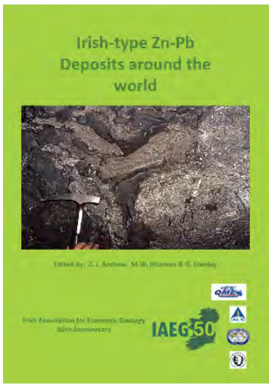


Irish Association for Economic Geology
(founded 1973)

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

Irish, but not Irish-type

Colin J. Andrew[1] **& Gerry Stanley**[2]

[1] *Independent Consultant, Navan, County Meath, Ireland.*
[2] *Geologist, retired*

Corresponding Author: Gerry Stanley gerrystanley30@gmail.com

To cite this article: Andrew, C.J. & Stanley, G. (2023) Irish, but not Irish-type. *In:* Andrew, C.J., Hitzman, M.W. & Stanley, G. '*Irish-type Deposits around the world*', Irish Association for Economic Geology, Dublin. 211-230. DOI: https://doi.org/10.61153/IQDT2752

To link to this article: https://doi.org/10.61153/IQDT2752

Irish, but not Irish-type

Colin J. Andrew[1] & Gerry Stanley[2]

[1] *Independent Consultant, Navan, County Meath, Ireland.*

[2] *Geologist, retired*

Abstract: Ireland is well known as a host to many carbonate-hosted zinc-lead deposits dating back to the discovery of the Tynagh deposit in 1961 which ushered in a prospecting rush which resulted in the discovery of several deposits and prospects, e.g., Ballinalack, Boston Hill, Carrickittle, Courtbrown, Harberton Bridge, Keel, Moyvoughly, Navan, Oldcastle and Silvermines. Research into understanding these deposits, in order to further advance successful exploration, initially adopted a Mississippi Valley Type model to direct exploration. However, it soon became apparent that many of the deposits in Ireland did not fit this model and a new paradigm was needed. The term Irish-type was coined to more fully describe those deposits. However, there were some deposits that did not fit this new model notably Abbeytown, Allenwood, Boston Hill and Harberton Bridge (the latter three deposits collectively known as the Kildare District). Unlike most Irish-type deposits they strongly cross-cut the stratigraphy and have a vertical extent that is far greater than the lateral extent. Mineralogically they are significantly different with marcasite being the dominant iron sulphide. Plots of fluid inclusion data fall within fields separate to all the deposits in the Irish Midlands and are similar to the ranges of major MVT deposits from around the world. Similarly sulphur isotopic results show no evidence of the bacterial sulphate reduction that typify the Irish-type deposits and generally all fall with the range of “hydrothermal sulphur”. Fluid inclusion data is indicative of high salinity fluids enriched in chloride relative to bromide and suggests a component of salinity derived via dissolution of halite or from evaporation of seawater. Therefore, the region in which these fluids formed should contain evidence of halite.

In this paper we describe the geological features of these deposits and critically assess the evidence which permits us to assign these deposits to the Mississippi Valley class of deposits – notwithstanding that clearly, they are geographically Irish, but they do not possess the typical diagnostic characteristics of Irish-type Zn-Pb deposits.

Keywords: Kildare District; Abbeytown; MVT; Irish-type; Ireland

Introduction

The underlying concept that led to the discovery of Tynagh in the early 1960s was that as the central midlands of Ireland were underlain by carbonates and many of the zinc-lead deposits in North America were hosted in carbonates and located in the region known as the Mississippi Valley Region leading to the common usage of the term “Mississippi Valley Type” (“MVT”) (Bastin, 1939). In the early days of the renaissance of mineral exploration in Ireland it was commonplace to refer to the Irish deposits as being of this type. However, once more detailed observations were made it became clear that the Irish carbonate-hosted deposits were significantly different to typical MVT deposits. In 1977, at a meeting of the IAEG held in Athlone to receive a presentation on the Silvermines orebodies the term “Irish-type Zn-Pb deposit” was first coined. Since then, the term Irish-type has been extended to describe other deposits in Ireland and has also found advocates to describe Zn-Pb mineralization lying between the end members of Clastic Dominated (CD) (or SedEx) and MVT deposits worldwide.

The Kildare Zn-Pb deposits at Harberton Bridge, Allenwood, Rickardstown, Boston Hill, Betaghstown and Cloncurry, are located around 40km WSW of Dublin. These deposits found in Ireland do not possess the characteristics typical of Irish-type deposits. It is these deposits and the deposit at Abbeytown, County Sligo (also known as Ballysodare) that are the subject of this paper. (Figure 1).

The Kildare District includes: Harberton Bridge (Canal or McGregor, Bridge or Shamrock and Church Zones); Allenwood (East, West, North and South); Boston Hill and Cloncurry; Rickardstown and Clongownagh (Figure 2).

Virtually all previous authors describing these deposits

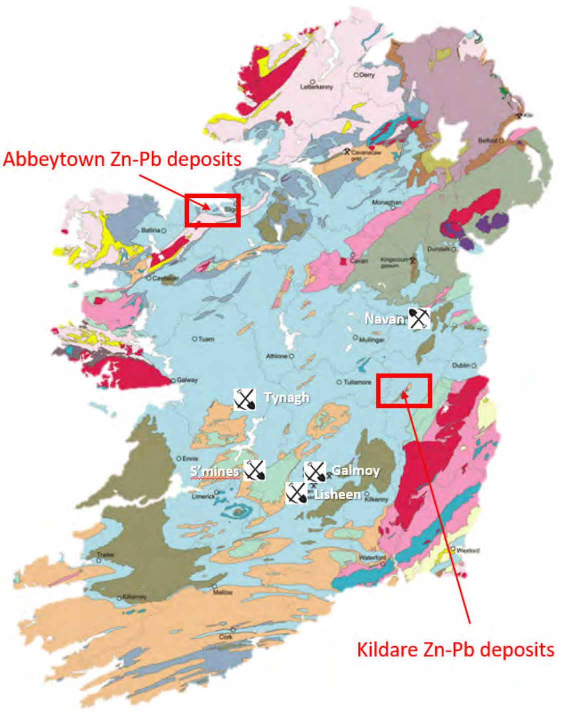


Figure 1: *Geological map of Ireland showing locations of the Kildare District and the Abbeytown Area*

considered that the prospects represent examples of MVT deposits. (Jones, 1979; Holdstock, 1982,1983; Emo, 1986; Hitzman & Beatty 1996; Gallagher *et al*, 1992, Trude & Wilkinson, 2001). However more recently some authors have used the term Irish-type for the Harberton mineralization.

The Abbeytown deposit lies on the northern fringe of the Irish Orefield in County Sligo and also displays features significantly different from the classical Irish-type deposits.

These deposits are enigmatic in that clearly, they are located in the Central Irish Orefield, but have characteristics that are demonstrably much closer to classical Mississippi-Valley Type ("MVT") than to their Irish-type cousins elsewhere in the Orefield. Wilkinson (2003) has stated that the term ''Irish type'' should be reserved for deposits that display the criteria usually associated with such deposits. This clearly would specifically exclude deposits such as Harberton Bridge, Allenwood and Abbeytown which display many features that are typical of MVT deposits and represent an endmember of the spectrum of mineral deposits observed in the Irish Orefield.

The critical aspect is that, in comparison with Irish-type deposits, MVT deposits have no requirement for a link between the tectonic environment in which the host rocks were deposited and that in which mineralization subsequently developed (Leach *et al*, 2010; Paradis *et al*, 2007).

Previous studies

Kildare

A number of studies and papers have been published on the Kildare deposits (Holdstock 1982, 1983; Emo 1986; Gallagher *et al.*, 1992; Trude & Wilkinson, 2001) and they all consider them to be examples of Mississippi Valley-type ("MVT") mineralization, characterized by sulphide and carbonate cemented cavity fill breccias (Andrew 1993; Hitzman & Beaty 1996). This is in contrast to most other Irish carbonate-hosted deposits which show a complex range of mineralization styles, dominated by syndiagenetic, replacive and cavity fill sulphides (Hitzman & Large 1986; Andrew 1993) with local exhalative mineralization at Silvermines and possibly Navan (Boyce *et al*., 1983; Anderson *et al*., 1998; Wilkinson *et al.*, 2005, Yesares *et al*., 2022).

Abbeytown

At Abbeytown Hitzman (1986) summarized the geology and history of the deposit and provided the initial fluid inclusion data. Later, Persellin (2009) and Persellin *et al* (2010) reported further detailed research which included stable isotope, cathode luminescence, further fluid inclusion work, and detailed petrographic studies. Both workers considered that the Abbeytown deposit has affinities similar to MVTs.

Deposit descriptions

Kildare

Exploration History

Initial ground selection to the Kildare area was guided by the location of historic mineral occurrences and the apparent common features of the zinc-lead deposits discovered up to that time, namely, 1) presence of Waulsortian Mudbank Limestones, and 2) known faults bounding, and in close proximity to, an inlier – in this instance the Kildare Inlier. Several exploration companies have held Prospecting Licences over the past 50 or so years and over different parts of the overall Kildare area. The companies which are credited with discoveries in the district are Newmont / Irish Base Metals (Boston Hill and Cloncurry – 1966); Syngenore (Harberton Bridge – 1975); and Athlone Prospecting and Development Company (APDC) (Allenwood – 1976). However, exploration by subsequent companies has both added to the identified resource base and knowledge, notably Billiton Exploration Ireland, Marathon Mining Ireland, Ennex International, Oliver Resources, Asarco and, latterly, Zinc of Ireland.

In initial exploration work, by Newmont and Munster Base Metals (MBM), a strong soil geochemical anomaly was located near Boston Hill and minor mineralization was noted in small nearby quarries. Drilling revealed the presence of disseminated and fracture-controlled Zn-Pb mineralization in the Upper Laminated Calcarenite ("ULC"), a unit initially thought to be part of the Navan Beds but subsequently revealed to be higher in the succession, but still some 200m below the base of the Waulsortian Mudbank. Mineralization estimated at 0.76 Mt at 4% Zn+Pb was outlined at Boston Hill/Cloncurry (Boland & Colthurst, 1995).

Exploration in the Harberton Bridge area commenced in the late 1960s with shallow soil geochemistry followed up by deep overburden sampling. This, in turn, was followed up by geophysical surveying, the most successful of which was dipole-dipole Induced Polarization (Emo, 1986; Cazalet, 1982). The initial soil geochemical surveys located zinc anomalies up to

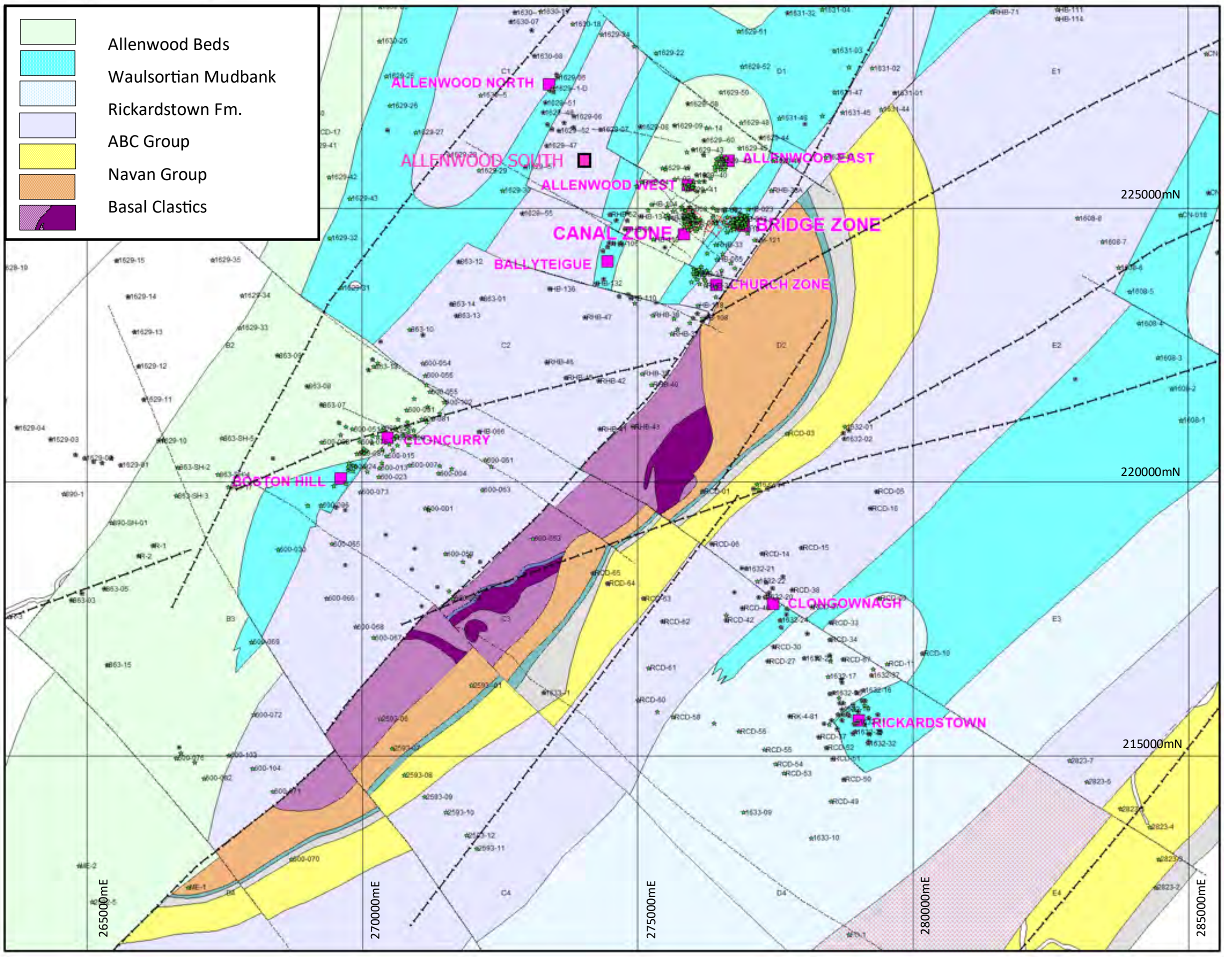


Figure 2: *Geological map of the Kildare District showing locations of the mineralized bodies and significant drillholes.*

600ppm with follow up deep overburden sampling identifying a weathered trough in the Waulsortian bedrock infilled with ‘rusty brown clay’ returning assays of up to 10.8% Zn and 1.84% Pb. In 1975, drilling by Syngenore (a joint venture between Barymin and Noranda) discovered breccia bodies hosting Zn-Pb mineralization in oolites and micrites of the Allenwood Formation lying above the Waulsortian Mudbank. Further work and deeper drilling by Noranda outlined an Inferred Resource of 3.7Mt at 9.9% Zn+Pb at Harberton Bridge (Jones, 1979).

Subsequent drilling (1979-85) by Billiton and Oliver Resources (1987-95) in these areas discovered extensive breccia bodies containing variable quantities of marcasite, sphalerite and galena across the Kildare area. These bodies were mostly developed in the Waulsortian Mudbank, but they extended upwards into the overlying Allenwood Formation shelf limestones and also continued down below the base of the Waulsortian where they were associated with dissolution, brecciation and marcasite mineralization in a fairly clean calcarenite unit, and which usually marked the base of the breccia systems (Holdstock 1982, 1983).

In early 1990 Ennex International, reported that a Cominco geologist with Pine Point experience had reviewed much of the data and concluded that the Kildare area had undergone extensive palaeo-karstification and that it was directly comparable to Mississippi Valley camps elsewhere. At that time, it was concluded that "..*there is excellent potential for an economic MVT style deposit to be present in the Kildare area*" (Rhodes & Vickers, 1990).

Further drilling at Harberton and Allenwood and the reinterpretation of earlier drill results, by Zinc of Ireland NL (“ZMI”) between 2016 and 2022 (the current permit holders) has increased the known mineralization to an Inferred Resource (to JORC standards) of 11.3Mt @ 7.8% Zn, 1.2% Pb using a 5% Zn Eq cut-off.

Regional and local geology

The Geological Survey Ireland published map for the area (scale 1:100,000), (McConnell *et al.*, 1994) is based largely on the work of exploration companies and in particular Mike Philcox, who acted as a consultant to many of the exploration companies operating in the area. The Kildare area of the map is located towards the northwest of the map area and comprises Carboniferous lithologies surrounding the Lower Palaeozoic Kildare Inlier (Figure 2).

The Kildare Inlier measures some 11km along strike by 1.5km wide and has a northeast – southwest trend. The Lower

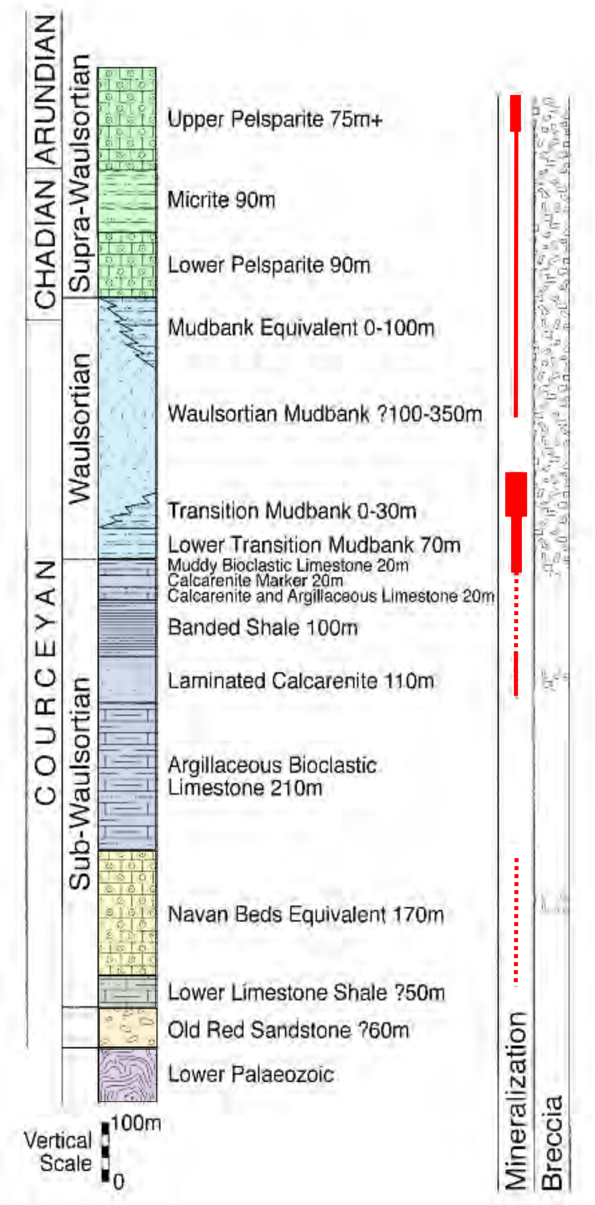


Figure 3: *Stratigraphic column for the Harberton Bridge Area after Emo (1986), showing extent of the breccia-hosted mineralization.*

Palaeozoic Inlier is bounded along its northwest side by the steeply southerly dipping Kilmeague Thrust Fault while the southeast side is an unconformity with overlying Old Red Sandstone.

The Inlier comprises two distinct parts separated by an unnamed northwest trending fault which separates Dunmurry Hill from Grange Hill. The area to the southwest of this fault comprises Silurian lithologies of the Guidenstown, Rahilla and Dunmurry Formations of Lower Silurian age. The area to the northeast of the fault comprises the Conlanstown, Grange Cottage, Allen Andesite, Grange Hill and Kildare Limestone Formations all of Upper Ordovician age (Figure 2).

The Lower Palaeozoic rocks are unconformably overlain by a basal Carboniferous succession commencing with clastic fluvial red beds of the Keeloges Sandstone (Holdstock, 1983) which is more commonly known as the “Old Red Sandstone Formation”. (Figure 3). The Keeloges Sandstone is typically 25m thick but may be up to 50 metres in some areas (Holdstock 1983).

Above the Old Red Sandstone Formation is a unit normally described as the Lower Limestone Shales or Mixed Beds (Ferbane Mudstone and Cloghan Sandstone). This is probably circa 60m thick in the Kildare area and consists of flaser bedded sandstones and shales. Above this unit is a sequence, around 175-200m thick, of oolitic calcarenites, micrites and argillaceous calcarenites (Feighcullen) interpreted as being the equivalent of the Navan Group of the Central Midlands (McConnell *et al*., 1994).

The Navan Group is overlain by an argillaceous bioclastic limestone unit (“ABL”) which is up to 228m thick dominated by argillaceous crinoidal calcarenites with wavy shale partings. Above this is the Upper Laminated Calcarenite (ULC) with a thickness of around 100m at Boston Hill and 110m at Harberton Bridge. The top of the unit is usually marked by a fairly massive pale shale-free calcarenite.

The overlying Banded Shale Unit comprising black and grey calcareous laminated argillites (thickening from around 65m at Boston Hill to 100m at Harberton Bridge) is overlain by the Silty Calcarenite Unit. The top part of this unit at Harberton Bridge is very clean, cross-bedded and locally dolomitised. It generally marks the base of the dissolution and brecciation systems associated with the Kildare Zn-Pb deposits.

At Boston Hill and in the Rathangan area, the Silty Calcarenite Unit is overlain by the Waulsortian Mudbank Complex and its equivalent lithologies. Holdstock (1983) and Emo (1986) recognised three units between the Calcarenite Marker (top of the Silty Calcarenite) and the base of the Waulsortian proper. These are in ascending order the Muddy Bioclastic Limestone (20m), the Lower Transition Mudbank (65m) and the Transition Mudbank (0-30m). In many of the Harberton Bridge drillholes and also at Allenwood East and West much of the Muddy Bioclastic Limestone has been affected by dissolution and these three units are represented by a complex mixture of muddy rock matrix breccias with or without marcasite and base-metal sulphides. The Lower Transition Mudbank usually consists of cherty crinoidal calcarenites and when thin stromatactid micrites appear, the unit gives way to the Transition Mudbank.

The Waulsortian Formation is well developed in the Harberton Bridge and Allenwood areas where in some holes it is up to 300m thick. There are however rapid facies changes, especially at the top, and stratigraphically equivalent cherty calcarenites and micrites are present in some drillholes. At Rickardstown the Waulsortian facies is developed as an isolated knoll attaining a thickness of up to 265m but thins rapidly in all directions into thinly interbedded nodular crinoidal, often cherty dolomitic micrites and sparsely fossiliferous shales, possibly deposited in a partially restricted nearshore sub-tidal sedimentary environment proximal to the Leinster Massif. Known locally as “Brown Calp” this is the lateral equivalent to the Upper Dolomites as seen further north at Cloncurry and further south

Figure 4: *Simplified structural plan at base of Waulsortian showing principal faults and distribution of mineralization within the "McGregor Corridor".*

in County Carlow in the Milford Formation (Nagy *et al.,* 2005).

The Waulsortian varies in thickness in the Kildare area, ranging from a sheet attaining 400m or greater in the north to a complex of knolls which rapidly vary in thickness around Harberton Bridge and further south-eastwards towards Rickardstown. Where the Waulsortian is not developed is a sequence of dolomitized argillaceous calcarenites and oolites usually termed Waulsortian-Equivalent or the Upper Dolomite. These Waulsortian Equivalent rocks also on-lap onto the Waulsortian knolls. Boland & Colthurst (1995) considered these to be a shallow water facies in a near emergent area probably with its axis in the Cappanargid to Cloncurry area. Whilst the development of the Waulsortian and equivalent facies is highly variable in thickness, importantly, no obvious syn-sedimentary structural control is evident.

The Allenwood Formation consists of pale grey, oolitic peloidal, mobile shoal facies limestones and their dolomitized equivalents. The formation is of Chadian to Arundian age and reaches a thickness of at least 400m in some places. The formation is locally seen to be overlaìn by calciturbidites of the Calp, but it is possible that deposition of shelf sediments continued uninterrupted into the Holkerian or Asbian in some areas. In the Allenwood-Harberton Bridge area three main units have been recognised within the formation. The ~90m thick Lower Pelsparite Unit consists of peloidal and crinoidal limestones and minor oolite. The ~90m thick Micrite Unit consists of micrites (some with birdseyes), pelmicrites and minor thin shales. The Upper Pelsparite Unit, over 75m thick, consists mainly of pelsparite. (Emo 1986, McConnell *et al.,* 1994).

The succession to the northwest of the Kildare Inlier is shown in Figure 3. To the southeast of the Inlier there is an additional Formation which overlies the Waulsortian which has been termed the Rickardstown Formation. It is only known from drilling and its extent and thickness is unknown, although McConnell (*op cit*) suggests that it is probably greater than 100m. Lithologically, lower and upper units have been described. The lower unit is varied with thinly interbedded nodular crinoidal, often cherty micrite and fossiliferous shale with scattered Waulsortian derived conglomerates. The upper part of the Rickardstown Formation consists of uniform, dark grey, fine-grained dolomite with abundant chert (McConnell *et al*., 1994). McConnell *et al*. (1994) also state that it is probably equivalent to the Allenwood Formation.

From a structural standpoint, the Kildare Inlier is a north-east trending anticlinal axis which separates the deposits at Rickardstown and Clongownagh (to the southeast) from those at Harberton Bridge, Allenwood and Boston Hill to the northwest. The northern boundary of the inlier is a major Hercynian-aged high-angle reverse fault dipping steeply to the SE formally known at the Kilmeague Fault (McConnell *et al.*, 1994). The thrust appears to bifurcate and diminish towards the NE whilst its extent to the SW is ill-defined. Such thrusts in the Irish Midlands are uniformly of Variscan age.

Apart from the northeast trending Kilmeague Fault bounding the northwest side of the Kildare Inlier there are numerous northwest trending faults which have been interpreted so as to accommodate the geology encountered by exploration drilling. Zinc of Ireland NL (the current licence holders) have identified several 'Corridors' and 'Fault Compartments' (Figure 4) which trend more or less east – west. These fault compartments have been named Allenwood, McGregor and Ballyteague, from north to south. These "corridor" bounding faults are seen in drilling to have high grade mineralization within and adjacent to them on their hangingwall sides and such faults are also known to shift and dislocate the Kilmeague Fault suggesting that mineralization controlling faulting post-dates Variscan compression.

Mineralization description

The main bulk of mineralization in the Kildare area, and especially at Harberton Bridge, is of a breccia hosted type (Trude & Wilkinson, 2001; Holdstock, 1982, 1983; Emo, 1986 and Gallagher *et al*., 1992. It is located primarily within the Waulsortian which is often but not always dolomitised, but also extends upwards into the Allenwood Formation and is often rooted in the Upper Laminated Calcarenite ("ULC") below the Waulsortian giving a total vertical extent of mineralization in excess of 500-600m.

The mineralization in the ULC occurs in graded calcarenite beds (interpreted as calcturbidites by Boland & Colthurst, 1995). The sphalerite and galena occur as fine disseminations within the calcarenites and also within fracture-controlled calcite veinlets. The mineralization is widespread within the ULC, but the best grades seen to date have been at Boston Hill (Cloncurry Cottage) where a small zone estimated at 0.76Mt averaging 3.35% Zn and 0.62% Pb has been outlined (Boland & Colthurst, 1995).

Most mineralization is found within and from slightly below the base of the Waulsortian Limestone with the 20m thick Calcarenite Marker forming the lower boundary to the mineralization (Emo 1986). Mineralization occurs within vertically extensive bodies of variable dissolution, collapse and crackle breccias with the best mineralization found as sulphide rock-

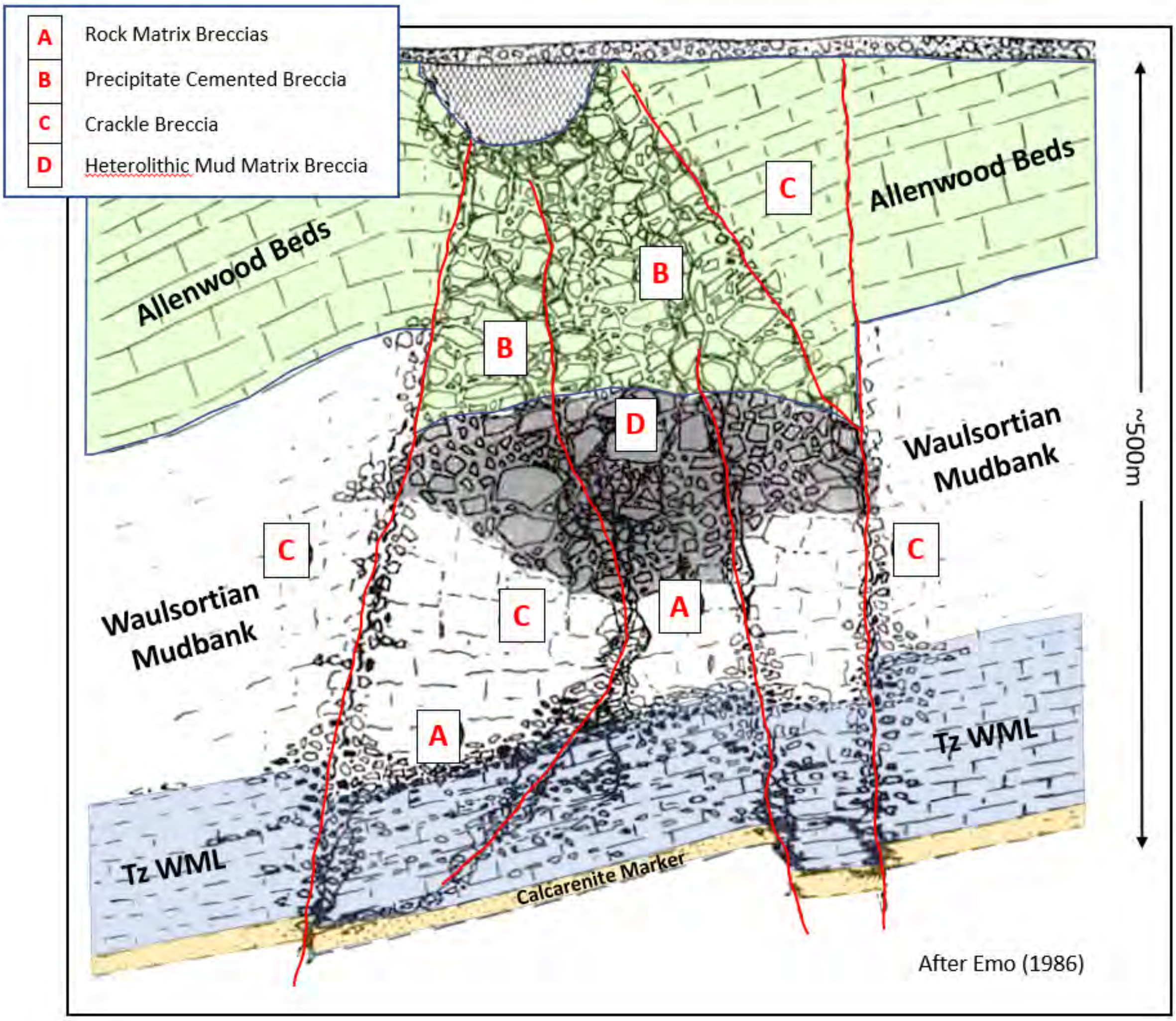


***Figure 5:** Schematic sketch section of a typical breccia body in the Kildare District showing the relative distribution of breccia styles and controlling faults. After Emo (1986).*

matrix breccia at the base of the Waulsortian Mudbank where impressive accumulations of clasts of colloform colour-banded sphalerite, bladed marcasite and subordinate galena have been intersected. For example, 16m @ 22% Zn+Pb in hole Z-4069-027, 36m @ 11% Zn+Pb in hole HB-087; 17m @ 21% Zn+Pb in hole HB-033 and 42m @ 9% Zn+Pb in hole HB-049. The individual breccia bodies vary from a few tens of centimetres to a few hundred metres in vertical extent.

Mineralogically the mineralization is simple with bladed marcasite and sphalerite as the dominant sulphides with minor amounts of galena, commonly intergrown with sphalerite. The most Pb-rich zones are located within the most extensively mineralized breccias near the base of the Waulsortian. In addition, massive coarse bladed marcasite can form stratiform lenses in the immediate sub-Waulsortian where it appears to have grown displacing soft mud-matrix breccia residuum at the base of the breccia systems. The Kildare sulphide breccia zones have a gangue of manganiferous calcite ± dolomite and occasional black resinous pyrobitumen. Locally a pink ferroan-dolomite phase can precede sulphide mineralization with a later dolomite stage also preceding the main base-metal mineralizing event.

Emo (1986) and Holdstock (1982) noted that the breccias form irregularly shaped bodies which crosscut the stratigraphy from above the Calcarenite Marker to the Upper Allenwood Formation.

Within a typical breccia bodies four styles of mineralization have been described by Emo (1986) and Holdstock (1982, 1983) - see Figure 5.

A. Sulphide rock-matrix breccias.
B. Sulphide precipitate-cemented breccias.
C. Sulphide-cemented crackle breccias; *and*
D. Heterolithic mud-matrix breccias.

The breccia bodies typically comprise a central and basal part consisting of a rubble of rotated sulphide and rock fragments set in a fine-grained, often argillaceous, carbonate matrix. This passes outward and upward into crackle breccias showing little or no rotation of clasts and finally into unaltered wall rocks. (Figure 5). Vein and fracture-fill sulphides seldom greater than a few centimetres wide have been recorded several kilometres from the major known breccia bodies. Such veins and fractures also locally occur adjacent to the main centres of breccia-hosted mineralization as in the Bridge Zone where they post-.

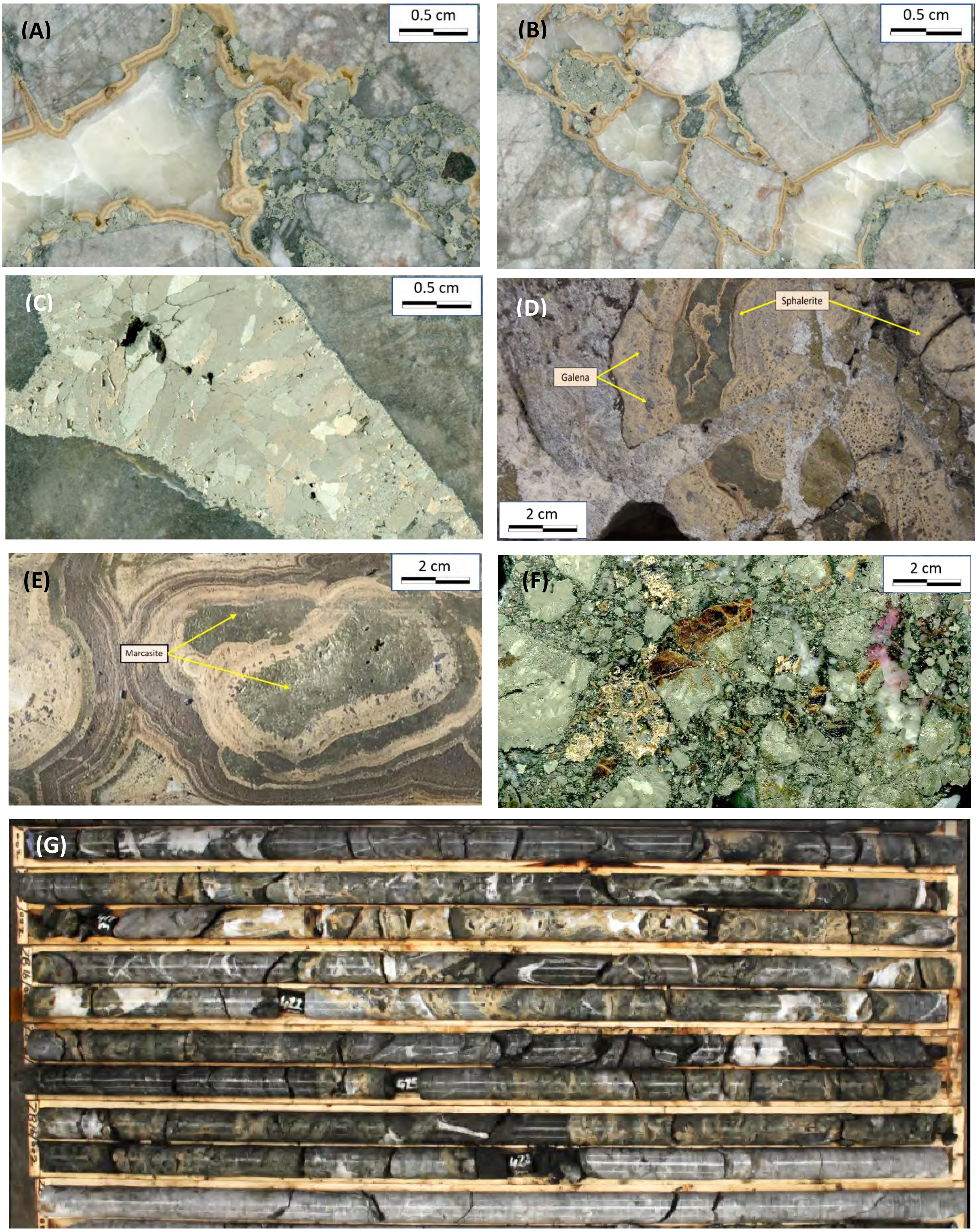


Figure 6: *Typical mineralization in the Kildare District:* ***(A)****: Collapse breccia lined with banded schallenblende sphalerite and marcasite, undolomitized clasts of Waulsortian – HB-98 at 98.9m;* ***(B)*** *Heterolithic collapse breccia with schallenblende sphalerite lining and minor marcasite - HB-98 at 98.1m;* ***(C)*** *Bladed marcasite vein cutting undolomitized Waulsortian – HB-42 at 125.7m;* ***(D)*** *Fractured banded sphalerite with minor galena, base of Waulsortian – Z-1046-027 at 465.4m (photo from ZMI Corporate Presentation);* ***(E):*** *Massive banded sphalerite with a core of marcasite, Harberton Bridge Canal Zone (McGregor) (photo from ZMI Corporate Presentation);* ***(F)****: Polymictic massive sulphide collapse breccia of clasts of bladed marcasite with two generations of sphalerite - dark brown and pale schallenblende – HB-86 at 120.3m (Harberton Canal Zone)* ***(G)*** *Drill core from Z4069-002 409-434m Canal Zone (McGregor), (photo from ZMI*

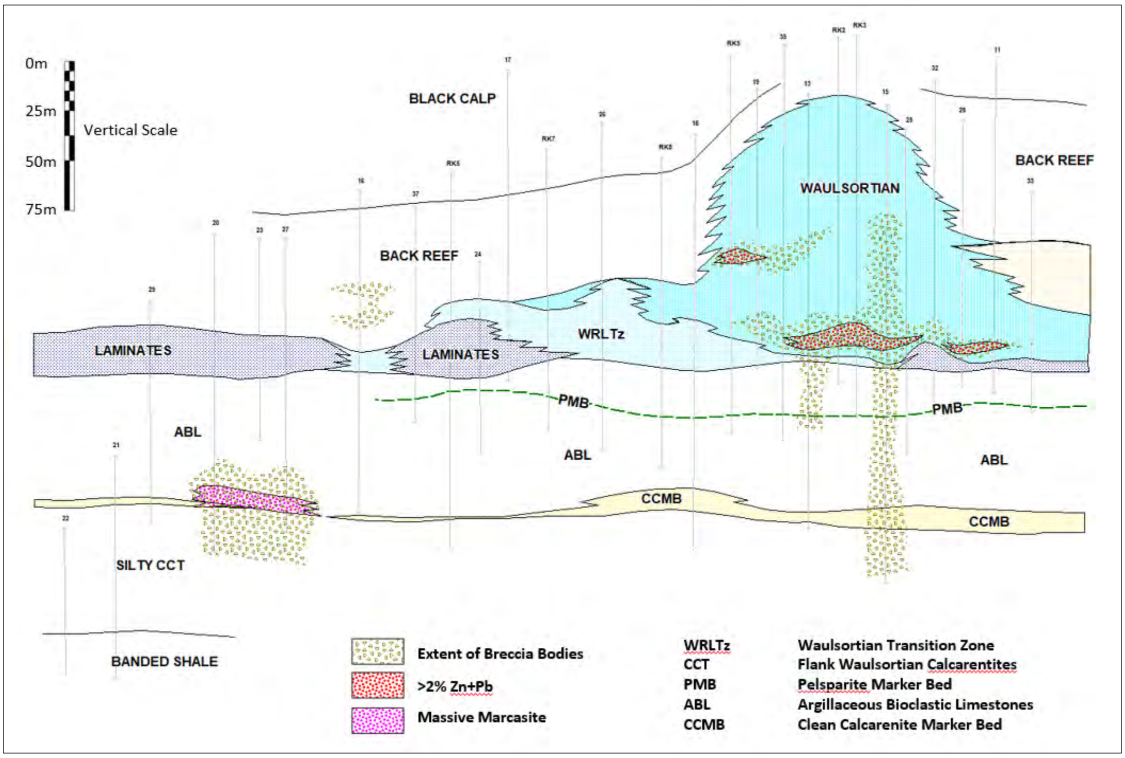


***Figure 7:** Schematic section through the Rickardstown Prospect showing location and distribution of brecciation and mineralization.*

date the principal brecciation/mineralization event. Such breccia types are closely reminiscent of many MVT deposits around the world such as those described in the literature by (amongst many) Anderson & McQueen (1982), Sass·Gustkiewicz (1983), Kyle (1981) and Paradis *et al.*, 2007).

Unlike most of the Irish-type deposits the dominance of marcasite over other iron sulphides in the Kildare district suggests that the fluids responsible for the mineralization were distinctly acidic (Buerger, 1934), a factor which would correspond to the extensive dissolution and the formation of resultant collapse breccias hosting the mineralization.

Ore textures at Harberton Bridge show many of the typical diagnostic characteristics of MVT deposits (e.g., Hagni, 1983). Sphalerite (*var.* schallenblende) and galena are commonly interlayered with coarse marcasite and occur as concentric colloform overgrowths on limestone clasts or in clasts of colloform banded sulphides similar to those described from Pine Point by Kyle (1981) (Figure 6A – 6G).

At Harberton Bridge, five mineralization stages have been identified by Holdstock (1982, 1983), each separated by a brecciation stage, namely:

- (M_1) – a marcasite–calcite stage found in fractures up to a few hundred metres from breccia bodies.
- (M_2), (M_3) and (M_4) – the main polymetallic marcasite–sphalerite–galena–calcite mineralization; *and*
- (M_5) – a late, calcite "flooding" event devoid of sulphides.

This paragenetic sequence is similar to that described for the deposits at Rickardstown, Cloncurry and Allenwood by Dixon *et al.*, (1986). In mineralogical terms the mineralization is simple and apart from the iron and base-metal sulphides there are very few other species present.

Emo (1986) noted that at least three phases of dolomitization have been recognized with the earliest phase occurring towards the top of the Waulsortian being represented by pink baroque ferroan dolomite (D_1) which predates the Zn-Pb mineralization. This pink baroque ferroan dolomite, whilst being early in the Kildare breccia bodies, is similar to that seen across the Irish Midlands where it is generally interpreted as being late and post-inversion (at least post late Asbian) which also suggests that the Kildare Zn-Pb mineralization is also late relative to most Irish-type mineralization (Andrew, 1993; Machel, 1987; Ashton *et al.*, this volume). In the Kildare deposits these pink dolomites have been brecciated and the resulting breccias have themselves been dolomitized (D_2). Minor marcasite appears to be associated with this dolomite phase, the main sulphide mineralization being introduced between this and the following phase (D_3). The fourth phase consists of vein dolomite (D_4) with calcite cross cutting the earlier formed dolomites (Emo, 1986).

At Allenwood East and Allenwood West the Waulsortian is well developed but shows rapid thickness changes from 10 to 200m. Over the thicker parts the Allenwood Formation rests directly on Waulsortian but in the thinner parts a "Reef Equivalent" of argillaceous cherty limestone separates the Waulsortian from the Allenwood Formation. The Allenwood Formation is at least 300m thick in the Allenwood East area with

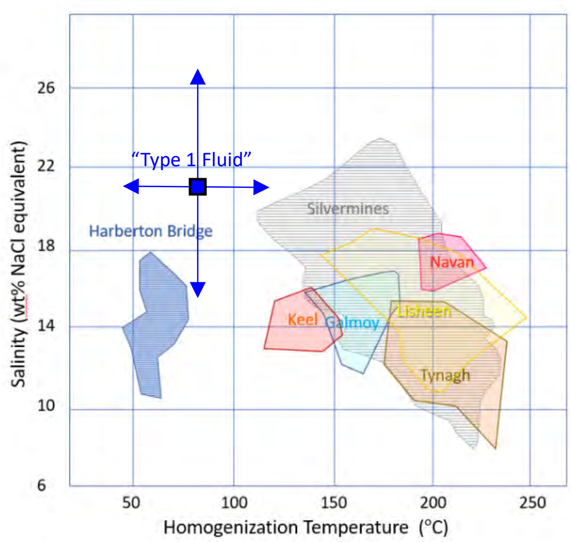


Figure 8: *Fluid inclusion data for the Harberton deposits plotted with the fields for primary inclusions in deposit sphalerites and carbonates from Irish-type deposits derived from data in Banks & Russell (1992), Everett et al. (1997, 1999), Eyre (1998) and Trude & Wilkinson (2001). Also shown is the approximate range of the "Type 1" fluid of Johnston et al (2009).*

a lower pelsparite dominant unit overlain by a micrite dominant unit. The two breccia bodies (Allenwood East and Allenwood West) are about 300m apart and in both cases the breccia extends from the sub-Waulsortian up through the Waulsortian and into the Upper Allenwood Formation. Minor dolomitization is recorded but the great bulk of the succession is undolomitized. At Allenwood East only marcasite is found in breccias within the Waulsortian whilst all Zn-Pb mineralization is hosted within breccias developed in the Allenwood Formation whilst at Allenwood West Zn-Pb mineralization is present in both Formations.

At the Allenwood North prospect the area is complex, and a down-faulted block of Allenwood Formation seems to be present with breccias extending over a vertical interval of at least 525m. Mineralization is generally low grade with thin selvedges of single bands of pale sphalerite (var. schallenblende) forming rims to clasts (Fig. 6-F).

The Allenwood South prospect lies approximately 600m SSE of the Allenwood North prospect and a well-mineralized breccia system is present from the base of the overburden to a depth of 230m.

At Clongownagh stratabound massive, bladed marcasite occurs in a zone up to 15.7m thick and is overlain by sparse Zn-Pb-marcasite breccia-hosted mineralization throughout the sub-Waulsortian succession. This massive marcasite seems to have replaced a residuum of argillaceous rock matrix breccia. It is generally similar to the base of the Harberton breccia bodies, but in this breccia body the marcasite is more massive and poorer in base-metals.

At Rickardstown an isolated Waulsortian knoll up to 265m in thickness, with steep flanks is dolomitised throughout (Figure 7). Solution breccias are present which also occur in the underlying sub-Waulsortian argillaceous limestones and penetrate down as far as the top of a clean calcarenite unit and are similar to the breccias at Harberton. The thickest and best grade mineralization appears to be associated with the western edge of the Waulsortian knoll with best intersections of 2m @ 14.03% Pb + Zn and 1.6m @ 10.62% Pb + Zn. There is evidence of multiple brecciation events (two or three phases) with sulphide infilling. At Rickardstown the best base-metal mineralization is developed on the periphery of the breccia body with the central part comprising mainly marcasite.

Fluid inclusion results

Fluid inclusion temperature data obtained from Harberton Bridge form a cluster and fall in the range 50–80ºC (Trude & Wilkinson, 2001). The scatter of salinity and temperature data shows a field distinctly different from all of the major Irish-type deposits with lower temperatures and higher salinities than those identified elsewhere. There is no clear evidence suggestive of fluid mixing (Figure 8). The scatter of points does, however, closely correspond to the "Type 1 Fluid" of Johnson *et al.* (2009) which is identified regionally across the Irish Midlands. This fluid being low-temperature, high salinity, and enriched in chloride relative to bromide, suggests a component of salinity derived via dissolution of halite or from evaporation of seawater. Therefore, the region in which these fluids formed should contain evidence of halite.

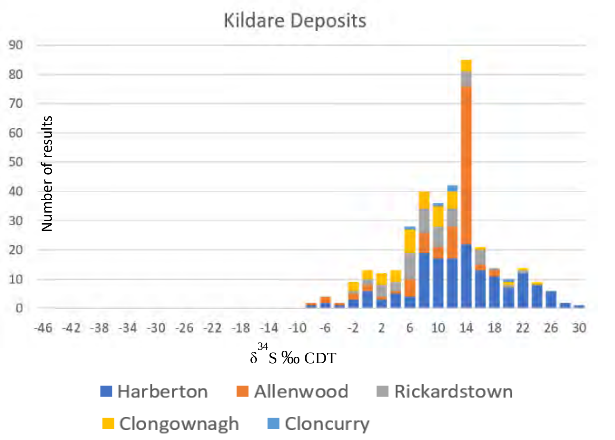
Nagy *et al.* (2001, 2004, 2005) have identified compelling evidence of evaporites (gypsum and halite) in Waulsortian equivalent and supra Waulsortian platform carbonates within the Chadian-aged Aghmacart Formation, which lies stratigraphically above the lithologies hosting the Kildare mineralization, adjacent to the Leinster Massif to the south and east. These contain fenestral fabrics, rhizoliths and desiccation cracks indicative of periodic subaerial exposure which is consistent with a shallow evaporitic environment.

Isotopic Results

Sulphides have a median $\delta^{34}S$ value of +10.5‰ (range -3.3 to +20.6‰). There is no evidence whatsoever for an isotopically light bacteriogenic sulphur component as seen in other Irish Zn+Pb deposits (Gallagher *et al*., 1992) (Figure 8).

The $\delta^{34}S$ data for sulphides at Harberton Bridge are among the heaviest known for carbonate-hosted base-metal mineralization in Ireland and are consistent with a hydrothermal origin for the sulphides (Anderson *et al.*, 1998). The values are very similar to those recorded for other, apparently similar deposits in the Kildare area *i.e.*, Rickardstown, Allenwood and Clongownagh, (Dixon *et al*., 1990) (Figure 9).

No systematic spatial control of the sulphur values has been observed in the Canal Zone at Harberton and any variations appear to be random as samples taken from within 5m of each other may show differences of 5‰ (Gallagher *et al*, 1992). Neither distance from the main breccia bodies nor proximity to the main faults appear to exert any systematic control unlike



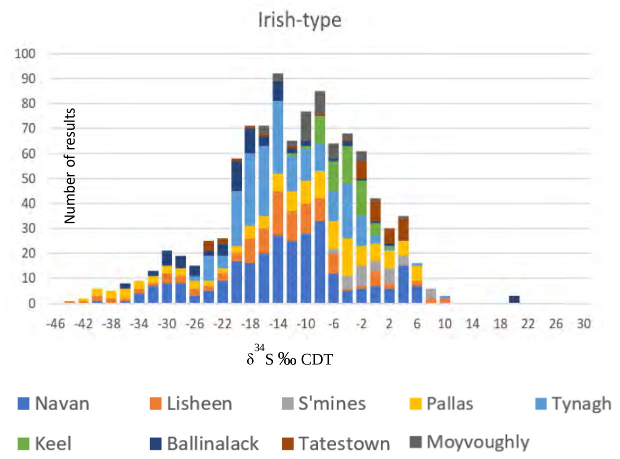


***Figure 9:** Histograms of sulphur isotope results from the Kildare deposits in comparison with results from Irish-type deposits in the Irish Orefield. Data from multiple sources including Gallagher et al (1992); Dixon et al (1986); Anderson et al (1998).*

that seen at Tynagh, Silvermines, Keel, Ballinalack where distinct zoning has been identified showing well developed mixing.

In fact, the relatively high and widespread $\delta^{34}S$ values are more typical of MVT deposits where sulphide is usually considered to be produced by reduction of evaporitic sulphate. Previous authors have considered evaporitic sulphate as unlikely due to the lack of any known significant evaporite deposits in the area (e.g., Dixon *et al.*, 1990). However, Nagy *et al.*, 2005 have demonstrated the potential existence of evaporites on the margins of the Leinster Massif.

Strontium $^{87}Sr/^{86}Sr$ analyses of calcite from the M_5 mineralization event (Holdstock 1982, 1983) returned a mean of 0.710, higher than that of contemporaneous seawater or Carbonifer ous limestone (0.708) (Gallagher *et al.* 1992).

Evidence as to age of the Kildare deposits

Three geologically well-defined constraints as to the age of the Zn-Pb mineralization in Kildare can be defined: 1) brecciation constraining faulting transects and dislocates Variscan reverse faults; such faults are intimately associated with the Zn-Pb mineralization acting as conduits for mineralizing fluids to the breccia bodies as evidenced by sulphides preferentially developed on their hangingwall sides as high grade masses; 2) no evidence of re-brecciation or recrystallization of the schallenblende sphalerite or galena within the faults bounded zones indicative of a later post-mineral faulting event, and 3)pink baroque dolomite, determined to be related to a basin-inversion phase in the late Asbian to Brigantian, predates brecciation and paragenetically early pre-sulphide dolomites. Thus, on geological evidence alone it is likely that the Kildare mineralizing event is contemporary to the late Sudetic Event in the Asselian Stage of the Permian.

Many of the palaeomagnetic ages obtained for the Irish Orefield have largely been discounted due to the absence of magnetic minerals in the mineralization, the uncertainty of Lower Carboniferous polar positions and thermal resetting during the Variscan orogeny (McCabe & Channel, 1994). However, it is worth noting that palaeomagnetic dates of 269±4 Ma for Magcobar, 290±9 Ma (Galmoy), 277±7 Ma (Lisheen) (Pannalal *et al.*, 2008a, 2008b) correlate well to the ages of the orogeny determined by syntectonic lamprophyres in Cornwall dated at 292±3.4, 296±5 and 281±1.6 Ma (Shail & Alexander 1997).

Thus, pending any further evidence to the contrary, it is tentatively suggested that the Kildare mineralization is of early Permian age and suggests a difference between the age of the host rocks and the mineralization of around 40Ma, typical of that seen in many MVT districts around the world (Paradis *et al.*, 2007).

Abbeytown

Within the immediate Abbeytown area five mineralized bodies have been worked. The earliest workings are thought to be located close to where an ancient Abbey was located and from which silver was produced from argentiferous galena by the monks from the monastic settlement. This is to the east of the area where mining that took place in the mid-20th Century which was centred on an open pit working the ore in the "Index Bed" (a local stratigraphic marker) and four bodies worked in shallow underground workings. Of these the orebody closest to the surface is located on the Index Bed and within a local syncline where there are several small-scale faults. The deeper bodies are referred to as the Lower Orebodies – 1 and 2 or LOB 1 and LOB2, and the M Zone. LOB1 is located around a locally identified thrust fault (the Abbeytown Fault); LOB2 occurs beneath the Index Bed mineralization; and the M Zone located to the north of LOB2. The Abbeytown Fault extends to the surface but the small-scale faults in and around LOB2 (beneath the Index bed Ore) do not extend to the Index Bed.

Production and exploration history

Unlike the Kildare area, Abbeytown was a producing mine with mining taking place intermittently from 1785 until 1961 (Hitzman, 1986). Early accounts of the mine include Hardman (1880) and Cole (1922) while a later internal report to Tara Exploration by Brown (1973) as well as Kelly (2007) provide historical information. The early mining focussed on Ag, and

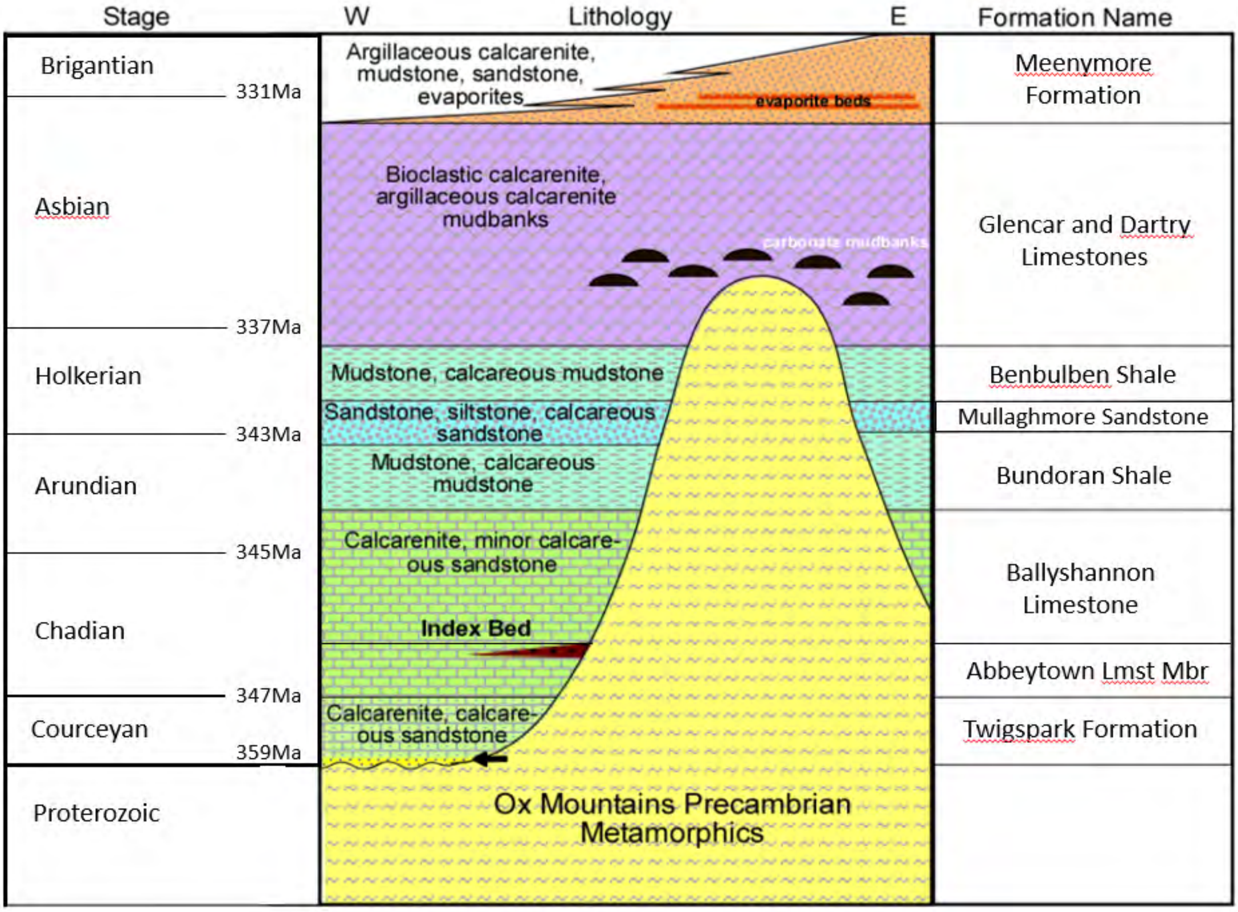


***Figure 10**: Stratigraphic column for the Abbeytown area (after Persellin, 2009 and Geological Survey Ireland (MacDermot et al., 1996). Arrow indicates thin (3-4m) siliciclastic unit at base of Twigspark Formation.*

then Pb and Ag, with Zn only being mined in the most recent Johannesburg Consolidated Investments (JCI) phase of mining between 1950 and 1961 when 730,000 tonnes at 1.38% Pb and 2.45% Zn was extracted – (GSI Mine Records). Hitzman (1986) estimated that a total of around 1.1Mt grading 1.5% Pb, 3.8% Zn and 40-45g/t Ag has been extracted with early mining from the surface of the East Abbeytown deposit while the JCI production came from the three underground deposits. Additional showings, trials and anomalies in the area include Lugawarry, Streamstown and Skreen. Production statistics for the various orebodies operated by JCI were summarised by Kelly (2007) (Table 3).

Exploration since the cessation of mining has been carried out by Dolan Creelman Trust (1962 – 1964); Tara – under various company names (1967 - 1978); Billiton (1980 – 1983); Chevron Mineral Corporation of Ireland, latterly in a joint venture with Northwest Exploration (1985 – 1989); Ennex International – including Westland Exploration & Getty Mining (1993 – 1997); and Erris Resources (2013 – present (2023)).

Exploration work in the area has included soil geochemical and geophysical techniques – induced polarization, airborne INPUT and magnetics, VLF-EM and R, and ground EM (including TEM). All anomalies worthy of being tested were investigated by diamond drilling. In addition, much drilling was directed geologically.

Regional and local geology

The regional geology of the Abbeytown area has been published by Geological Survey Ireland at a scale of 1:100,000 (MacDermot *et al*, 1996) (Figures 10 and 11). The carbonate rocks of the area are a small outlier measuring some 6km (east-west) by 2km (north-south). This small area is bounded to the south by the Slishwood Division of the Northeast Ox Mountain Inlier with which the Mississippian (Dinantian) Rocks are in fault contact – the Ox Mountains-Pettigoe Fault. These older rocks have been assigned to the Slishwood Division as they have been affected by extreme metamorphism which distinguishes them from typical Dalradian rocks (Max and Long, 1985). They are therefore Dalradian (Upper Proterozoic) or older in age and are comprised of psammitic paragneisses and semi-pelitic biotite schists. Slishwood Division rocks also bound the carbonate rocks to the east upon which they lie unconformably. The northern boundary is found offshore where an east-west trending fault is interpreted (informally called the Ballysodare fault by Hitzman, 1986), and this separates the Abbeytown carbonate rocks from other carbonate rocks to the north (The Dartry Limestones – part of the so-called Upper

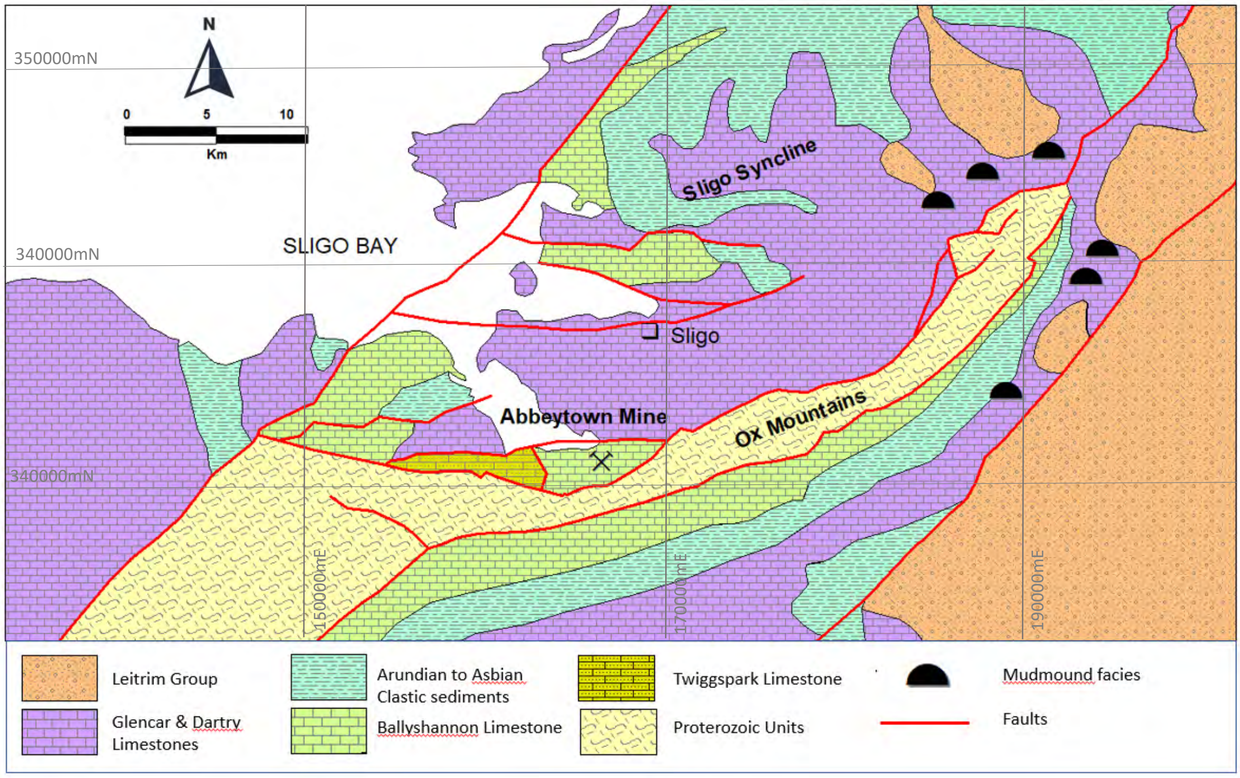


Figure 11: *Geology of the Abbeytown area (after Geological Survey Ireland (MacDermot et al., 1996) and Hitzman 1986).*

Limestones). This fault joins the Ox Mountain-Pettigoe Fault some 4km east of Ballysodare. To the west the Abbeytown carbonate rocks are bounded by the Bundoran Shale, also of Dinantian age.

The lowest Mississippian rocks belong to the Twigspark Formation of MacDermot *et al.*, 1996 (or Ballysodare Formation of Hitzman, 1986) of early Chadian age. The Twigspark Formation is comprised of four informally named members.

Overlying the Twigspark Formation is the Ballyshannon Limestone Formation which has at its base the Abbeytown Member in the mine area and the Red Hill Member further to the west near Skreen. The host rock for the deposit is the Abbeytown Limestone Member of the Ballyshannon Limestone Formation. The Abbeytown Member has been divided into several units (MacDermot *et al.*, 1996).

The Ballyshannon Limestone is overlain by the Bundoran Shale followed by the Mullaghmore Sandstone, the Benbulben Shale, the Glencar. Limestones, the Dartry Limestone and the Meenymore Formation. The Meenymore Formation contains evaporites which may be important as a source of sulphur

Deposit overview

The largest quantity of ore was extracted from the Index Bed both in the Open Pit and from underground. The ore extracted from the deeper parts of the orebody was hosted by crinoidal limestone of the Abbeytown Limestone Member. The ore in the Index Bed and the Open Pit is tabular while the ore in LOB1 was located in and around the Abbeytown fault and had greater depth extent. The ore in LOB2 and the M Zone was more irregular but nonetheless flat lying.

Up until 1954, the mine workings – both opencast and underground – were centred on the rich portion at the top of Index Bed. These workings show the horizontal distribution of ore to be very irregular with rich lenses and disseminations separated by areas of barren ground in a manner that does not follow a simple pattern. Drilling has shown the same conditions to hold for some distance to the south and west of the mine. Under such conditions, barren boreholes do not necessarily establish a boundary to the mineralization.

The vertical distribution of ore is even more erratic. For example, within closely spaced drillholes there may be holes that are entirely barren, others have weak showings at the more favourable horizon (Index Bed, Lower Grit and perhaps the upper portion of the Crinoidal Limestones) while others show almost continuous mineralization, although largely low grade, from the surface to depths of over 60m. The best example of the latter occurs in drillhole TA-8 which showed some degree of mineralization almost all the way from the surface to 80m. Where such a vertical extent of ore has been found it is associated with brecciation and dolomitization providing strong evidence of vertical faulting.

Mineralogically the ores at Abbeytown are simple and comprise sphalerite, galena with some chalcopyrite and pyrite. The galena is invariably coarsely crystalline, but some very fine galena has been found as a replacement of fine textured breccia fragments. Galena typically contains inclusions of

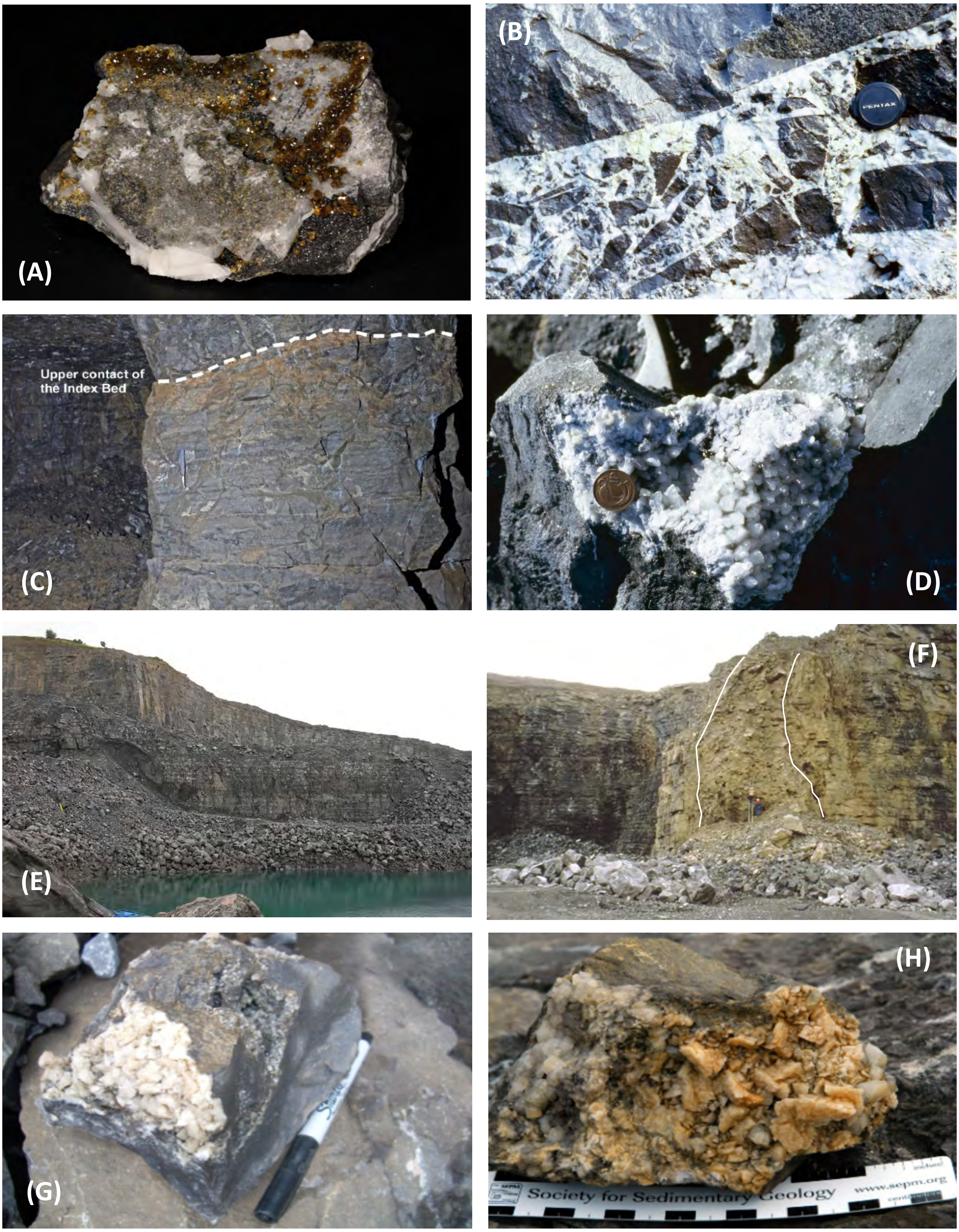


Figure 12: *Photographs of aspects of the Abbeytown Deposit;* ***(A)*** *Crystalline sphalerite on dolomitized and brecciated host.* ***(B)*** *Calcite vein with angular clasts of dolomitized host rock.* ***(C)*** *Underground photograph of pillar showing upper contact of the Index Bed (from Persellin, 2009).* ***(D)*** *Scalenohedral calcite infilling vugh with pyrite and hydrocarbons.* ***(E)*** *View of the well bedded Ballyshannon Limestone in the Abbeytown Quarry.* ***(F)*** *View of sidewall in the Abbeytown Quarry showing a large "plug" of calcite (demarked by white lines).* ***(G)*** *&* ***(H)*** *Two types of dolomite cements at Abbeytown - G) large white saddle dolomite (left) and small grey dolomite rhombs (right). H). Large, white-brown ferroan saddle dolomite with white calcite. (After Persellin, 2009.)*

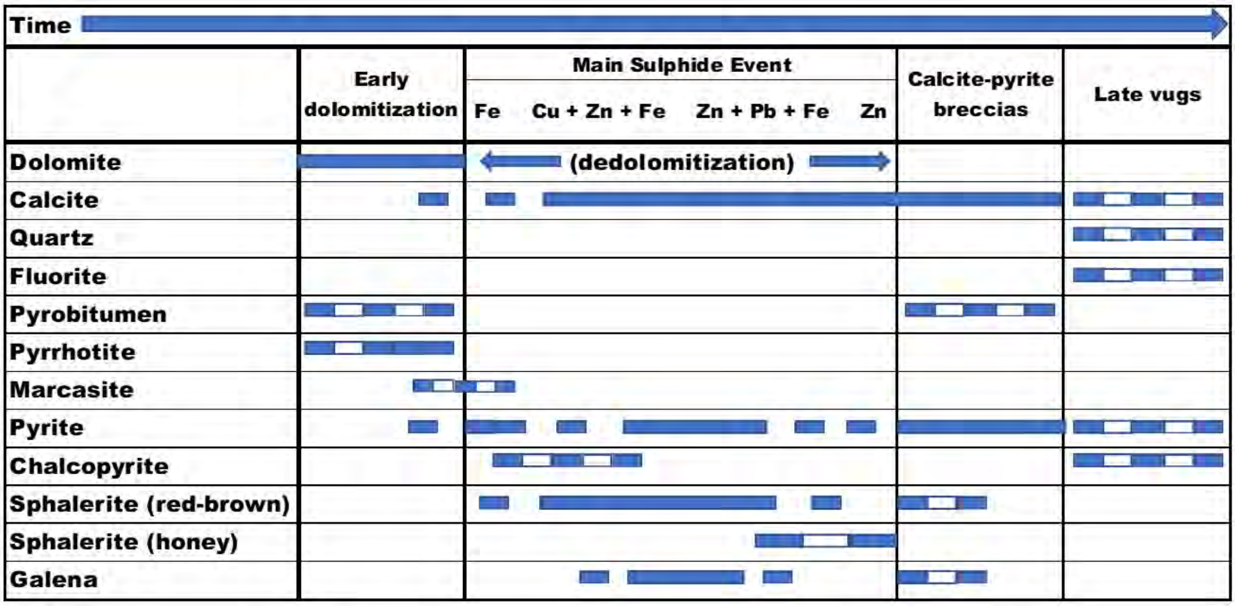


***Figure 13:** Paragenesis of sulphide and gangue minerals at Abbeytown, after Hitzman, 1986.*

boulangerite ($Pb_5Sb_4S_{11}$). The overall metal content if the ores is lead dominant with significant silver credits for example drillholes ERAB-001 4m @ 10.85% Zn+Pb and 31 g/t Ag or ERAB-0074.5m @ 9.14% Zn+Pb with 93 g/t Ag. Silver grades as high as 230 g/t have been recorded over intervals of 0.5m

Iron sulphides occur in three forms, as disseminations of fine cubic crystals of pyrite, as cavity linings as coarse pyritohedra and as strings of fine bladed marcasite crystals. Pyrite is such more widely distributed than either sphalerite or galena and is usually found associated with the zinc-lead sulphides partly filling any remaining cavity space. However, thicker bands of pyrite also occur in the mine area in cavities devoid of base-metal sulphides. Pyrite occurs more widely outside of the immediate mine area within both dolomitized and unaltered limestones for up to some 800m from zinc-lead mineralization.

Euhedral crystals of chalcopyrite occur fairly commonly in vugs within calcite veins.

The lead-zinc mineralization occurs almost entirely as cavity and fissure fillings and only to a very limited extent as replacements of the country rock. The usual occurrence, in order of importance, are:

(1) Near horizontal lenticular bands up to 30cm in thickness. These fill or partly fill bedding plane partings (and termed cavity filling flats by Cunningham);

(2) Within the matrix of breccias with rare partial replacement of breccia fragments; and

(3) Thin stringers and disseminations along bedding planes, stylolites and irregular fractures, and in the more permeable coarse grit beds.

The cavity filling flats are often crustified showing a succession of galena-sphalerite, pyrite and calcite but sometimes consist of a solid intergrowth of galena and sphalerite. They are best developed near the top of the Index Bed where they may occur at three different levels. The most persistent is that at the top of the coarse grit bed but similar bands are sometimes found at the base of this bed and in the silty dolomite above it. Identical bands, sometimes crustified, have been found in the dolomite beds between the Index and Lower Grit beds.

The breccia mineralization is closely related to the cavity fillings but differs in not being crustified and is normally of lower grade. It varies from rich bands showing replacement of breccia fragments to breccias with rare specks of galena and sphalerite scattered through the matrix. The richest breccia bands are found near the cavity filling flats. A notable feature of these rich bands is that they are almost entirely horizontal or really bedding plane in aspect. There appears to be a complete absence of well-defined vertical strings and bands such as might be expected in joints and fault fissures.

In addition to the ore minerals, gangue minerals comprise dolomite, calcite and minor quartz. Dolomite is pervasive in the mine area. Indeed, dolomite is not common outside the mine area (Hitzman, 1986).

Both Hitzman (1986) and Persellin (2009) noted that replacement dolomitization in the Abbeytown Mine is generally limited to the main ore body and is contained within and adjacent to the Index Bed. The western ore body is not dolomitized or only partially dolomitized near the Abbeytown Fault, except for the presence of epigenetic open space-filling dolomite cements. Replacement dolomite is commonly dark grey, coarsely crystalline (2-4 mm), and nonplanar, although some planar s-type dolomite is present and the primary pelloidal texture of the limestone is generally preserved.

White rhombohedral calcite occurs in joint fillings, strings and veins, over the whole district but occurs in greatest abundance in the more fractured beds of the mine area where it forms a

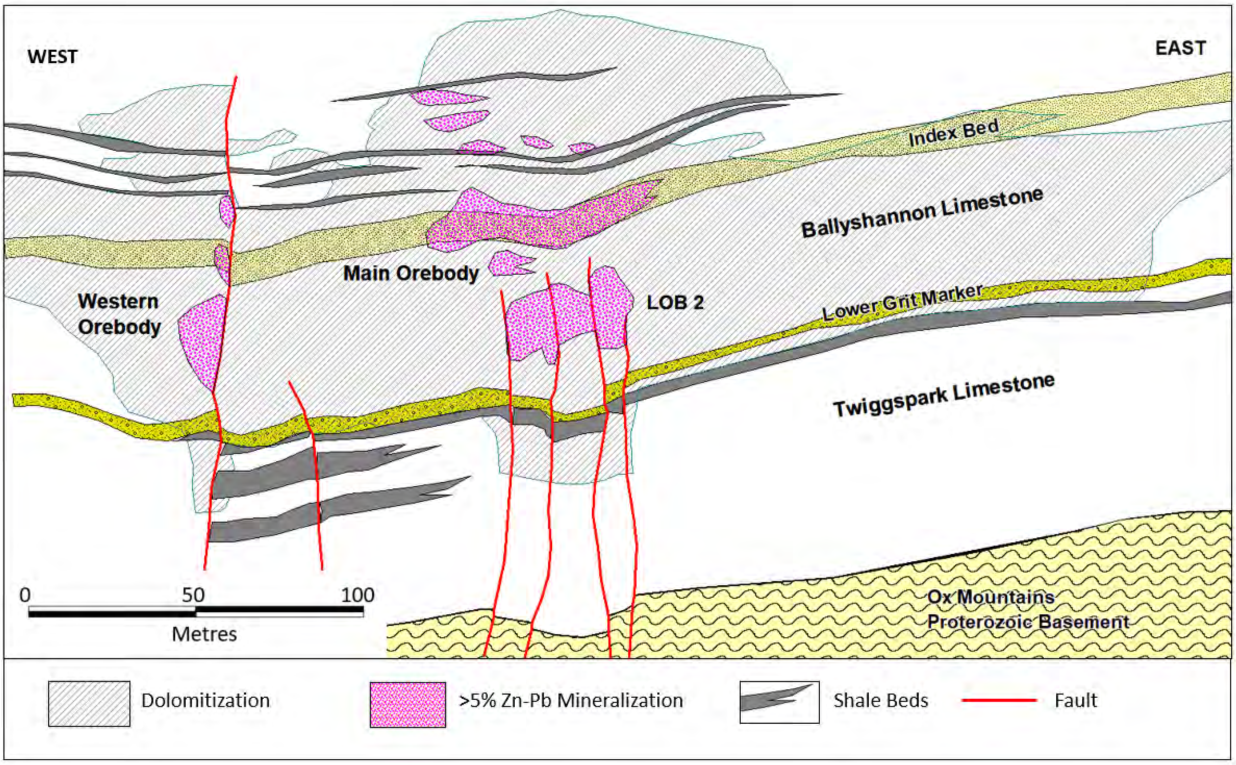


Figure 14: *East-West section through the Abbeytown Deposit showing the control of mineralization and dolomitization by faulting (After Hitzman (1986) and Persellin(2009).*

close network of joint and vein fillings; and occupying any spaces remaining in the ore cavities, vugs or breccias, i.e., it is the final filling mineral. Calcite also occurs as a replacement of dolomite in dedolomitized areas and as fine to coarse intergrowths with base metal sulphides. The thicker calcite veins and lenses usually contain vugs lined with transparent scalenohedral calcite.

Hitzman (1986) developed a four stage paragenesis for the Abbeytown deposit (Figure 10). The four events, in chronological order, are: (1) early dolomitization; (2) main sulphide event; (3) calcite-pyrite breccia event; and (4) late mineralized vughs. Much of what follows is based on Hitzman (1986). The early dolomitization is hydrothermal in origin and completely affected the original limestones in the mine vicinity as both stratabound and crosscutting zones. The Index Bed is the most completely dolomitized, and coincidentally the most highly mineralized unit. However, the non-fossiliferous and crinoidal limestones and the Lower Grit Unit of the Abbeytown Limestone Member are also dolomitized but to a lesser extent. These zones of pervasive dolomite are surrounded by a large region of partial or disseminated dolomite. The dolomite is fine- to medium- grained and non-vuggy and does not appear to have increased either porosity or the permeability of the limestone. The dolomite is non-ferroan to mildly ferroan with the dolomites closest to the feeders being the most iron rich. Hitzman (1986) also notes that framboidal pyrite, ubiquitous in the Ballyshannon Limestone has been destroyed

		Hitzman (1986)		Persellin (2009)	
Event	**Mineral**	**T_h (°C)**	**Salinity (wt % NaCl equiv)**	**T_h (°C)**	**Salinity (wt % NaCl equiv.)**
Main	Sphalerite	105 – 123	10 – 11	109 – 168	10.5 – 16.5
Main	Calcite (bimodal)	88 – 146 105 – 180	22 – 25 10 – 16	70 – 220	4.2 – 22.7
Calcite-pyrite	Calcite	139 – 174	10 – 13		
Main	Dolomite (bimodal)			108 – 147 157 – 207	5 – 10 9 – 15

Table 1: *Fluid inclusion results from Abbeytown (Hitzman, 1986 and Persellin, 2009).*

by the dolomitizing event and pyrrhotite precipitated as intragranular grains only to be replaced by marcasite and finally pyrite during the later stages of the dolomitizing event.

The main sulphide event resulted in the dedolomitization of the earlier formed dolomite as well as the precipitation of base-metal and iron sulphides over several phases. Hitzman (1986) comments that mineralization generally is confined close to the feeder structures except for the Index Bed where it spread laterally for some distance. Pyrite was first precipitated along with calcite through dedolomitization. The calcite – pyrite phase occurs in veins and irregular breccia zones in previously dolomitized rock. This pyrite-calcite phase was followed by the precipitation of base-metal sulphides: first dark red-brown sphalerite with chalcopyrite lath inclusions; followed by paler coloured sphalerite, galena, pyrite, and calcite. The early sphalerite – chalcopyrite mineralization replaced calcite and pyrite and formed a disseminated interporosity infill within the host rock. The later sphalerite, galena, pyrite, and calcite phase forms a network of veins which both cut and replace early calcite, pyrite and the early red-brown sphalerite. Vertical veins tend to occur close to the feeder structures while flat lying or bedding parallel veins tend to occur some distance from the feeders. Where these coalesce a sulphide matrix breccia may be formed (Cunningham, 1954).

The next phase was the calcite-pyrite breccia event. This cuts the earlier main sulphide event. The breccias are narrow features (several cm to 3m) and are centred on the eastern (syncline) and western (Abbeytown Fault) structural zones (Hitzman, 1986). The breccia fragments are composed of angular clasts of dolomite, dedolomitized limestone, mineralized rock and limestone. The matrix of the breccia is composed of calcite and pyrite. Two types of calcites have been recognized – white and a less common dark grey variety. Open vugs are common in the white calcite. The grey colour is due to abundant included pyrite within the calcite, and it may have been deposited as an internal sediment in vugs. The final event formed vugs and veins which are filled with calcite, dolomite and quartz (Fernandez, 1957 and Hitzman, 1986).

Two limited fluid inclusion studies have been carried out at Abbeytown (Hitzman, 1986 and Persellin, 2009). Hitzman sampled and had analysed sphalerite and calcite while Persellin sampled and analysed sphalerite, dolomite, and calcite. Samples were taken from both the Main Orebody and the Western Orebody. The results for all are provided in Table 1.

The results from Abbeytown for both T_h and salinity are characteristic of MVT deposits in general, with slightly lower salinity values for the Abbeytown samples. The values are lower than for the Keel, Silvermines and Tynagh deposits (Hitzman, 1986). Hitzman suggested that the similar values for both T_h and salinity for the Main Sulphide and Calcite-pyrite events was evidence for a continuation of one event to the other.

With respect to the age of the mineralization at Abbeytown, mineralization has been shown to have taken place after the initial onset of movement on the faults associated with the uplift of the Ox Mountains Inlier. The fluids responsible for dolomitization are thought to have ascended the Abbeytown Fault and the syncline, in which the most extensive mineralization was developed.

Movement on both the Ox Mountains and Ballysodare Faults probably commenced in Asbian times. Hitzman (1986) favoured an Asbian or later age for the mineralization at Abbeytown based on the structural history of the area. Halliday and Mitchell (1983) proposed a Permian age based on K-Ar dating (270 and 285Ma) of chlorite intergrown with sphalerite and galena.

Cunningham (1954) thought that the mineralizing fluids ascended the Ballysodare Fault, to the north, but how they migrated to the ore site was a more difficult question. He considered two possibilities:

1. They might have migrated laterally along the more permeable grit beds and bedding planes but this - on the present disposition of the strata - would involve downdip migration and would tend to produce a belt of mineralized ground parallel to the fault rather than transverse to it.
2. Movement along a series of fault fissures running from the major fault to the north, into the mineralized ground. This is contradicted by the absence of mineralized vertical fissures in the mine workings. This contradiction may, however, be more apparent than real. The mine workings do show a series of nearly north-south faults and fracture zones which may have acted as feeder channels and were later closed by compression from the northwest.

The latter possibility was favoured by Cunningham (op cit).

Hitzman (1986) agreed that the source of the metal bearing fluids was likely to be to the north in the Sligo Syncline where there was a basal clastic section with a provenance from the underlying basement. The basal clastic section would provide an easier source rock from which to leach metals. A downward excavation model, such as proposed by Russell, was not favoured by Hitzman (*op cit*) as the underlying lithologies are high grade metamorphic rocks (amphibolites to granulites) with little intergranular or fracture porosity or permeability. Also, whatever veins are present within the basement rock have little alteration surrounding them with little penetration of fluids into the rocks.

The Ox Mountains and Ballysodare Fault were joined by a series of NNE trending faults (the nearly north-south faults of Cunningham) one of which was the locus for the Abbeytown deposit. Fluid movement was initiated/ facilitated by periodic pressure release or heat flow or a combination of both. Precipitation of galena and sphalerite took place on the walls of whatever cavities and open fractures existed and in places within the pores of the coarser grit beds. Later precipitation of pyrite and calcite took place in many of the cavities giving them crustified infillings. Sometime after the hydrothermal activity had ceased, compression from the north-west closed these fissures, removing any ore bands contained in them, and thus masking their identity as original feeder channels (Cunningham, 1954).

Comparison of the Kildare and Abbeytown deposits with classic Irish-type deposits

There are a number of aspects of the mineralization at Abbeytown and in the Kildare District that distinguish them from the classically defined Irish-type deposits of the Irish Midlands

The setting of the Kildare district and Abbeytown are both at basin margins and at locations of significant lithological and/or facies changes within individual stratigraphic units. In general terms virtually all evidence suggests that both the Kildare deposits and Abbeytown are classical MVT deposits possibly formed by topographically driven fluid flow in and around the time of the Variscan orogeny.

The most striking differences between Harberton Bridge and the classic Irish-type deposits are the geometry and structure of the mineralization. The most common style of mineralization in Irish-type deposits consists of stratabound lenses developed in the hangingwall of synsedimentary faults with abundant evidence for syndiagenetic mineralization whilst Harberton Bridge has a very different, vertical pipe-like geometry with mineralization that is clearly post-lithification. Collapse breccias with angular, rotated clasts of carbonate and banded sulphide that pass vertically and horizontally into crackle breccias are not well-developed outside the Kildare District, although crackle brecciation with calcite-pyrite cement has been observed on the fringes of some Irish-type deposits.

Both fluid inclusion and sulphur isotope data from the Kildare deposits are significantly different from other Irish-type deposits. Basukj & Spooner (2002) examined more than 2800 published fluid inclusion data (primary inclusions) from eighteen typical Mississippi Valley-type (MVT) Zn-Pb deposits and districts and note that. the mean T_h and salinity values for fifteen MVT deposits and districts are 122°C ± 21°C and 20.7 ± 2.6 wt% $NaCl_2$ equivalent, respectively. In general, temperatures increase from pre-ore to ore stages, and salinities decrease from ore to post-ore stages.

Basuki & Spooner (2002) concluded that sedimentary rock-hosted Zn-Pb deposit types show a trend of salinity decrease and temperature increase from MVT, sandstone-hosted and diapir-related Pb-Zn deposits, to vein-type and Irish-type Pb-Zn deposits, and then to CD- (SedEx) deposits.

The results from both the Kildare deposits and Abbeytown fall within the MVT ranges and not within the ranges typical of Irish-type deposits.

The age of most of the Irish-type deposits in the Irish Midlands is well constrained around the late Chadian whilst at Harberton the breccia-bodies cut late Chadian to Arundian rocks and are seemingly controlled by late-Hercynian cross-cutting NW trending faults that themselves transect major Hercynian thrust and reverse faults.

It is tentatively suggested that the Kildare mineralization is of early Permian age and formed from tectonically driven fluids expelled by pore-fluid reduction in parts of the sedimentary

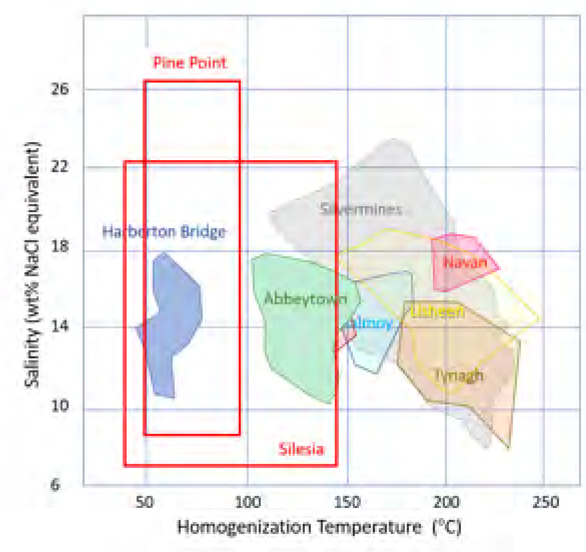


Figure 15: *Fields for primary inclusions in deposit sphalerites and carbonates derived from data in Banks & Russell (1992), Everett et al. (1997, 1999), Eyre (1998) and Trude & Wilkinson (2001). Fields for Silesia and Pine Point from Basuki & Spooner (2002).*

pile closer to the Hercynian front. A model closely identifiable with that of Leach & Sangster (1993) for classic MVT-type deposits wherein they state:

> *"MVT deposits originate from saline basinal metalliferous fluids at temperatures in the range of 75°-200°C. They are set in carbonate platform settings, typically in relatively undeformed orogenic foreland rocks, commonly in foreland thrust belts, and rarely in rift zones."*

With respect to the Abbeytown deposit the mineralization textures are epigenetic - cavity and fissure filling; hydrothermal dolomite replaces calcite; there are sharp edged veins with base metal mineralization, temperatures of ore deposition (105° to 168° C) and the mineralization is late in comparison to the host rocks. Hitzman (1986) proposed an Asbian age for the mineralization while a late Carboniferous to Permian age (270 and 285Ma) was suggested by K-Ar following dating of chlorite intergrown with sphalerite and galena (Halliday & Mitchell, 1983). In addition, there is no evidence that any of the faults were active at time of sedimentation (Hitzman, 1986) thus removing one of the main features typical of Irish-type mineralization. Persellin *et al* (2010) concluded that the base-metal sulphide prospects in northwest Ireland indicate no connection with the regionally extensive flow system thought to be responsible for Zn-Pb deposits throughout the Irish Midlands.

Geologically well-defined constraints as to the age of the Zn-Pb mineralization in Kildare can be defined: 1) brecciation constraining faulting transects and dislocates Variscan reverse faults; such faults are intimately associated with the Zn-Pb mineralization acting as conduits for mineralizing fluids to the breccia bodies as evidenced by sulphides preferentially developed on their hangingwall sides as high grade masses; 2) no evidence of re-brecciation or recrystallization of the schallenblende sphalerite or galena within the faults bounded zones indicative of a later post-mineral faulting event, and 3) pink baroque dolomite, determined to be related to a basin-inversion phase in the late Asbian to Brigantian, predates brecciation and paragenetically early pre-sulphide dolomites. Thus, on geological evidence alone it is likely that the Kildare mineralizing event is contemporary to the late Sudetic Event in the Asselian Stage of the Permian.

Conclusions

Having reviewed the available information on both the Kildare District deposits and the Abbeytown Deposit it is the authors opinion that these they belong to the MVT class of deposits. The conclusions expressed here that both the Kildare District and the Abbeytown deposit should be assigned to the MVT deposit class is the same as previous workers (Holdstock, 1982; Emo 1986, Gallagher *et al*. 1992; Trude & Wilkinson, 2001 for the Kildare District; and Hitzman 1986; and Persellin 2009 for Abbeytown). The important corollary is that both the Kildare District deposits and the Abbeytown deposit are clearly Irish on their geographic setting but are not Irish-type Zn-Pb deposits and should not be grouped as such. An important conclusion is, however, that within the Irish Orefield Zn-Pb mineralizing processes extended over a greater time scale than may have previously been assumed rendering stratigraphy higher in the succession potentially prospective.

Acknowledgements

Both authors worked on the Kildare District deposits to a limited extent during their past careers. However, we have relied on the work of many others in preparing this work. We are grateful for the careful observations made by many geologists too many to mention but would like to mention Dave Blaney, Mike Boland, John Colthurst, George Emo, Mark Holdstock and Gareth V Jones.

References

Anderson, G.M. & Macqueen, R.W. (1982) Mississippi Valley-Type Lead-Zinc Deposits. In: Ore Deposit Models, *Geol Assoc Can Reprint Series* 3. Roberts, R.G. and Sheahan, P.A. (Eds) 79-90.

Anderson, I.K., Ashton, J.H., Boyce, A.J., Fallick, A.E. & Russell, M.J. (1998) Ore depositional processes in the Navan Zn-Pb deposit, Ireland: *Economic Geology,* v. 93, 535–563.

Andrew, C.J. (1993) Mineralization in the Irish Midlands. *In*: Pattrick, R.A.D. & Polya, D.A. (eds). Mineralization in the British Isles. *Chapman & Hall, London* p208-269.

Bastin, E.S. (1939) Contributions to a Knowledge of the Mississippi Valley region. *Geol Soc Amer Special Paper* 24 156p.

Basuki, N. & Spooner, E. (2002) A Review of Fluid Inclusion Temperatures and Salinities in Mississippi Valley-type Zn-Pb Deposits: Identifying Thresholds for Metal Transport. *Geology*, v. 11 (1-4): 1–17

Boland, M. & Colthurst, J. (1995) The geology, mineralisation and exploration potential of the Kildare East licence block, County Kildare. Confidential Report to Ennex International plc (Licences 600, 863, 1629, 1630, 1631, 1632.)

Boyce, A.J., Anderton, R. & Russell, M.J. (1983) Rapid subsidence and early Carboniferous base-metal mineralization in Ireland. *Trans Instn Min Metall*, v.92, B55-65.

Brown, A.G. (1973) Renewal Report for Licences 755-759, 1660 up to June 1973. 58p. Accessed via Geological Survey Ireland's website.

Buerger, M.J. (1934) The pyrite – marcasite relationship. *Jour Min Soc. Amer,* v. 19 37-61.

Carne, R.C. & Cathro, R.J. (1982) Sedimentary exhalative (sedex) zinc-lead-silver deposits, northern Canadian Cordillera. *Can Min Metall Bull,* v. 75 66-78.

Cazalet, P.C.D. (1982) A review of geochemical exploration techniques 1979-1981. In: Mineral Exploration in Ireland – Progress and Developments 1971-1981. Brown, A.G. and Pyne, J. (Eds). *Irish Association for Economic Geology, Dublin* 148 –156.

Clifford, J.A., Ryan, P. & Kucha. H. (1986) A review of the geological setting of the Tynagh orebody, Co. Galway. In: Geology and Genesis of Mineral Deposits in Ireland. Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M. & Pyne, J.F. (Eds). *Irish Association for Economic Geology, Dublin*. 419-439.

Cole, G.A.J. (1922) Memoir and Map of Localities of Minerals of Economic Importance and Metalliferous Mines in Ireland. *Geol Surv Ire* 154p.

Cunningham, M.A. (1954) Mineral Deposit at Abbeytown, Co. Sligo. Internal report to Geological Survey Ireland. 11p. Accessed visa Geological Survey Ireland's website.

Dixon, P.R., LeHuray, A.P. & Rye, D.M. (1986) An isotopic and textural study of Pb-Zn mineralization around the Kildare Inlier, Co. Kildare, Ireland. *Geological Society of America Abstracts with Programs,* 18, (6), 670.

Dixon, P.R., LeHuray, A.P. & Rye, D.M. (1990) Basement geology and tectonic evolution of Ireland as deduced from Pb isotopes. *Jour Geol Soc.* v.147, 121-132.

Emo, G.T. (1986) Some considerations regarding the styles of mineralisation at Harberton Bridge, County Kildare. In: Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M. and Pyne, J.F. (eds*), Irish Association for Economic Geology, Dublin.* 461-469

Fernandez, L.L. (1957) The geology and mineralization of Abbeytown Mine, Co. Sligo, Eire. Unpubl. BSc thesis, Royal School of Mines, London 85p.

Gallagher, V.; Boyce, A.J., Fallick, A.E. & Mohr, P. (1992) An isotopic study of the Harberton Bridge Fe-Zn-Pb deposit, County Kildare, and its implications for metallogenesis in Ireland. In: Bowden, A.A., Earls, G., O'Connor P.G. & Pyne, J.F. (eds) The Irish Minerals Industry 1980–1990. *Irish Association for Economic Geology, Dublin* p261–272.

Goodfellow, W.D., Lydon, J.W. & Turner, R.J.W. (1993) Geology and genesis of stratiform sediment-hosted (SEDEX) zinc-lead-silver sulphide deposits. In: Mineral deposit modelling. *Geol Assoc Can Special Paper* 40, 201-251.

Grennan, E.F. & Andrew, C.J. (2019) The Mining Heritage and History of the Silvermines area, County Tipperary, Ireland since the 13th century. *European Geologist Journal.* v.48 43-48.

Hagni, R.D. (1983) Ore microscopy, paragenetic sequence, trace element content, and fluid inclusion studies of the copper-lead-zinc deposits of the Southeast Missouri lead district. In: Kisvarsanyi, G., Grant, S.K., Pratt, W.P. & Koenig, J.W. (eds*)* International conference on Mississippi Valley type lead-zinc deposits 243–256.

Halliday, A.N. & Mitchell, J.G. (1983) K-Ar ages of clay concentrates from Irish orebodies and their bearing on the timing of mineralization. *Tran Roy Soc Edin Earth Sci*. v.74 1-14.

Hardman, E.T. (1880) Notes on reverse side of Six-inch sheet Sligo 56-1 (NW quadrant) and referenced on p31 of Memoir 55.

Hitzman, M.W. (1986) Geology of the Abbeytown mine, Co. Sligo, Ireland. In: Geology and Genesis of Mineral Deposits in Ireland.

Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M. & Pyne, J.F. (Eds). *Irish Association for Economic Geology, Dublin.* 341-353.

Hitzman, M.W. & Large, D. (1986) A review and classification of the Irish carbonate-hosted base metal deposits. In: Geology and Genesis of Mineral Deposits in Ireland. Andrew, C.J., Crowe, R.W.A., Finlay, S., Pennell, W.M. & Pyne, J.F. (Eds). *Irish Association for Economic Geology, Dublin.* 217-238.

Hitzman, M.W. & Beaty, D.W. (1996), The Irish Zn-Pb-(Ba) Orefield: Carbonate-hosted Lead-Zinc Deposits. *Soc Econ Geol Special Publication*, v. 4 112-143.

Holdstock. M. P. (1982) Breccia-hosted Zinc-Lead mineralization in Tournaisian and Lower Visean Carbonates at Harberton Bridge, County Kildare. *In:* Brown, A. G. and Pyne, J. F. (eds.), Mineral Exploration in Ireland: Progress and Developments 1971-1981. *Irish Association for Economic Geology, Dublin* 83·91.

Holdstock. M. P. (1983) The Lower Carboniferous Geology and Base Metal Mineralization of north·east County Kildare. Ireland. Unpubl. Ph.D Thesis. University College, Cork.

Johnson, A.W., Shelton, K.L., Gregg, J.M., Somerville, I.D., Wright, W.R. & Nagy, Z.R. (2009) Regional studies of dolomites and their included fluids: recognizing multiple chemically distinct fluids during the complex diagenetic history of Lower Carboniferous (Mississippian) rocks of the Irish Zn-Pb ore field. *Miner Petrol,* v.96 1–18.

Jones. G. V. (1979) Discovery of zinc-Iead mineralization at Harberton Bridge, County Kildare, Ireland. *Trans Instn Min Metal,* v.89 B50.

Kelly, J. (2007) A history of Zn-Pb-Ag mining at Abbeytown, Co. Sligo. *Jour Mining Heritage Trust of Ireland* v.7**,** 9-18.

Kyle. T. R. (1981) Geology of the Pine Point Lead-Zinc District. In: K. H. Wolf. (Ed). Handbook of Stratabound and Stratiform Ore Deposits. v.9. Regional studies and specific Deposits. Amsterdam. Elsevier. p643·741.

Leach, D.L., Bradley, D.C., Huston, D., Pisarevsky, S.A., Ryan D., Taylor, R.D. & Gardoll, S.J. (2010) Sediment-Hosted Lead-Zinc Deposits in Earth History. *Economic Geology,* v.105 593–625.

Leach, D.L. & Sangster, D.F. (1993) Mississippi Valley-type lead-zinc deposits. *Geol Assoc Can Special Paper* 40. 289-314.

Leach, D.L., Sangster, D.F., Kelley, K.D., Large, R.R., Garven, G., Allen, C.R., Gutzmer, J. & Walters, S. (2005) Sediment-hosted lead-Zinc Deposits: A Global Perspective. In: Economic Geology: One hundredth anniversary volume. Hedenquist, J.W., Thompson, J.F.H., Goldfarb, R.J. and Richards, J.P. (Eds). 561-607.

Machel, H.G. (1987) Saddle dolomite as a byproduct of chemical compaction and thermochemical sulphate reduction. *Geology,* v.15 936-940.

Max, M.D. & Long, C.B. (1985) Pre-Caledonian basement in Ireland and its cover relationships. *Geol Jour,* ***v.20*** 341-366.

McCabe, C. & Channell, J.E.T. (1994) Late Palaeozoic re-magnetization of limestones of the Craven Basin (northern England) and the rock magnetic fingerprint of re-magnetized sedimentary carbonates. *Jour Geophys Res*, v. 99 4603-4612.

McConnell, B., Philcox, M.E., Sleeman, A.G., Stanley, G., Flegg, A.M., Daly, E.P. & Warren, W.P. (1994) The Geology of Kildare – Wicklow, Sheet Memoir 16 *Geological Survey Ireland* 70p.

MacDermot, Long, C.B. & Harney, S.J. (1996) A Geological description of Sligo, Leitrim, and adjoining parts of Cavan, Fermanagh, Mayo and Roscommon, to accompany the Bedrock Geology 1:100,000 Scale map Series, Sheet 7. *Geological Survey Ireland* 99p.

Megaw, P.K.M., Ruiz,J. & Titley, S.R. 1988 High-temperature carbonate-hosted Ag-Pb-Zn(Cu) deposits of northern Mexico. *Economic Geology*, v. 83 1856-1885.

Nagy Z.R., Somerville I.D., & Becker S. (2001) Petrology and biostratigraphy of a peritidal environment from the early to late Visean (Lower Carboniferous) Milford Formation, Co. Carlow, Ireland. *Geol Soc Am.* Abs Prog **33** A443.

Nagy Z.R., Gregg J.M. & Shelton K.L. 2004 Early dolomitization and fluid migration through the Lower Carboniferous platform carbonates in the SE Irish Midlands: implications for reservoir attributes. In: Braithwaite, C.J.R., Rizzi, G. and Darke, G. (eds) The Geometry and Petrogenesis of Dolomite Hydrocarbon Reservoirs *Geol Soc Spec Pub* 231 367–392.

Nagy Z.R., Somerville I.D. & Gregg J.M. (2005) Lower Carboniferous peritidal carbonates and associated evaporites adjacent to the Leinster Massif, southeast Irish Midlands. *Geol. Jour.* v.40 173–192.

Pannalal, S.J., D. T. A. Symons, D.T.A. & Sangster, D.F. (2008a) Palaeomagnetic evidence of a Variscan age for the epigenetic Galmoy zinc–lead deposit, Ireland. *Terra Nova*, v. 20 385-393.

Pannalal, S.J., D. T. A. Symons, D.T.A. & Sangster, D.F. 2008b Paleomagnetic Evidence for an Early Permian Age of the Lisheen Zn-Pb Deposit, Ireland. *Economic Geology*, v. 103 1641-1655.

Paradis, S., Hannigan, P. and Dewing, K. (2007) Mississippi Valley-type lead-zinc deposits In Goodfellow, W.D. (ed) Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods: *Geol Assoc Can, Mineral Deposits Division, Special Publication* No. 5 p185-203.

Persellin, C.J. (2009) Dolomitization and sulfide mineralization of lower carboniferous strata, NW Ireland. Unpubl. MSc thesis, Oklahoma State University. 93p.

Persellin, C.J., Gregg, J.M., Shelton, K.L., Somerville, I.D. & Atekwana, A. (2010) Base Metal Sulfide Mineralization in Lower Carboniferous Strata, Northwest Ireland. *Exploration and Mining Geology*, v.19, Nos. 1–2, p. 35–54,

Philcox, M.E. (1984) Lower Carboniferous Lithostratigraphy of the Irish Midlands. *Irish Association for Economic Geology, Dublin* 89p.

Popp, B.N., Anderson, T.F. & Sandberg, P.A. (1986) Brachiopods as indicators of original isotopic compositions in some Paleozoic limestones: *Geol Soc Amer Bull*, v. 97 1262-1269.

Rhodes, D & Vickers, J. (1990) Internal Report on Westland Exploration Licences (1629, 1632, 600, 863, 1630 and 1631, County Kildare, Ireland. 22p. Accessible via Geological Survey Ireland's website.

Sass·Gustkiewicz, M. (1983) Zinc-lead ore structures from Upper Silesian Region in the light of solution transfer: In*:* Kisvarsanyi, G., Grant, S.K., Pratt, W.P. & Koenig, J.W. (eds) *International conference on Mississippi Valley type lead-zinc deposits*. Proceedings Volume, p20-26.

Shail, R.K. & Alexander, A.C. (1997) Late Carboniferous to Triassic reactivation of Variscan basement in the western English Channel: Evidence from onshore exposures in south Cornwall. *Jour Geol Soc,* v.154 163-168.

Trude, K.J. & Wilkinson, J.J. (2010 A mineralogical and fluid inclusion study of the Harberton Bridge Fe-Zn-Pb deposit, County Kildare, Ireland. Jour Geol Soc **158** 37-46.

Wilkinson J.J. (2003) On genesis, dolomitization and mineralisation in the Irish ore-field. *Mineralium Deposita* v.38, 968-983.

Wilkinson J.J. (2014) Sediment-Hosted Zinc–Lead Mineralization. In: Holland H.D. and Turekian K.K. (eds.) Treatise on Geochemistry, Second Edition, Oxford: Elsevier. 13, 219-249.

Yesares, L., Menuge, J. F., Blakeman, R. J., Ashton, J. H., Boyce, A. J. , Coller, D., Drummond, D. A. & Farrelly, I. (2022) Pyritic mineralization halo above the Tara Deep Zn-Pb deposit, Navan, Ireland: Evidence for sub-seafloor exhalative hydrothermal processes? *Ore Geology Reviews,* v.140, 23p.

Wilkinson, J.J., Crowther, H.L., & Coles, B.J., (2011) Chemical mass transfer during hydrothermal alteration of carbonates: Controls of seafloor subsidence, sedimentation and Zn-Pb mineralization in the Irish Carboniferous: *Chemical Geology*, v. 289, p. 55-75.

Woodcock, N.H. & Strachan, R.A., (2009) Geological history of Britain and Ireland. John Wiley & Sons.

Yesares, L., Drummond, D., Hollis, S.P., Doran, A.L., Menuge, J.F., Boyce, A.J., Blakeman, R., & Ashton, J.H. (2019) Coupling mineralogy, textures, stable and radiogenic isotopes in identifying ore-forming processes and vectoring possibilities in Irish-type carbonate hosted Zn-Pb deposits: *Minerals*, v. 9 (335), p. 1-27

Yesares, L., Menuge, J. F., Blakeman, R. J., Ashton, J. H., Boyce, A. J. , Coller, D., Drummond, D. A. & Farrelly, I. (2022) Pyritic mineralization halo above the Tara Deep Zn-Pb deposit, Navan, Ireland: Evidence for sub-seafloor exhalative hydrothermal processes? *Ore Geology Reviews*, **140**, 23p