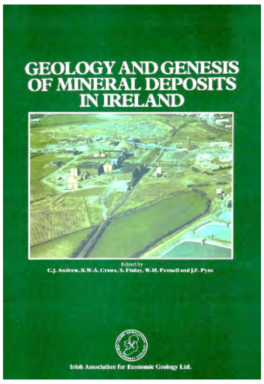

GEOLOGY AND GENESIS OF MINERAL DEPOSITS IN IRELAND

Some considerations regarding the styles of mineralization at Harberton Bridge, County Kildare.

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Some considerations regarding the styles of mineralization at Harberton Bridge, County Kildare.

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Abstract

The Zn-Pb-Fe mineralization at Harberton Bridge occurs in Lower Carboniferous Limestones of Courceyan to Arundian age situated on the northern side of the Lower Palaeozoic Kildare Inlier. The styles of mineralization are significantly different from those in most other Irish Carboniferous deposits and consist of Zn-Pb-Fe sulphide breccias, sulphide-cemented breccias and fracture-filling sulphides. In addition, sub-drift secondary enriched zones are developed. In the lower part of the carbonate sequence, beneath the main breccia development, disseminated and fracture-fill Zn-Pb-Fe-Ba mineralization is also present.

Brecciation occurs through 500m of the carbonate sequence and is particularly well developed in beds immediately below and at the base of the Waulsortian Mudbank. The breccias have been classified into three main divisions:— rock-matrix, precipitate-cemented and crackle types.

The bodies formed as a result of solution and precipitation from acidic, low temperature, hydrothermal fluids. The origin of these fluids is uncertain. Geophysical and regional geological evidence suggest that Harberton Bridge was located close to an active basin margin. The mineralizing fluids may have been derived from this basin or from a deep-seated source.

Introduction

The Harberton Bridge Zn-Pb-Fe mineralization is situated in County Kildare approximately 40km WSW of Dublin (Fig. 1). Breccia-hosted mineralization occurs in Lower Carboniferous rocks of Courceyan to Arundian age which flank the northwestern margins of the Lower Palaeozoic Kildare Inlier.

The mineralization differs in many respects from the other Carboniferous deposits described in this volume (e.g. Navan, Ashton et al.; Silvermines, Andrew; Tynagh, Clifford et al.). At Harberton Bridge the mineralization is epigenetic (Mississippi Valley-type) compared with dominantly syndiagenetic styles at the other deposits. Mineralization extends over a thick stratigraphic interval, and only rarely, (e.g. Abbeytown, Hitzman, this vol.) has substantial mineralization been recorded so high up in the Carboniferous sequence. In addition to the mineralization at Harberton Bridge a number of other similar or related mineral occurrences are present in the surrounding area (Fig. 1).

Exploration history

The discovery of Zn-Pb mineralization in the Harberton Bridge licence area has been summarized by Jones (1979). Exploration commenced in the late 1960s with reconnaissance shallow (0.5m) auger sampling over the licence area. A low order zinc anomaly (maximum 630ppm) near Harberton Bridge was enhanced by more detailed soil sampling (maximum value 2,400ppm). Deep overburden sampling through the glacial overburden yielded a number of anomalies (Cazalet, 1982) with maximum values of 10.8% Zn and 1.9% Pb in the area of the soil anomaly.

Various geophysical techniques including dipole-dipole IP, VLF-EM16R, SP, Pulse EM and Magnetics were applied in the area. the most successful was dipole-dipole IP, which outlined two significant anomalies (Williams, 1982). One of the IP responses was almost directly over a deep overburden anomaly, but the other was significantly displaced suggesting glacial, geochemical dispersion.

Diamond drilling of the IP anomalies commenced in 1975 and identified two secondary enriched zones of unconsolidated mineralization containing Zn, Pb, Fe sulphides/oxides/carbonates and clays beneath the glacial deposits. Mineralized breccia bodies were discovered below the secondary zones.

Exploration in the area is currently being carried out by Billiton Exploration Ireland Limited as operator of a joint venture with Syngenore Explorations Limited.

Regional geological setting

The dominant topographic feature in the area is the Kildare Inlier which is composed of Ordovician and Silurian sediments and volcanics. The Ordovician rocks consist of Llanvirn graptolitic shales, Caradocian basic to andesitic volcanics and Ashgillian limestones. The Silurian is composed of greywackes and siltstones. These rocks were initially described by Gardiner and Reynolds (1896) and later dated by Wright (1967). The volcanics are thought to have been part of an island-arc system on the SE side of the Iapetus Ocean (Phillips et al., 1976). This palaeo-environmental setting has been further discussed by Stillman and Williams (1978).

A significant aeromagnetic anomaly is located over the inlier and a major NE-trending gravity axis possibly representing some deep-seated structure, passes along its northwestern flanks (Brown and Williams, in press).

The Lower Palaeozoic rocks were folded and faulted during the Caledonian orogeny, and evidence from thickness and facies variation, within the succeeding Carboniferous sequence, suggest that the inlier may have formed a palaeohigh and controlled the deposition of these later sediments.

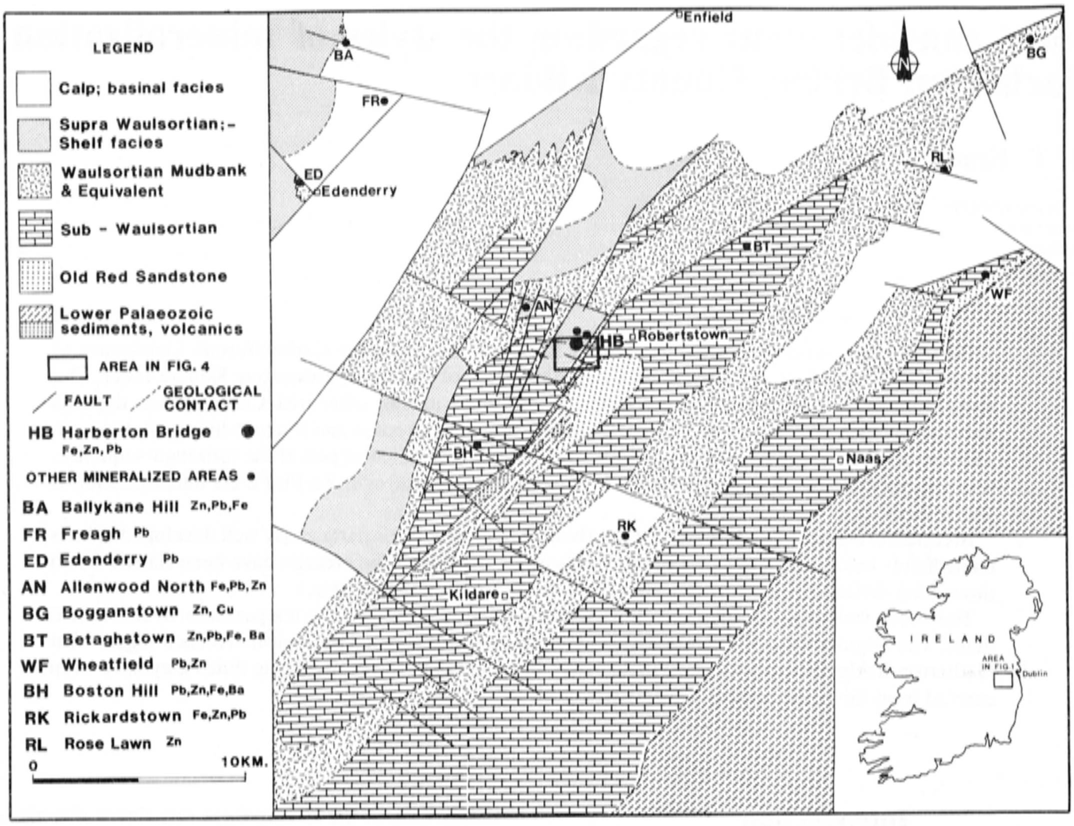

Figure 1. Regional geological setting of the Harberton Bridge area.

Fluviatile Old Red Sandstone facies rocks, of probable early Carboniferous age (Clayton and Higgs, 1978) and possibly derived from the SE, unconformably overlie the Lower Palaeozoic strata. These are in turn overlain by a thick marine carbonate sequence.

The sub-Waulsortian Mudbank limestones contrast significantly with those found elsewhere in the Irish midlands (Philcox, 1984) and consist of a varied sequence of calcarenite, shale, oolite and argillaceous bioclastic limestone which reach a thickness of over 700m. Regional data for the thickness of the sub-Waulsortian is sparse, but estimates and projections together with geophysical evidence (Brown and Williams, 1985) indicate that Harberton Bridge is located close to a basin margin.

Locally the Waulsortian Mudbank is highly variable in thickness and passes laterally into muddy, cherty calcarenite (Mudbank Equivalent) and dolomite. A sequence of shelf limestone, consisting of pelsparite and micrite of Chadian to Arundian age, overlies the Waulsortian in the Harberton area. (Similar shelf limestones are not present on the southeastern side of the inlier where the Waulsortian is overlain by dark limestones and shales.) To the north of Harberton Bridge (Fig. 1), either Calp limestone of presumed deep water origin or shelf limestone overlies the Waulsortian.

The Lower Palaeozoic rocks are folded about NE-trending axes and this trend is also reflected in the succeeding Carboniferous rocks. A major, northeasterly trending, southeasterly dipping reverse fault separates the Carboniferous from the Lower Palaeozoic succession on the northwestern edge of the inlier. Both normal and reverse faults parallel this structure elsewhere in the area. A number of later easterly, northeasterly and northerly trending faults are also present, but their precise age and nature is unknown due to lack of exposure and drill information. The faults and especially their intersections appear to be highly significant with regard to the location of breccia/mineral bodies.

Local Carboniferous stratigraphy

The upper part of the Lower Carboniferous stratigraphy in the Harberton area has been described previously by Holdstock (1982). Formal names have been given to the units by Holdstock (1983) but as these are unpublished, lithostratigraphical descriptions are used in this account. Detailed logging of diamond drill core has established the succession shown in Figure 2, but since few boreholes in the Harberton area have penetrated the entire carbonate sequence, information on the lower part of the succession is incomplete. However at Boston Hill, 7km to the SW, Philcox (1984) has described the sub-Waulsortian sequence in some detail. The two successions are broadly similar but different nomenclature has been used as shown in Figure 3.

The Lower Limestone Shale sharply overlies the Old Red Sandstone and is composed of fine-grained sandstone, flaser-bedded sandstone and shale. It reaches a thickness of up to 50m and the lithologies present represent the commencement of marine deposition in the area.

A varied sequence of generally mud-free carbonates consisting of calcarenite, micrite, oolite and biosparite follows. These beds bear some resemblance to the Pale Beds at Navan hence the terminology 'Navan Beds Equivalent'. A complete sequence has not been intersected in the Harberton area, but at Boston Hill they reach a thickness of 170m (Philcox, 1984). The beds were deposited in shallow-water environments.

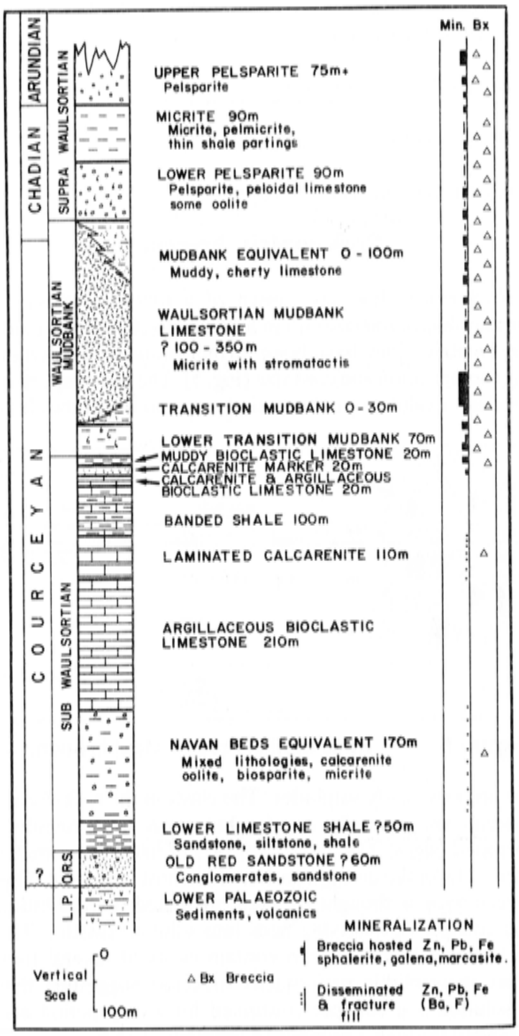

Figure 2. Stratigraphy of the Harberton Bridge area showing breccia and mineral distribution.

The overlying Argillaceous Bioclastic Limestone consists of a monotonous sequence of argillaceous calcarenite up to 210m thick. Diffusely interbedded biomicrite and argillaceous crinoidal calcarenite are common. These beds are thought to have been deposited on the open shelf in relatively quiet water below wave base (Holdstock, 1983).

The succeeding Laminated Calcarenite Unit is composed of laminated limestone interbedded with banded biosparite, silty calcarenite and minor thin shale. Sub-oolitic horizons and the presence of shoal-colonizing brachiopods suggest a shallower water environment than the underlying unit.

The Banded Shale Unit, which is up to 100m thick, consists of thinly banded shales and fine bioturbated calcarenites. The shales are up to 1.5m thick and the calcarenites are often crinoidal. The abundance of shale points to relatively quiet deposition on the shelf.

Above the Banded Shale Unit are beds consisting of calcarenite and argillaceous limestone with minor chert. This Calcarenite and Argillaceous Bioclastic Limestone Unit is 20m thick. The overlying Calcarenite Marker is composed of calcarenite, usually clean, with minor chert and has a thickness of 20m. The unit is often recrystallized or dolomitized and contains cross-bedding, suggesting relatively shallow-water deposition. The Calcarenite Marker is a very significant unit because major dissolution and brecciation is rarely found below it in the area.

A Muddy Bioclastic Limestone consisting of limestone with thin bryozoan shales overlies the Calcarenite Marker. Solitary corals and brachiopods are common fossils within this 20m thick unit. The succeeding Lower Transition Mudbank consists of calcarenite, often cherty and crinoidal with minor wispy shales. Where thin stromatactis micrite beds are interbedded, the unit is termed Transition Mudbank. The Lower Transition Mudbank is 70m thick while the Transition Mudbank is up to 30m thick.

The Waulsortian Mudbank forms a distinctive unit of pale grey micrite and biomicrite with characteristic stromatactis cavities. Extreme facies and thickness variations are present within the Waulsortian. Near Betaghstown (Fig. 1) in the northeastern part of the area approximately 350m of Waulsortian micrites have been drilled (G. V. Jones, pers. comm.). In the Harberton area, along the margins of the inlier, up to 300m are present, but over a distance of 200m the thickness is reduced to 100m. The pale micrites pass laterally into Mudbank Equivalent which consists of dark grey, poorly fossiliferous calcarenite, muddy cherty limestone, crinoidal limestone, pale calcarenite and dolomite. A reef knoll-type environment is suggested with the inter-knoll facies represented by the Mudbank Equivalent. Lees (1982) has presented evidence that the Waulsortian formed in deep water.

Boston Hill (Philcox, 1984)	Harberton Bridge (This paper)
Upper Dolomite (152m)	Waulsortian Mudbank (?100-350m)
	Transition Mudbank (0-30m) Lower Transition Mudbank (70m) Muddy Bioclastic Limestone (20m)
Calcarenite A (45m)	Calcarenite Marker (20m) Calcarenite and Argillaceous Bioclastic Limestone (c. 20m)
Shaley Unit (c. 98m)	Banded Shale (100m)
Calcarenite B (11m) Upper Laminated Calcarenite (97m)	Laminated Calcarenite (110m)
Main Bioclastic Limestone (228m)	Argillaceous Bioclastic Limestone (210m)
Lower Laminated Calcarenite (24m) Oolite Unit. (44m) Calcarenite C (60m) Micrites (25m) Calcarenite D (15m)	Navan Beds Equivalent (?170m)
Lower Limestone Shale (60m)	Lower Limestone Shale (?50m)

Figure 3. Stratigraphy of the Boston Hill area compared with Harberton Bridge.

The Lower Pelsparite Unit, overlying the Waulsortian Mudbank and the Mudbank Equivalent, consists of pale crinoidal limestone, pelsparite, peloidal limestone and minor oolite. The Unit is 90m thick and the presence of oolites suggest a shallow-water origin.

The overlying 90m thick Micrite Unit is composed of micrites and pelmicrites with minor thin shales. Fine pelsparite is present in the lower part which also contains a 10cm grey-green shale (possible tuff) 5m above the base. Birdseye micrite, suggesting a shallow, restricted environment, is often present. A further sequence of pelsparites of unknown thickness (top not seen) overlies the Micrite Unit.

The units described above, in particular those above the Calcarenite and Muddy Bioclastic Limestone Unit are locally dolomitized and often extensively brecciated.

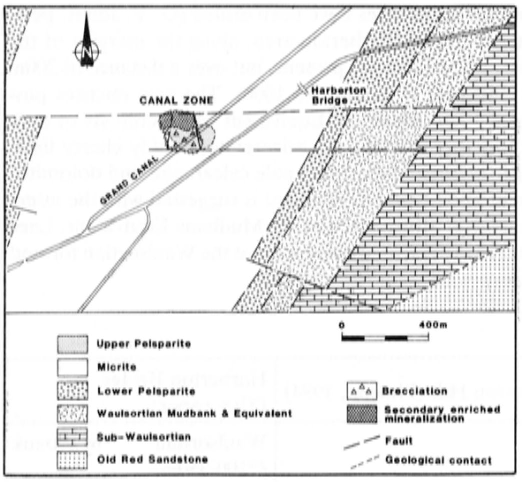

Figure 4. Geology of the Harberton Bridge area.

Dolomitization

Within the Harberton area (Fig. 4) dolomitization is locally developed but may be quite intense, along faults and fault intersections.

At least three phases of dolomitization have been recognised. The earliest phase occurs towards the top of the Waulsortian and is represented by pink dolomite which pre-dates mineralization and could possibly represent an emergence of the Waulsortian. These pink dolomites have been brecciated and the resulting breccias have themselves been dolomitized. Minor marcasite appears to be associated with this phase, the main sulphide mineralization being introduced between this and the following phase. The third phase consists of vein dolomite with calcite cross-cutting the earlier-formed dolomites.

Brecciation

The lithological units previously described, in particular those above the Calcarenite Marker are often intensely brecciated. The breccias form irregularly shaped bodies which cross-cut the stratigraphy (Holdstock, 1982). The central and basal part of a particular breccia body consists of a rubble of rotated rock fragments set in a fine-grained matrix. These pass outwards into breccias showing little or no rotation and finally into unaltered wallrock.

Three main breccia divisions (after Holdstock, 1982) have been recognized:—

(a) Rock-matrix breccia,

(b) Precipitate-cemented breccia,

(c) Crackle breccia.

Rock-matrix breccia

Rock-matrix breccias consist of a rubble of clasts of various shapes and sizes set in a fine-grained (down to mud-size) matrix. They have been further subdivided based on clast composition and clast size (Fig. 5). The most important subclass is sulphide rock-matrix breccia in which the clasts are predominantly sulphides. The clasts in the rock-matrix breccias are generally angular but many have rounded, corroded edges. The matrix consists of fine rock particles derived from the disaggregation of the host limestone. This breccia type is thought to have originated by dissolution and collapse of overlying beds into solution cavities. The rock-matrix breccias often contain clasts of several rock types (heterolithic rock-matrix breccias) suggesting that dissolution and collapse continued for a long period and extended through a number of lithological units.

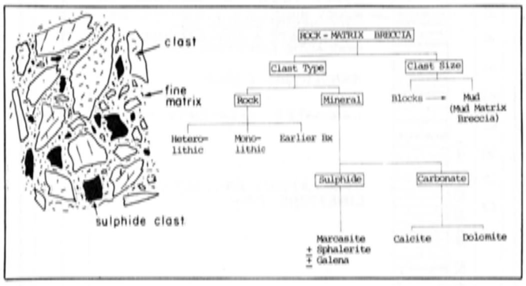

Figure 5. Rock-matrix breccia classification.

Precipitate-cemented breccia

The precipitate-cemented breccia type overlies the rock-matrix breccias and forms the bulk of individual breccia bodies. This division has been further divided into two groups based on the clast type and the kind of the precipitate-cement (Fig. 6). The clasts are usually angular and range in size from a few millimetres to several tens of centimetres. This breccia type is considered to have formed as a result of solution and collapse of limestone into cavities with the cementing of the inter-fragmental voids by sulphides and calcite. In addition to sulphide-coated fragments and infilled voids, earlier formed sulphide clasts may also be present.

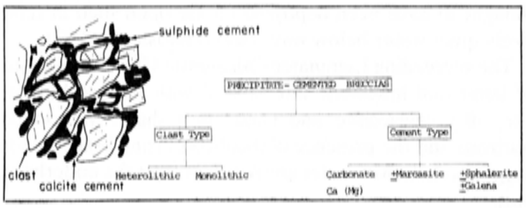

Figure 6. Precipitate-cemented breccia classification.

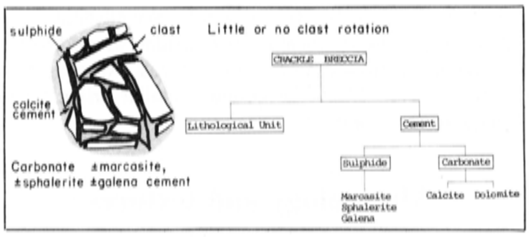

Figure 7. Crackle breccia classification.

Crackle breccia

Crackle breccias consist of angular clasts of limestone which have undergone little or no rotation and which are cemented by carbonate with or without sulphide (Fig. 7). They pass laterally outwards into a network of veined limestone and finally into unbrecciated rock and inwards into rock-matrix and precipitate-cemented breccias. They are sub-divided on the basis of clast composition and on the type of cement. Although not significant with regard to mineralization, their presence may indicate the proximity of a major breccia body.

Breccia distribution

The distribution of the various breccia types in a typical Harberton body is illustrated in Figure 8.

A typical body consists of rock-matrix breccia at the base overlain by precipitate-cemented breccia, with both passing laterally into crackle breccias. Vertical scale varies from a few tens of centimetres to a few hundred metres.

Mineralization

Mineralization in varying degrees and styles occurs throughout the Carboniferous at Harberton Bridge (Fig. 2). It is best developed in units above the Calcarenite Marker, and especially immediately above and below the base of the Waulsortian. The following mineral styles are present:—

(a) Disseminated and fracture-fill mineralization,

(b) Breccia-hosted mineralization,

(c) Secondary enriched zones of mineralization.

Disseminated and fracture-fill mineralization

The disseminated and fracture-fill style of mineralization is largely confined to beds beneath the Waulsortian Mudbank. In the Laminated Calcarenite Unit, for example, 250m below the base of the Waulsortian, disseminated galena and sphalerite occur together with narrow fractures filled with calcite, marcasite, sphalerite and galena. In addition, minor barite and fluorite are present. In the Navan Beds Equivalent, trace amounts of lead, zinc and iron sulphides with minor barite have been observed.

The relation of the disseminated and fracture-fill to the main breccia mineralization is unclear at this stage because few boreholes in the Harberton area have penentrated far enough below the Waulsortian. However, the mineralogy of both zones (marcasite, sphalerite and galena) is similar except for the presence of barite and flourite in the lower mineralized zone. Thin section examination shows that the disseminated sulphides replace clasts or limestone pellets. Small-scale breccias are locally developed close to the fracture-fills, pointing to similarity with the main breccia mineralization. A mode of emplacement similar to that for the main breccia mineralization described below is suggested. The possibilities, however, of a very early mineralizing phase similar to that at Navan cannot be ruled out.

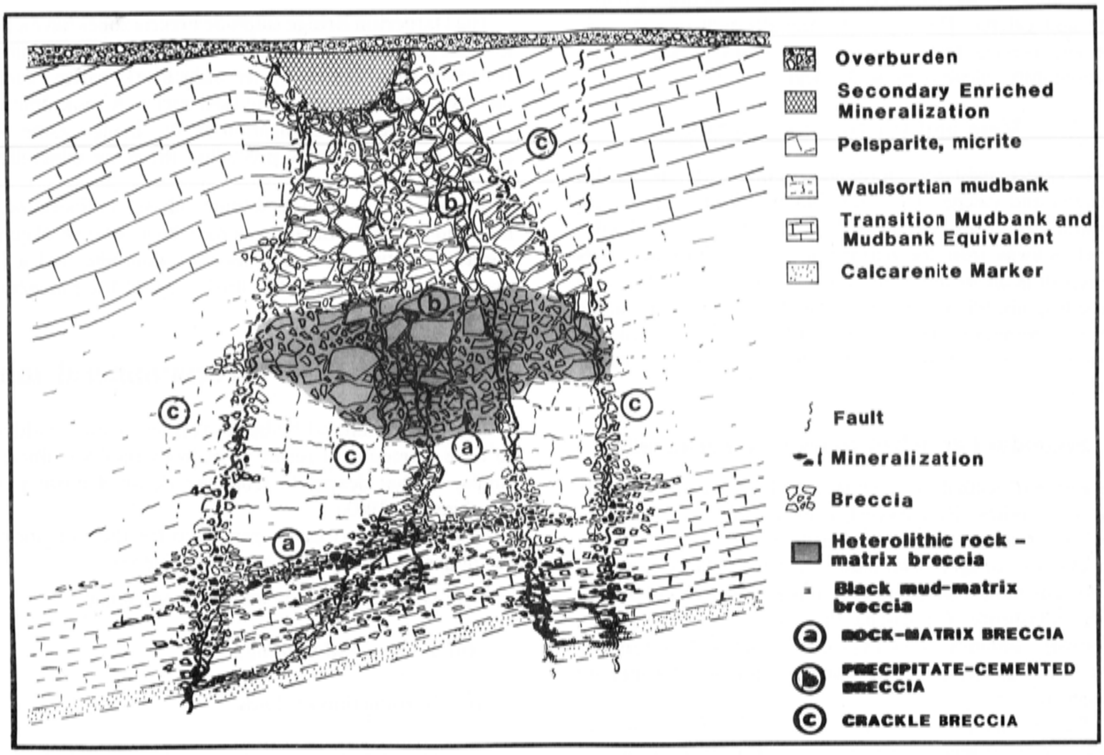

Figure 8. Breccia body showing distribution of mineralization and brecciation (not to scale).

Breccia-hosted mineralization

Breccia-hosted Zn, Pb, Fe mineralization is the most important style intersected in the Harberton area. This type of mineralization occurs in a number of breccia bodies, e.g. the Canal Zone (Fig. 4).

Within a particular breccia body, the following styles of mineralization are recognised:—

(i) Sulphide rock-matrix breccias,

(ii) Sulphide precipitate-cemented breccias,

(iii) Sulphide-cemented crackle breccias,

(iv) Vein and fracture-fill sulphides.

Sulphide rock-matrix breccias

Some of the best mineralization occurs in sulphide rock-matrix breccias at the base of the Waulsortian Mudbank. Impressive accumulations of clasts of colloform, banded marcasite, sphalerite and galena are present, together with rock clasts and calcite set in a fine, often muddy, matrix. In the immediate sub-Waulsortian, sulphide, rock- to mud-matrix breccias are also present. In addition, massive marcasite at this level appears to have grown within the soft mud-matrix breccias around earlier-formed sulphide clasts.

Sulphide precipitate-cemented breccias

Sulphide precipitate-cemented breccia mineralization consists of breccia clasts cemented by sulphide and calcite. This type of mineralization is particularly well developed above the sulphide rock-matrix breccias near the base of the Waulsortian and at the top of individual breccia bodies.

Sulphide-cemented crackle breccias

Sulphide-cemented crackle breccias consist of clasts cemented by marcasite and calcite with or without sphalerite and galena. This style of mineralization occurs close to the breccia body margins and passes outwards into dominantly calcite-cemented crackle breccias.

Vein and fracture-fill sulphides

"The veins consist of fractures filled by marcasite, sphalerite, galena and calcite. They are seldom greater than a few centimetres wide and have been recorded several kilometres away from the major known breccia bodies. It is often difficult in core-size samples to distinguish the vein and fracture-fill type from the sulphide-cemented crackle breccia mineralization. In the Bridge Zone, cross-cutting fractures and veins filled with sulphides post-date brecciation.

Secondary enriched zones of mineralization

Zones of secondary mineral enrichment occur above the breccia bodies. They consist of irregularly-shaped masses of unconsolidated material which, in places, may reach thicknesses of up to 50m under a cover of glacial overburden. The bodies are composed of partially oxidized marcasite, sphalerite and galena in addition to smithsonite, cerussite, limonite, clays and rock fragments. This mineralization is underlain by sulphides in precipitate-cemented breccias.

The secondary zones are considered to be the result of dissolution of limestone resulting in the concentration of sulphides in karstic hollows. This is thought to have occurred from Tertiary to Recent times. Weathering of the sulphides produced various iron oxides in addition to smithsonite, cerussite and other minerals. Morrissey and Whitehead (1969) have proposed a similar origin for the Tynagh residual orebody.

Mineralogy and textures

The sulphide mineralogy in the breccia bodies is simple, consisting of marcasite, sphalerite, galena and minor pyrite. Marcasite is the dominant sulphide phase, followed by sphalerite and galena; the Zn to Pb ratio is approximately 10:1. Clasts of colloform, banded sulphides similar to those described from Pine Point by Kyle (1981) are the most common mode of sulphide occurrence. The colloform sulphides consist of alternating bands of pale yellow, yellow, pale brown to dark brown sphalerite, green marcasite and galena. The colour variations within the sphalerite are probably due to variations in iron content. The paler, low iron sphalerite is the more abundant variety at Harberton Bridge.

In addition to individual bands of galena, intergrowths with sphalerite are common. Usually this takes the form of a very fine intergrowth but small cubes of galena up to 5mm are sometimes present. Well-developed dendritic forms of galena are also common within the sphalerite. According to Anderson and MacQueen (1982) this form of galena suggests relatively rapid deposition from the mixing of H_2S with metal-bearing brines. The iron sulphides are dominantly green marcasite with the cockscomb crystal form well developed. Pyrite is present only in minor amounts, and is usually enclosed entirely by marcasite (T. Finlow-Bates, pers. comm.).

Paragenesis

The Harberton Bridge sulphide breccia zones have a non-metallic gangue of calcite±dolomite with minor amounts of pseudomorphic calcite (after anhydrite), barite, fluorite and pyrobitumen within the host rocks. A pink dolomite phase precedes mineralization in the Bridge Zone with a later dolomite locally preceding the main mineralizing event.

Marcasite is the earliest sulphide phase of mineralization followed by sphalerite and galena. Calcite of several generations, sometimes accompanied by dolomite and a late marcasite phase, forms the final stage of the paragenetic sequence.

Formation of the breccia/mineral zones

The breccia/mineral bodies at Harberton are considered to have formed as a result of hydrothermal karstification similar to that described from the Polish deposits (Sass-Gustkiewicz, 1983).

A four-stage process is envisaged for the formation of the mineral bodies at Harberton Bridge viz.

(i) Deposition of the carbonate sequence,

(ii) Folding and faulting,

(iii) Introduction of fluids,

(iv) Dissolution of limestone and precipitation of sulphides.

Deposition of the carbonate sequence

The thick varied carbonate sequence present in the area alternates from shallow- to deep-water environments of deposition. Up to three breccia phases have been recognized, the earliest of which contains clasts of red to pink dolomitized Waulsortian. This reddening is considered to be possible evidence for the emergence of the Waulsortian as a result of movement along the Inlier fault.

Current thinking on the Waulsortian (Lees, 1982) points to a deep-water origin, yet the Waulsortian at Harberton is overlain by shallow water shelf limestones and there is no evidence to suggest that these were redeposited (e.g. by slumping) from elsewhere. It is possible that the Waulsortian may have grown vertically very rapidly with its top at much shallower water levels than its base. Shelf limestones could easily have been deposited on such elevated portions (G. D. Sevastopulo, pers. comm.) with the off-reef facies consisting of muddy, possibly slumped, calcarenites. This, in part, may explain the source of the micrite, pelsparite and muddy calcarenite clasts in the heterolithic breccias (Fig. 8).

The top of the shallow-water carbonate sequence overlying the Waulsortian is not present in the Harberton area. At Edenderry, 15km to the NW, basinal facies Calp limestones and shale overlie the shelf limestones. Assuming that these shaly, Calp limestones did in fact overlie the shelf limestones at Harberton Bridge, but are now eroded, they may have formed an upper impermeable seal to the mineralizing system.

The beds below the Calcarenite Marker are also shaly and may have formed a lower impermeable barrier. In addition, many of the units below this level are siliceous and these also may have been relatively impermeable to hydrothermal fluids.

Folding and faulting

Following deposition and diagenesis of the carbonate sequence, the rocks were folded and faulted during the Hercynian. The presence of stylolitized, veined and tectonized clasts within the breccia bodies suggests that brecciation post-dated deformation. In addition, incorporation of younger rock fragments in the breccias and the angular nature of these clasts supports the view that the mineralization and hydrothermal karstification events post-dated structural events. Also, layering, where observed within the breccia bodies, is usually horizontal compared to the dipping limestone beds.

Introduction of hydrothermal fluids

It is envisaged that hydrothermal fluids probably used the Inlier fault system as a channelway and moved laterally along the base of the Calcarenite Marker and upwards along faults, fractures and joints through the overlying sequence.

Fluid inclusion studies are in progress and the evidence to date suggests that the fluids were warm, of the order of 100°C, and very acidic (Finlow-Bates, pers. comm.). In addition, as there is usually very little dolomitization associated with mineralization, the fluids were probably magnesium-poor. Such acidic fluids would have been capable of preparing their own space by dissolution of calcite and, most importantly, would not have immediately reprecipitated it as dolomite blocking the space created (Finlow-Bates, pers. comm.). Whether or not there was a single fluid containing both the metals and reduced sulphur, or two fluids with H_2S travelling separately from the metal solution, has been the subject of much discussion (see Anderson and MacQueen, 1982, for review). Dendritic galena within sphalerite is thought by Anderson (1983) to indicate the presence of two fluids. This type of galena occurs at Harberton Bridge and it suggests that the metals and H_2S travelled separately.

An interesting consequence of the two-fluid theory is discussed by Anderson (1983). He suggests that, provided that the sulphate-reduction site is separated from the sulphide precipitation site, the precipitation of the sulphides generates acid for further limestone dissolution. So, presuming the early fluids at Harberton were acidic enough to create sufficient initial space for sulphide precipitation, the process, once started, would have been able to continue.

Dissolution of limestone and precipitation of sulphides

Major dissolution is thought to have been initiated in beds immediately above the Calcarenite Marker. It is suggested that calcium carbonate was dissolved and removed, leaving an insoluble residue which accumulated on the floor of the developing cavity. The roof of the cavity became unstable and blocks of partly corroded limestone fell into the insoluble material forming the black mud-matrix breccia. Precipitation of sulphide (with release of acid) took place on the walls and roof of the cavity in parallel or alternating with dissolution of the carbonate, resulting in the instability and collapse of the roof to produce the sulphide clasts in rock-matrix breccias.

The process continued upwards to the base of the Waulsortian where there is a marked lithological contrast between the muddy carbonates and the pure carbonate of the overlying Waulsortian. Significant preferential solution of limestone, precipitation of sulphides, and collapse into the developing cavity took place at this level. The solution-collapse process worked its way upwards through fractures and joints in the massive Waulsortian Mudbank creating large breccia clasts with a sulphide/calcite cement.

It is thought that the facies changes and contrasting lithologies within the stratigraphic sequence controlled fluid movement and space-generating processes. On reaching contrasting lithologies, dissolution and precipitation-collapse processes appear to have accelerated, e.g. in the Muddy Limestone of the Mudbank Equivalent and Waulsortian micrites. Eventually, an upwards solution-collapse stoping process formed a breakthrough breccia body with breccias in the Lower Pelsparite, Micrite and Upper Pelsparite. In the upper parts of the breccia body, in addition to sulphide precipitation, large amounts of calcite deposition occurred, probably representing the carbonate removed by dissolution from lower units.

Discussion and conclusions

Although epigenetic styles of mineralization do occur at the major carbonate-hosted Irish deposits, much of the mineralization is thought to be syndiagenetic. The host rocks at Harberton Bridge range in age from Courceyan to Arundian, and the age of at least some of the mineralization is therefore post-Arundian. However, that does not exclude the possibility that mineralizing processes may have continued for a longer period of time, possibly commencing in the Courceyan.

However, one feature which Harberton Bridge has in common with the other Irish deposits is its position close to a Lower Palaeozoic inlier. The margins of the inlier are

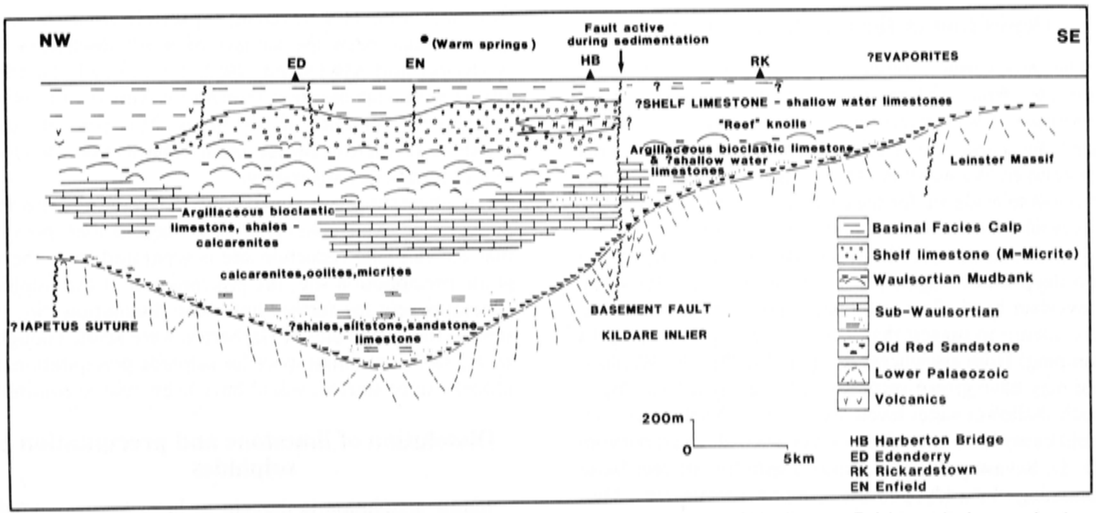

Figure 9. Diagrammatic regional cross-section showing the position of Harberton Bridge relative to the basin margin. (Mineralizing fluids may have migrated from the basin up the Inlier Fault and along the base of the Waulsortian or they may have been derived from the Lower Palaeozoic basement.)

faulted and the faulting is thought to have been active during sedimentation. Geophysical evidence (Brown and Williams, in press) suggests that the Kildare inlier Fault is a deep basement structure and Russell (1978) has proposed that the Irish deposits formed from basement-derived brines using major faults as conduits for the mineralizing fluids. Support for Russell's theory is suggested by the thick Ordovician basic to intermediate volcanic pile which may be a source for the iron-rich sulphide mineralization at Harberton Bridge.

An alternative explanation for the formation of mineralization at Harberton Bridge and one which has been applied to Pine Point and most of the other Mississippi Valley-type deposits is the "basin dewatering model" of Beales and Jackson (1966). This model proposes that fluids expelled from a basin acquire heat and metals during lateral migration and when they encounter H_2S they deposit sulphides in carbonates around the basin margin. Jackson and Beales (1967) suggested that the H_2S necessary for sulphide precipitation was produced by the bacterial reduction of sulphate from nearby evaporite in the presence of petroleum.

Evidence has been presented that Harberton Bridge lies close to a basin margin. The basin, which is centred on Trim (20km to the north) contains a thick (>1,000m) sub-Waulsortian sequence (Sheridan, 1972 and G. D. Sevastopulo, pers. comm.). A possible sulphate source may have existed to the SE near Wheatfield, where, despite the absence of evaporites, the overall nature of the sequence suggests the possibility of their presence as lateral equivalents, (Strogen and Somerville, 1984). Volcanic rocks occur within the Carboniferous at Edenderry and indicate a possible heat source. (Even at the present time a number of warm springs occur in the Enfield area (Brock and Barton, 1984) close to the basin centre.)

Although the basin dewatering model appears very attractive (Fig. 9), most of the evidence from the Harberton area points to a post-lithification, post-early deformation age for the mineralization. This would imply that the basin sequences were also lithified and that formational waters would have long been expelled thus excluding the possibility of the basin being a source for the mineralizing fluids. However, if the sediments close to the margin of the basin lithified rapidly and were subjected to tectonism while those at the basin centre remained largely undisturbed, then it may still be possible to apply the model. Evidence has been presented by Bathurst (1983) that lithification of the Waulsortian Mudbanks took place on the sea floor soon after deposition, and Taylor (1984) has shown this to be the case at Silvermines.

Assuming that the Waulsortian and the overlying shelf limestones lithified rapidly after deposition, and that the basin sequences remained permeable, movement on the Inlier Fault would result in various tectonic features in the limestones. The hydrothermal activity of fluids expelled from the basin would then produce breccias containing these tectonized clasts.

Whatever the source and timing of mineralization, Harberton Bridge is unique amongst the Irish deposits and it is expected that further research will establish links between it and the other Pb-Zn deposits described in this volume.

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