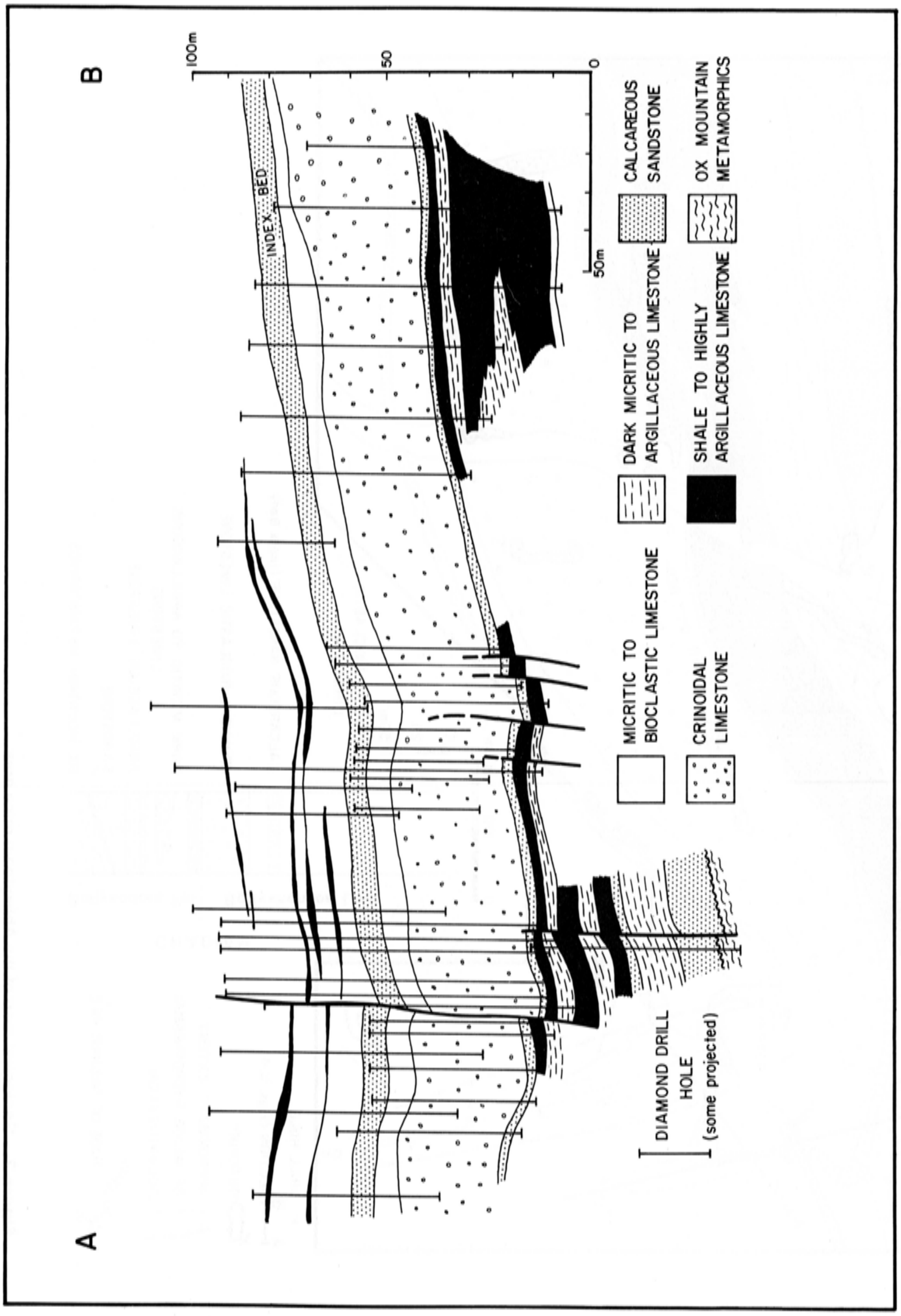


Figure 3. Geological cross-section through the Abbeytown mine showing lithology and structure.

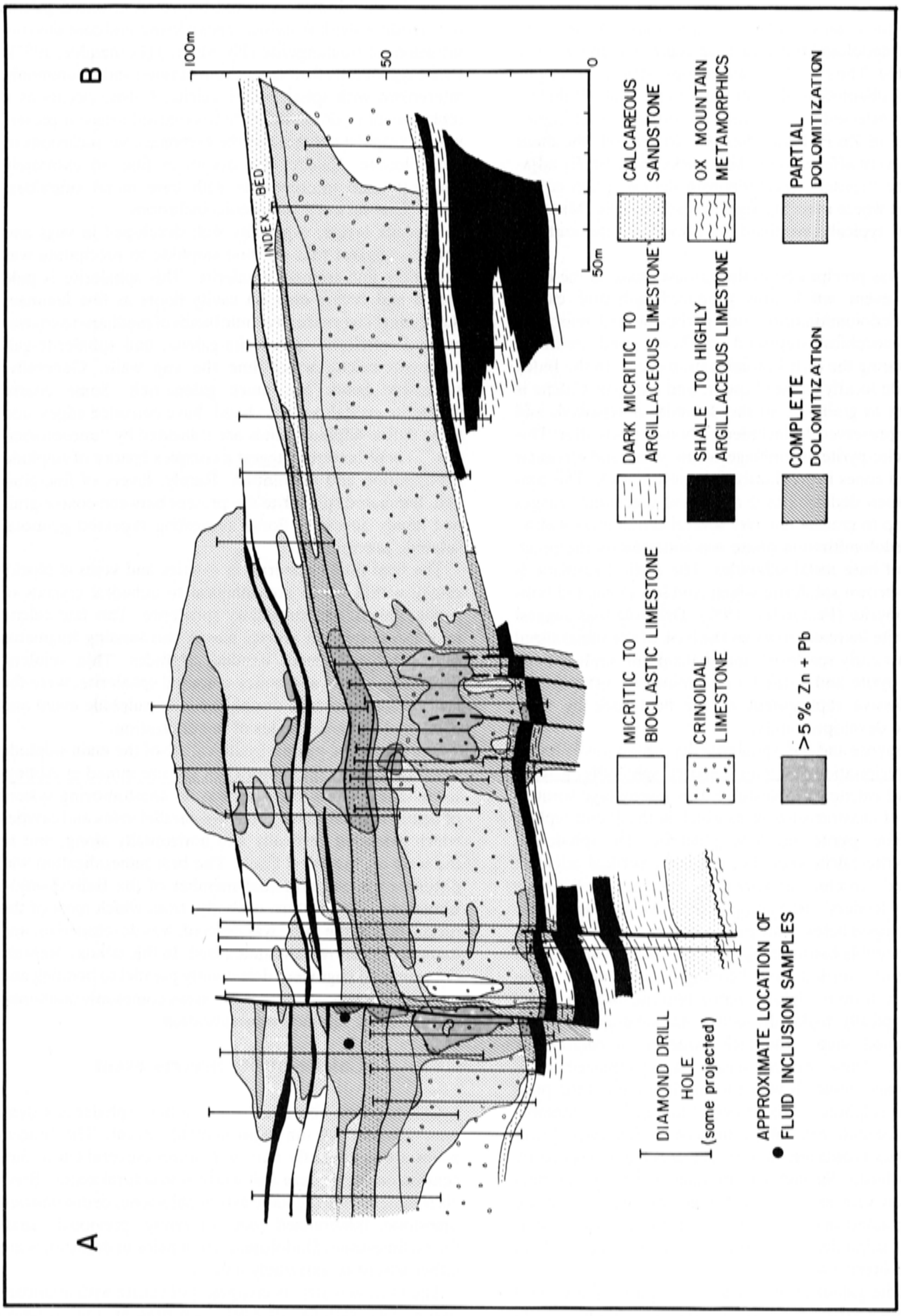


Figure 4. Geological cross-section through the Abbeytown mine showing zones of dolomitization and mineralization.

ally replaced by marcasite and, finally, by pyrite during the later stages of the dolomitization event.

Main sulphide event

During the main sulphide event, previously dolomitized rock was dedolomitized and base metal sulphides were precipitated. The event includes multiple stages of precipitation and dissolution of both carbonates and sulphides. The areas affected by this event are presented on Figure 5 as zones of Zn-Pb mineralization. In general, the main sulphide event affected only those rocks immediately adjacent to the "feeder" structures with the exception of the Index Bed where mineralization spread laterally. Mineralization is typically confined to previously dolomitized zones.

Pyrite was precipitated in the earliest phase of the main sulphide event which also produced anhedral calcite through dedolomitization. This pyrite-rimmed marcasite and idiomorphically-replaced pyrrhotite and dolomite formed during the early dolomitization event. In the Index Bed, pyrite locally replaced quartz and feldspar. Calcite is equivalent in grain size to the dolomite it replaced, and generally preserved the included carbonaceous matter. This early calcite-pyrite assemblage forms veins and irregular brecciated zones in previously dolomitized rock. The contact between dedolomitized rocks and dolostones ranges from sharp to gradational over several centimetres width.

The dedolomitization phase was followed by the precipitation of base metal sulphides. The earliest sulphide is dark red-brown sphalerite which contains elongated laths of chalcopyrite (Fernandez, 1957). Drillhole logs suggest chalcopyrite increases towards the base of the mineralized zone. This early sphalerite and chalcopyrite replaced calcite and pyrite and formed a disseminated, interporosity infill. Massive replacement of the host rock by early sphalerite developed rarely.

Chalcopyrite and dark sphalerite deposition was followed by the precipitation of lighter-coloured sphalerite, galena, pyrite and calcite. In dolostones this assemblage forms a network of anastomozing veins which both cut and replace early calcite, pyrite and dark sphalerite. The sphalerite-galena-pyrite-calcite veins are generally vertical adjacent to "feeder" structures and are more bedding-parallel away from the "feeders". Bedding-parallel veins are particularly well developed below shale beds which presumably formed an impermeable barrier to upward migrating hydrothermal fluids. Both vertical and bedding-parallel veins often coalesce to form a sulphide-matrix breccia. Breccia "fragments" typically display distinctive cuspate edges, a generally rounded shape, and lack evidence of rotation or movement. These textures suggest direct replacement of the carbonate minerals which formerly occupied the position of the sulphide matrix. Breccia "fragments" commonly retain a dolomite mineralogy but have dedolomitized rims (2-4cm thick) containing minor, fine-grained, interporosity infill sphalerite. Sulphides in breccias and veins are fine-grained on vein margins and "fragment" edges, and are coarser-grained in vein centres or in the breccia matrix. Geopetal sulphides are present within rare vugs in both veins and breccia zones.

Sphalerite-galena-pyrite-calcite veins and replacements in the Index Bed are similar in style and orientation to those in dolostones. Sulphide-filled vugs, some with well-developed geopetal textures, are more common in the Index Bed than in dolostones, and some have diameters of 1m. Dedolomitization associated with this period of mineralization extends further from mineralized zones in the Index Bed sandstones and conglomerates (tens of centimetres) than in adjacent dolostones.

Sphalerite is the most abundant sulphide and ranges in colour from pale brown to red-brown. Associated galena is generally euhedral, cubic, argentiferous and contains tiny inclusions of boulangerite ($Pb_5 Sb_4 S_{11}$) (Fernandez, 1957). Pyrite is generally fine- to medium-grained and is commonly intergrown with sphalerite or calcite. Calcite occurs as a replacement of dolomite in dedolomitized areas; it preserves the original texture and the carbonaceous inclusions of the dolomite. Calcite also occurs as fine- to extremely coarse-grained intergrowths with base metal sulphides. This calcite lacks carbonaceous inclusions.

Sulphide layers, especially well developed in vugs and cavities, suggest that the first sulphide to precipitate was extremely fine-grained sphalerite. This sphalerite is pale brown and occurs only on cavity floors as fine laminae. Succeeding layers are rhythmic bands of medium- to coarse-grained sphalerite, sphalerite-galena, and sphalerite-galena-pyrite-calcite which line the vug walls. Generally, successive bands are more galena-rich. Some coarse sphalerite crystals in these bands have corroded edges, and some entire sulphide bands are truncated by "unconformities". These textures suggest a complex history of sulphide precipitation and dissolution. Rarely, layers of fine-grained, laminated sphalerite are present between coarse-grained bands on cavity floors suggesting repeated geopetal sulphide precipitation.

The final filling material in cavities and veins is blocky calcite within which are anhedral to euhedral crystals of pyrite, galena and subsidiary sphalerite. This late calcite may also occur as a breccia matrix surrounding fragments of the earlier-formed, banded sulphides. Thin veinlets, containing calcite and honey-coloured sphalerite, were the last structures formed during the main sulphide event and cut across all earlier styles of mineralization.

The sphalerite-galena-pyrite-calcite of the main sulphide event comprised the majority of the ore mined at Abbeytown. The western orebody was an anastomozing system of nearly vertical, short, bedding-parallel veins and cavities which extended vertically and horizontally along, and to the west of, the West Fault. The best mineralization was developed in the crinoidal member of the Ballyshannon Limestone. The eastern orebody, from which most of the production of the mine was derived, was developed in, and immediately above, the Index Bed. In this tabular orebody the veins and vugs were dominantly parallel to bedding and were closely spaced. Inter-vein areas commonly contained disseminated sulphide mineralization.

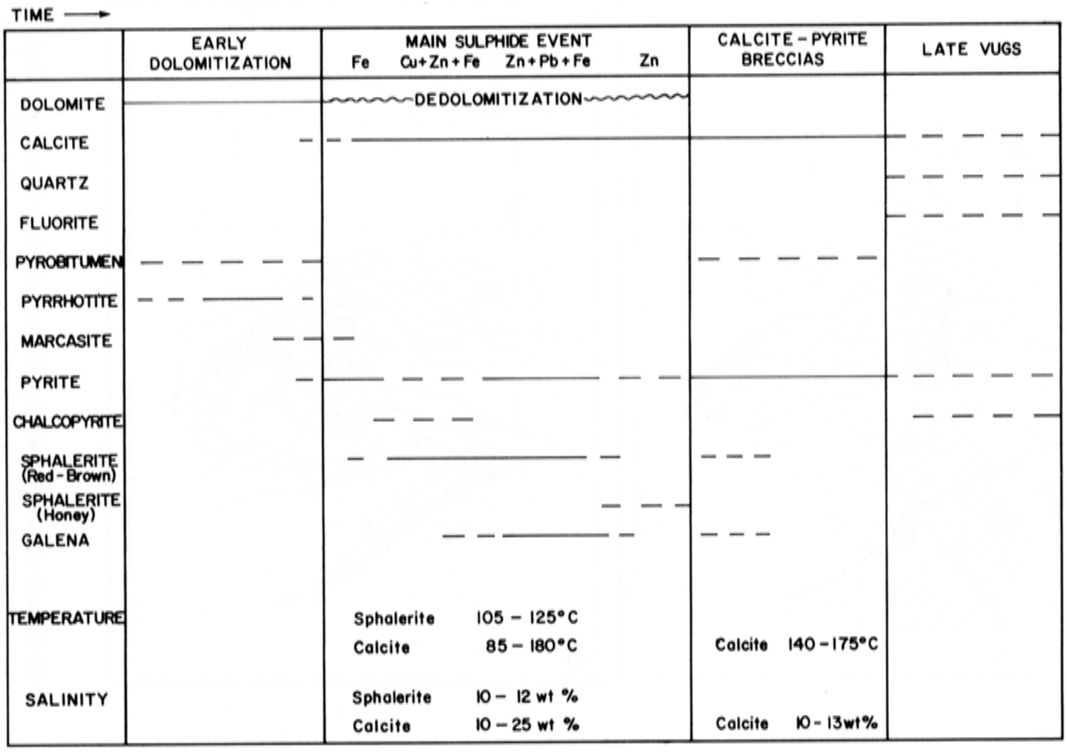
Calcite-pyrite breccia event

Calcite-pyrite breccias cut earlier sphalerite-galena mineralization of the main sulphide event. The breccia zones are dominantly narrow features (several cm to 3m) centred on the eastern and western structural zones. Breccia fragments are angular clasts of dolostone, dedolomitized limestone, mineralized rock, or rarely, previously unaffected limestone. Dedolomitization halos in dolostones are either absent or extremely narrow.

The breccia matrix is composed of calcite with abundant pyrite. Two varieties of calcite are present. One is white and free of included carbonaceous material, the other is dark grey. The white calcite crystals are blocky, coarse and subhedral to euhedral; pyrobitumen is locally present as a coating between crystals. Open vugs are common in this

Table 2

Paragenesis of alteration and mineralization of the Abbeytown mine.



white calcite. The dark grey, fine-grained calcite is much less common. Its dark colour is due to included pyrite. It occurs interlayered with laminated pyrite and trace sphalerite and galena, on the floors of vugs in the breccia matrix, suggesting that it was deposited as an internal sediment. Coarse-grained pyrite, along with minor sphalerite, galena and pyrobitumen, occur as rims on breccia fragments, in veins and on cavity walls. Purple fluorite is found in similar, but scarce and less well-developed, calcite-pyrite breccias in the area surrounding the Abbeytown deposit, but fluorite has not been observed in the mine area.

Late vugs

The final hydrothermal event recognized at Abbeytown formed vugs and veins filled with euhedral calcite, pink dolomite and quartz (Fernandez, 1957). Rarely these vugs contain late, euhedral, chalcopyrite crystals growing on the carbonate minerals. These structures are apparently analogous to the late veins and vugs at Tynagh (Boast et al., 1981) which display a similar mineralogy.

Fluid inclusion studies

Six samples, four representing the main sulphide event and two representing the calcite-pyrite breccia event, were examined for fluid inclusions by Robert Bodner of the Chevron Oil Field Research Laboratory in La Habra, California.

Main sulphide event

Coarse-grained, rhythmically banded sphalerite from the sphalerite-galena-pyrite-calcite assemblage contains a sparse number of small, two-phase inclusions. Homogenization temperatures for these inclusions, uncorrected for pressure, range from 105° to 123°C (Fig. 6). These temperatures are similar to those found by McLimans (1977) for several generations of sphalerite in the Upper Mississippi Valley district. Inclusions in sphalerite from Abbeytown show consistent freezing point salinities of 10 to 11 weight per cent NaCl equivalent. This is slightly lower than average salinities measured in other Mississippi Valley-type (MVT) deposits (Roedder, 1967).

Blocky calcite, deposited late during the main sulphide event, also contains small, two-phase fluid inclusions. Temperatures and salinities display a bimodal distribution. One population has an uncorrected homogenization temperature range of 88° to 146°C with corresponding salinities of 22 to 25 weight percent NaCl equivalent. The second population gives temperatures ranging from 105° to 180°C with salinities of 10 to 16 weight percent NaCl equivalent.

Two samples of calcite-pyrite breccia were examined for fluid inclusions. Coarse calcite grains in this assemblage contain two-phase inclusions which display an uncorrected temperature range of 139° to 174°C. These inclusions have freezing point salinities of 10 to 13 weight percent NaCl equivalent. The similarities in regard to temperature and salinity to those in the final calcite generation of the main sulphide event suggest that the calcite-pyrite breccia event is a continuation of the main sulphide event.

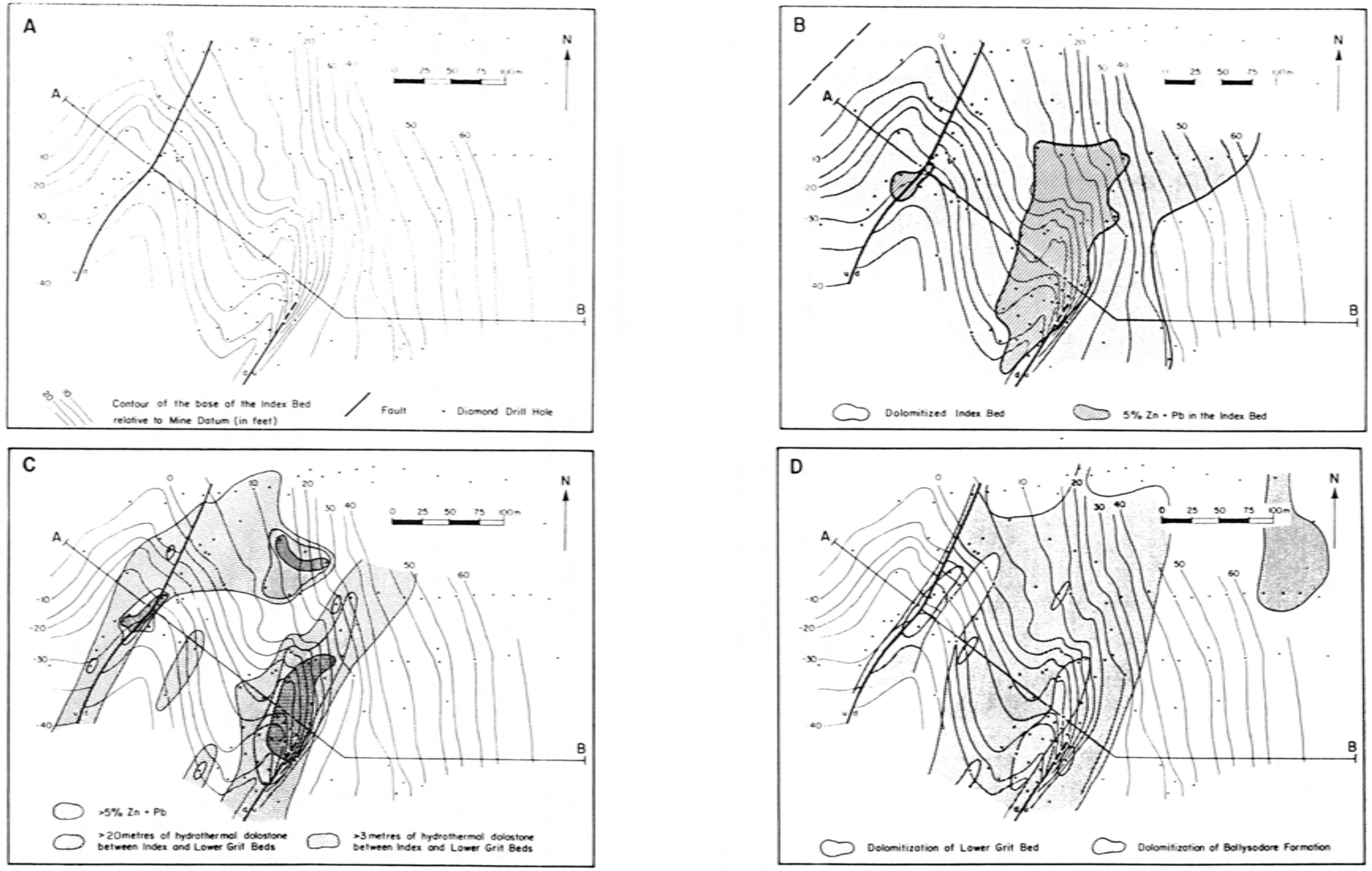


Figure 5. Plan maps of the Abbeytown mine area.

(A) Contour map of the base of the Index Bed.

(B) Extent of dolomitization and mineralization in the Index Bed.

(C) Extent of dolomitization and mineralization in the Ballyshannon Limestone between the Index and Lower Grit Beds.

(D) Dolomitization of the Lower Grit Beds and the underlying Ballysodare Formation.

The variability of homogenization temperatures and freezing-point salinities from the inclusions in calcite and sphalerite supports the petrographic observations of a complex hydrothermal history with numerous pulses of fluid causing both precipitation and dissolution of sulphides and carbonates. The nearly uniform vapour-to-liquid ratios suggest boiling did not occur. The overall temperature and salinity range is characteristic of the Mississippi Valley-type of deposits (Roedder, 1967). However, the values are low compared to temperatures of 175°C to nearly 300°C derived from the Keel (Morrissey et al., 1971), Tynagh (Boast et al., 1981), and Silvermines deposits (Samson and Russell, 1983).

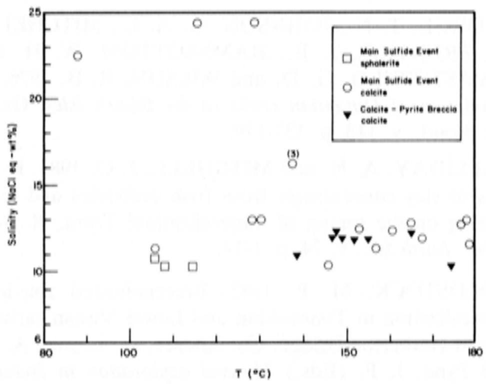


Figure 6. Salinity — homogenization temperature plot of fluid inclusion data from six samples from the west zone of Abbeytown mine.

Genesis of the Abbeytown deposit

The Abbeytown deposit is structurally controlled by two NNE-trending fault zones which are parallel to the mapped fault east of Ballysodare which connects the termination zone of the Ox Mountains Fault with the Ballysodare Fault. In plan view, early dolomitization in the mine area forms a highly elongate, oval shape centred on these Faults. The oval is characteristic of tension "gashes" formed by movement on two adjacent and parallel transcurrent faults.

The structures which localized mineralization at Abbeytown apparently formed as pull-apart structures related to the termination zones of the Ox Mountains and Ballysodare Faults. This structural setting is similar to that recently recognized as controlling the location of mineralization at Silvermines (Taylor, 1984). Unlike Silvermines, however, there is no evidence at Abbeytown that the formation of the tensional structures was contemporaneous with deposition of the sediments hosting the ore deposit. The fact that early hydrothermal dolomite replaced calcite which had previously filled moldic porosity in the limestones, combined with the occurrence of sharp-edged vein structures containing base metal mineralization, suggests that both alteration and mineralization occurred after diagenesis and lithification of the enclosing sediments.

Exact dating of the structures is difficult. The thinning of the Mullaghmore Sandstone in the southern Sligo region and its apparent nondeposition south of the Ox Mountains are circumstantial evidence that uplift, perhaps due to anticlinal folds along the developing transcurrent system, may have begun in the Abbeytown area by the Holkerian (Fig. 7). Both the Ballysodare and Ox Mountains Faults were probably active by the Asbian, and their termination zones would have been joined by a series of transverse faults and fractures, including the tensional fractures in the Abbeytown area. Continued movement along these faults apparently resulted in the breakthrough of the Ballysodare Fault to the Ox Mountains Fault west of Abbeytown in the late Asbian. Such a breakthrough would have imposed a compressional regime on the area which would not favour open-space filling styles of mineralization. Late, nearly easterly trending joints which cut mineralization may be related to this movement.

The inferred local and regional structural history favours mineral emplacement during Asbian time. Lead isotope studies by Pockley (1961) and Moorbath (1962) indicate a possible Lower Carboniferous age of mineralization. Two K-Ar dates (270 and 285Ma, latest Carboniferous to early Permian) for the mineralization at Abbeytown have recently been derived by Halliday and Mitchell (1983) from chlorite apparently intergrown with sphalerite and galena in dedolomitized limestone. These late dates probably reflect minimum ages of ore formation, and further analytical work on carefully collected samples is required to ascertain their significance. The available evidence points to an Asbian or later date for mineralization at Abbeytown, after the inferred period of lead-zinc mineralization at the major deposits further south in Ireland.

The source of the hydrothermal fluids which created the Abbeytown deposit is not known with certainty. Russell's (1978) concept of downward excavating hydrothermal cells seems unreasonable with regard to the Abbeytown area. The basement at Abbeytown is amphibolite to upper amphibolite grade metamorphic rocks which have virtually

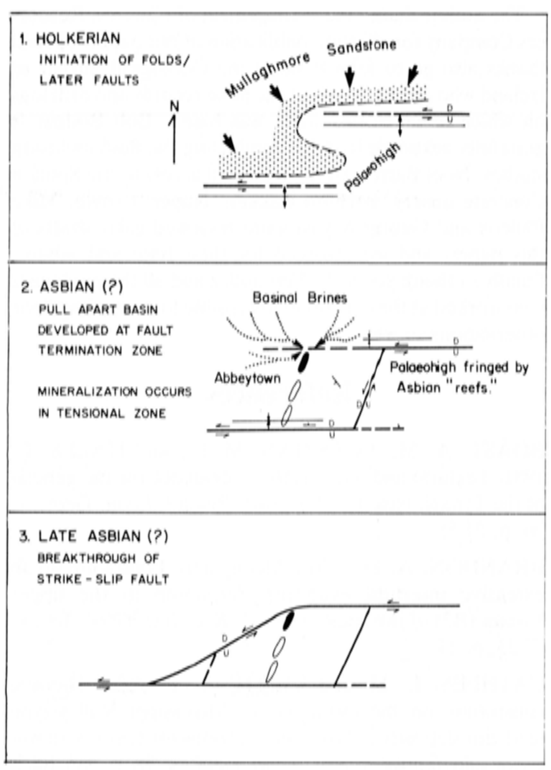


Figure 7. Inferred structural and sedimentological history of the Abbeytown area during the early Carboniferous, relating mineralization to structural events.

no remnant permeability or porosity. Fracture-induced permeability is not well developed in samples of basement drilled at the mine or exposed within one kilometre of the mine. The few fractures in these exposures often contain minor pyrite, but the fracture walls do not display alteration envelopes exceeding several millimetres in thickness. The absence of thicker alteration envelopes makes it doubtful that sufficient rock has been altered to liberate the elements necessary to form the known mineralization.

A more likely source for the mineralizing solutions is the sedimentary rocks in the Sligo syncline, a major basin to the north of Abbeytown, which contains a basal clastic section derived from the same high-grade metamorphic basement rocks underlying the Abbeytown deposit. The surface area available for leaching by basinal brines in these sandstones and conglomerates during the early Carboniferous was probably greater than that in the mildly fractured basement. Fluid movement may have been initiated by periodic pressure release from geopressured zones (Cathles and Smith, 1983), by increased heat flow related to crustal extension associated with the transcurrent fault systems, or, more probably, a combination of these factors.

Abbeytown is dissimilar to the stratabound deposits in the Courceyan (lowest Carboniferous) rocks of central and southern Ireland in both style and timing of mineralization. It may be more similar in style to the Harberton Bridge deposit (Holdstock, 1982; Emo, this volume). The textures, temperatures, and timing of the mineralization at Abbeytown suggest it should be classified as a replacement-style Mississippi Valley-type deposit.

Acknowledgements

The author thanks the management of Chevron Resources Company for allowing publication of this paper. Special thanks also go to John Pyne of the Geological Survey of Ireland who located many of the mine records and drill logs on which much of this study was based. Bob Bodnar is gratefully acknowledged for conducting the fluid inclusion studies. Noel Barrett kindly provided access to the Spollen Concrete quarry. Barbara Bakken, Rupert Crowe, Mike Philcox and George Sevastopulo reviewed early drafts of this paper, and are thanked for their time and advice. Finally, a thank you to L. Fernandez and all the geologists who worked at the old Abbeytown mine for recording their observations so well.

References

BOAST, A. M., COLEMAN, M. L., and HALLS, C. 1981. Textural and stable isotopic evidence for the genesis of the Tynagh base metal deposit, Ireland: *Econ. Geol.*, v. 76, p. 27-55.

BRANDON, A. 1977. The Meenymore Formation — an extensive intertidal evaporitic formation in the upper Visean (B2) of northwest Ireland: *Rep. Inst. Geol. Sci.*, v. 77/23, p. 14.

CATHLES, L. M. and SMITH, A. T. 1983. Thermal constraints on the formation of Mississippi Valley-type lead-zinc deposits and their implications for episodic dewatering and deposit genesis: *Econ. Geol.*, v. 78, p. 983-1002.

DENNISON, J. B. and VARVILL, W. W. 1952. Prospecting with the diamond drill for lead-zinc ores in the British Isles: *Trans. Instn. Min. Metall.*, v. 62. p. 1-21.

DICKSON, J. A. D. 1966. Carbonate identification and genesis as revealed by staining: *J. Sed. Petr.*, v. 36, p. 491-505.

EMO, G. T. 1986. Some considerations regarding the style of mineralization at Harberton Bridge, Co. Kildare. *This volume.*

FERNANDEZ, L. L. 1957. The geology and mineralization of Abbeytown Mine, Co. Sligo, Eire: Unpubl. B.Sc. thesis, Royal School of Mines, London. 85pp.

GEOL. SURVEY N. IRELAND. 1970. *Geological map of Northern Ireland, 1:250 000.* Dept. Comm., N. Ireland Ordnance Survey.

GEORGE, T. N., JOHNSON, G. A. L., MITCHELL, M., PRENTICE, J. E., RAMSBOTTOM, W. H. C., SEVASTOPULO, G. D. and WILSON, R. B. 1976. *A correlation of Dinantian rocks in the British Isles:* Geol. Soc. Lond., v. 113, p. 137-179.

HALLIDAY, A. N. and MITCHELL, J. G. 1983. K-Ar ages of clay concentrates from Irish orebodies and their bearing on the timing of mineralization: *Trans. R. Soc. Edin.: Earth Sci.*, v. 74, p. 1-14.

HOLDSTOCK, M. P. 1982. Breccia-hosted zinc-lead mineralization in Tournaisian and Lower Visean carbonates at Harberton Bridge, Co. Kildare: *In:* Brown, A. G. and Pyne, J. F. (Eds.) *Mineral exploration in Ireland: Progress and Developments, 1971-1981:* Dublin, Irish Assoc. Econ. Geology, p. 83-91.

LONG, C. B., and MAX, M. B. 1977. Metamorphic rocks in the SW Ox Mountains inlier, Ireland: their structural compartmentation and place in the Caledonian orogen: *J. Geol. Soc. Lond.*, v. 133, p. 413-432.

MCLIMANS, R. K. 1977. Geologic, fluid inclusion and stable isotope studies of the Upper Mississippi Valley zinc-lead district, southwest Wisconsin: Unpubl. Ph.D. thesis, Penn. State Univ., 175pp.

MOLLOY, M. A., and SANDERS, I. S. 1983. The NE Ox Mountains Inlier: Coolaney Area. *In:* Archer, J. B. and Ryan, P. D. (Eds.). *Geological Guide to the Caledonides of western Ireland:* Geol. Surv. Ireland Guide Series, no. 4, p. 52-55.

MOORBATH, S. 1962. Lead isotope abundance studies on mineral occurrences in the British Isles and their geological significance: *Phil. Trans. R. Soc.*, v. A254, p. 295-360.

MORRISSEY, C. J., DAVIS, G. R. and STEED, G. M. 1971. Mineralization in the Lower Carboniferous of central Ireland: *Trans Instn. Min. Metall.*, v. 80, p. B174-185.

O BRIEN, M. V. 1959. The future of non-ferrous mining in Ireland. *In: The future of non-ferrous mining in Great Britain and Ireland:* Instn. Min. Metall., London. p. 5-26.

OSWALD, D. H. 1955. The Carboniferous rocks between the Ox Mountains and Donegal Bay: *Q. Jl. Geol. Soc. Lond.*, v. 111, p. 167-186.

PHILLIPS, W. E. A., TAYLOR, W. E. G. and SANDERS, I. S. 1975. An analysis of the geological history of the Ox Mountain inlier: *Sci. Proc. R. Dublin Soc.* v. 5A, p. 311-329.

PHILLIPS, W. E. A., STILLMAN, C. J. and MURPHY T. 1976. A Caledonian plate tectonic model: *Jl. Geol. Soc. Lond.*, v. 132, p. 579-609.

POCKLEY, R. P. C. 1961. Lead isotope and age studies of uranium and lead minerals from the British Isles and France: Unpubl. Ph.D. thesis, Univ. of Oxford.

ROEDDER, E. 1967. Environment of deposition of stratiform (Mississippi Valley-type) ore deposits, from studies of fluid inclusions: *Econ. Geol. Monograph 3,* p. 349-362.

RUSSELL, M. J. 1978. Downward-excavating hydrothermal cells and Irish-type ore deposits: importance of an underlying thick Caledonian prism. *Trans. Instn. Min. Metall.,* v. 87, p. B168-171.

SAMSON, I. M. and RUSSELL, M. J. 1983. Fluid inclusion data from Silvermines base-metal-baryte deposits, Ireland: *Trans. Instn. Min. Metall.,* v. 92, p. B67-71.

SCHULTZ, R. W. 1971. Mineral exploration practice in Ireland: *Trans. Instn. Min. Metall.,* v. 80, p. B238-258.

SHERIDAN, D. J. R. 1972. *Upper Old Red Sandstone and Lower Carboniferous of the Slieve Beagh syncline and its setting in the northwest Carboniferous basin, Ireland:* Geol. Surv. Ireland Spec. Pap. 2. 129 pp.

TAYLOR, S. 1984. Structural and paleotopographic controls of lead-zinc mineralization in Silvermines orebodies, Republic of Ireland: *Econ. Geol.* v. 79, p. 529-548.

WILLIAMS, C. E. and McARDLE, P. 1978. Ireland: *In:* Bowie, S. H. U., Kvalheim, A. and Haslam, H. W. (Eds.) *Mineral deposits of Europe, Volume 1: Northwest Europe:* Inst. Min. Metall., p. 339-340.