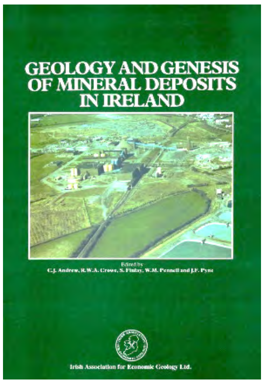

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The geological setting and style of mineralization at Ballyvergin, County Clare.

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Abstract

The Ballyvergin deposit, estimated to contain approximately 233 000t grading 0.97% Cu and 15g/t Ag, occurs in basal carbonates of the Courceyan succession. The deposit is localized by an elongate N-S periclinal fold and is concentrated in its crestal regions. Sulphide mineralization pre-dates quartz-carbonate veining which locally remobilizes earlier sulphides. The deposit has many affinities with the other Cu-Ag deposits of SW Ireland, and is thought to be related genetically to Asbian volcanism.

Introduction

The Ballyvergin Cu-Ag deposit occurs within Lower Carboniferous carbonate sediments on the northern limb of the East Clare Syncline. This area has been the site of numerous small mining ventures for copper and lead in the 18th and 19th centuries and at Ballyvergin some 366t of c. 8% Cu ore and 119t of galena concentrates were raised from workings 10 fathoms (~ 20m) deep between 1856 and 1861.

In 1960, Irish Base Metals Ltd. undertook an exploration programme for base metals around the sites of former historic producers in Ireland and examined, amongst others, those in the East Clare area. At Ballyvergin, to the east of the old mine workings, a well-defined Induced Polarization anomaly, initially interpreted as being due to a sulphide source (Hallof et al., 1962), was diamond drilled. This revealed that disseminated and fracture-fill sulphide mineralization occurs in the crestal regions of a faulted pericline. The IP anomaly is now regarded as having been produced by carbonaceous shales overlying the mineralized zone (Schultz, 1971; Poustie, pers. comm.).

Various estimates of the size of the deposit have been made, ranging from 150 000t grading 1.2% Cu and 15g/t Ag to 233 000t grading 0.97% Cu and 15g/t (Schultz, 1971; Tyler, 1980 IBM company reports).

Stratigraphy

The Lower Carboniferous (Courceyan) succession in the Ballyvergin area of the East Clare Syncline is grossly similar to that described from NW County Limerick (Shephard-Thorn, 1963), Silvermines (Andrew, this vol.) and Tynagh (Clifford et al., this vol.). The uppermost beds of the generally red to buff and green siliciclastics of the "Old Red Sandstone" facies comprise up to 30m of cyclical red sandstone-siltstone sequences. These are overlain by 2-10m of dark grey calcareous bioclastic and bioturbated sandy siltstones and shales with minor sandstone lenses, which become increasingly shaly and laminated upwards.

The overlying Lower Limestone Shales (28-35m) comprise dark grey to black calcareous, linsen-bedded shales with thin layers of winnowed bioclastic detritus and sporadic large fragments of thin-shelled articulate brachiopods, rugose corals, zaphrentids and bryozoa. These shales are immediately overlain by the Ballyvergin Shale, a regional chronostratigraphic marker seen for up to 100km away from Ballyvergin, where it was first recognized (Brown, 1967). This marker, from 3 to 10m in thickness, comprises fissile pale grey-green shales with wispy silt bands and sparse small brachiopods. Petrologically the shale comprises detrital angular quartz, feldspars, muscovite and opaque minerals. This, combined with the presence of a derived fauna of Silurian acritarchs, suggests derivation from a terrigenous source and deposition during a rapid influx of mud into the transgressive lagoonal environment present at the time.

The Ballyvergin Shale is overlain by the Argillaceous Bioclastic Calcarenite (ABC), 175-200m thick, which has been subdivided into four units. The lowest (L1), comprises 30m of dark grey skeletal shales with thin bands of bioclastic calcisiltites. Upwards the L2 (70-85m) dominantly comprises medium grey, well-bedded crinoidal biomicarenites with black skeletal shale partings up to 15cm thick. The superceding L3 (55-65m) comprises 20 to 30cm beds of crinoidal biomicarenites with occasional crinoid biosparrudites and wispy shale partings. The L4 (20m) marks a transition to the overlying Waulsortian Mudbank Reef Limestone and comprises thick beds of nodular cherty crinoidal biomicarenites with wispy shale partings.

The Waulsortian in the East Clare area varies from 300-450m in thickness, thinning to the north and west and typically comprises massive pale grey stromatactid biomicrites. The upper contact of the Reef with the superceding 500m thick, Chadian to Lower Asbian, Gorteen Limestone Group, is often extensively dolomitized beneath a thin chert cap.

Minor volcanics occur at Steele's Turrett, 10km southeast of Ballyvergin, where coarse ashes, lapilli tuffs and vesicular olivine basalts occur in the Middle Asbian. These, and the Gorteen Group, are superceded by the 200m thick Killane Limestone Group comprising cherty medium grey ostracodal Upper Asbian to Brigantian micrites. An erosion surface separates these beds from the Namurian (Pendleian-Sabdenian/E_{1-2}-H) Clare Shales.

Structure

The Ballyvergin deposit is situated on the northern limb of the regional East Clare Syncline, a gently WSW-plunging broad synform of main-phase Hercynian age. The regional structure is complicated by two broad, approximately

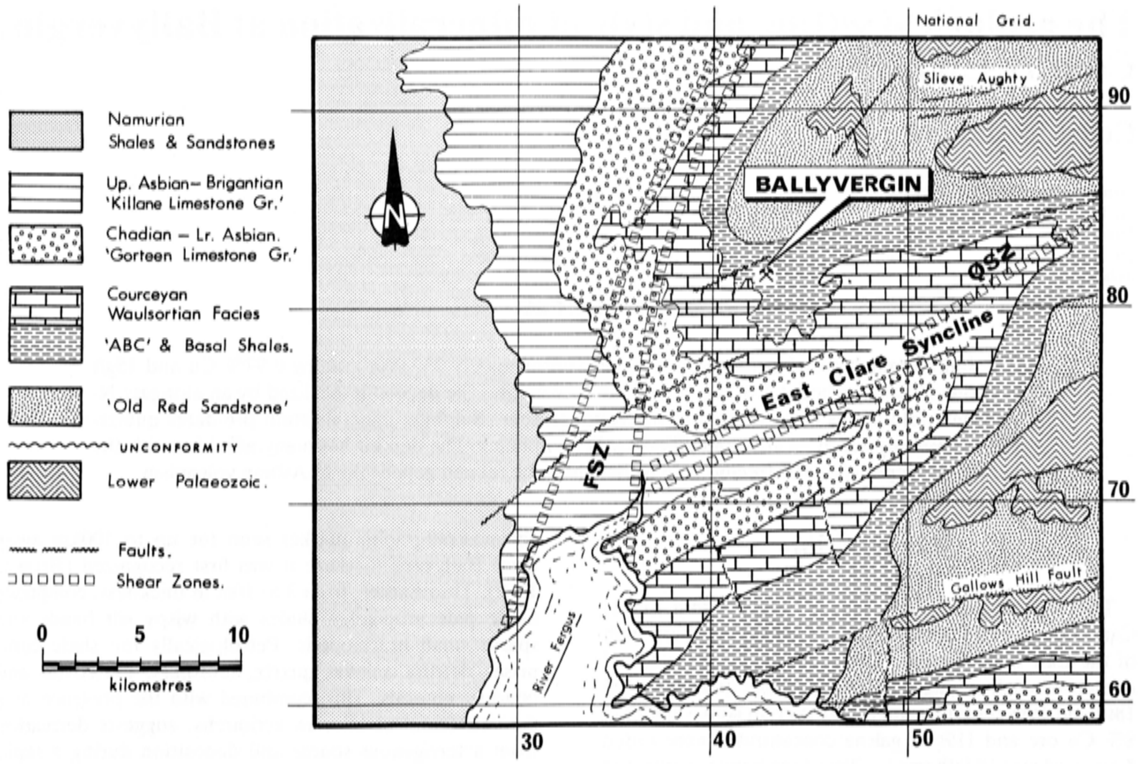

Figure 1. Regional geological map of E County Clare showing the location of the Ballyvergin deposit. FSZ = Fergus Shear Zone; QSZ = Quin Shear Zone. (after Coller & Phillips, 1982).

synchronous, shear zones up to 1km in width, recognized by Coller et al. (1982). Of these the dextral "Quin Shear Zone" trends ENE close to the axis of the East Clare Syncline (Fig. 1), while the sinistral "Fergus Shear Zone" trends NNE from the Fergus estuary up the western flank of the Slieve Aughty inlier (Fig. 1). Minor folding and faulting trending NNE is thought to have developed contemporaneously with the movement of the shear zones (Coller et al., 1982).

At Ballyvergin the regional dip is to the south but is considerably complicated by moderately steep periclinal folding trending northerly. These folds are cut by later NNE-trending steeply dipping faults and thrusts and by NW-trending oblique-slip shears (Figs. 2 and 3). Brown (1967) and Coller et al. (1982) have identified complex spatial and temporal relationships in this region between bedding-parallel veins, crosscutting principal extension veins, *en echelon* veins, and folding and faulting. At Ballyvergin , though, most of these tectonic veins appear to be contemporaneous with, or to post-date, sulphide mineralization.

Mineralization

Mineralization occurs throughout the lower part of the carbonate succession and in the uppermost beds of the Old Red Sandstone, but is primarily concentrated in the Lower Limestone Shales in the crestal region of a periclinal fold (Figs. 2 and 3). Mineralogically, pyrite, chalcopyrite, arsenopyrite and galena are the dominant sulphides, with minor sphalerite, bornite and tennantite; traces of native silver, argentiferous bournonite and geocronite ($5PbS.Sb_2S_3$) have also been recorded (Brown, 1967). The gangue is dominated by ferroan calcite, barite, ferroan dolomite, quartz, ankerite and chlorite-penninite.

Mineralization occurs as intergranular disseminations, as infill of diagenetic void spaces, as replacements of bioclasts and in bedding-parallel and cross-cutting tectonic veinlets.

Disseminated mineralization comprises fine-grained framboidal marcasite-pyrite aggregates (0.01-0.10mm) locally recrystallized and overgrown by subhedral pyrite crystals. Pyrite also occurs as euhedral cubes up to 1mm in laminae on bedding surfaces, and as infill or replacement of bioclasts. Coarse (<1cm) euhedral lozenges and stellate growths of arsenopyrite occur which transect, but do not deform, bedding laminae and bioclasts. Chalcopyrite locally coats and replaces all forms of iron sulphides, and also occurs in minor irregular carbonaceous stylolitic fractures with barite, bornite and, rarely, galena.

Bedding-parallel, or bedding surface veins vary in thickness from thin veneers to several centimetres, and typically show coarsely crystalline symmetrical bands of ferroan calcite, quartz and barite with penninite-muscovite selvages. Variable amounts of subhedral to euhedral pyrite and chalcopyrite occur within the veins and are enriched where the veins cut zones of disseminated mineralization.

Cross-cutting steeply-dipping, dominantly fold axial-parallel (*bc*), irregular veinlets, typically 0.5 to 1.0cm in width, infilled by ferroan calcite with minor dolomite, barite, quartz and penninite are sporadically developed. These veinlets most frequently occur in the crestal regions of periclinal folds and adjacent to sheared zones; they generally dip into the core of the folds and make an average intersection angle with the bedding of 45°. These veins carry sulphides where they cut zones of disseminated and bedding-parallel veinlet mineralization.

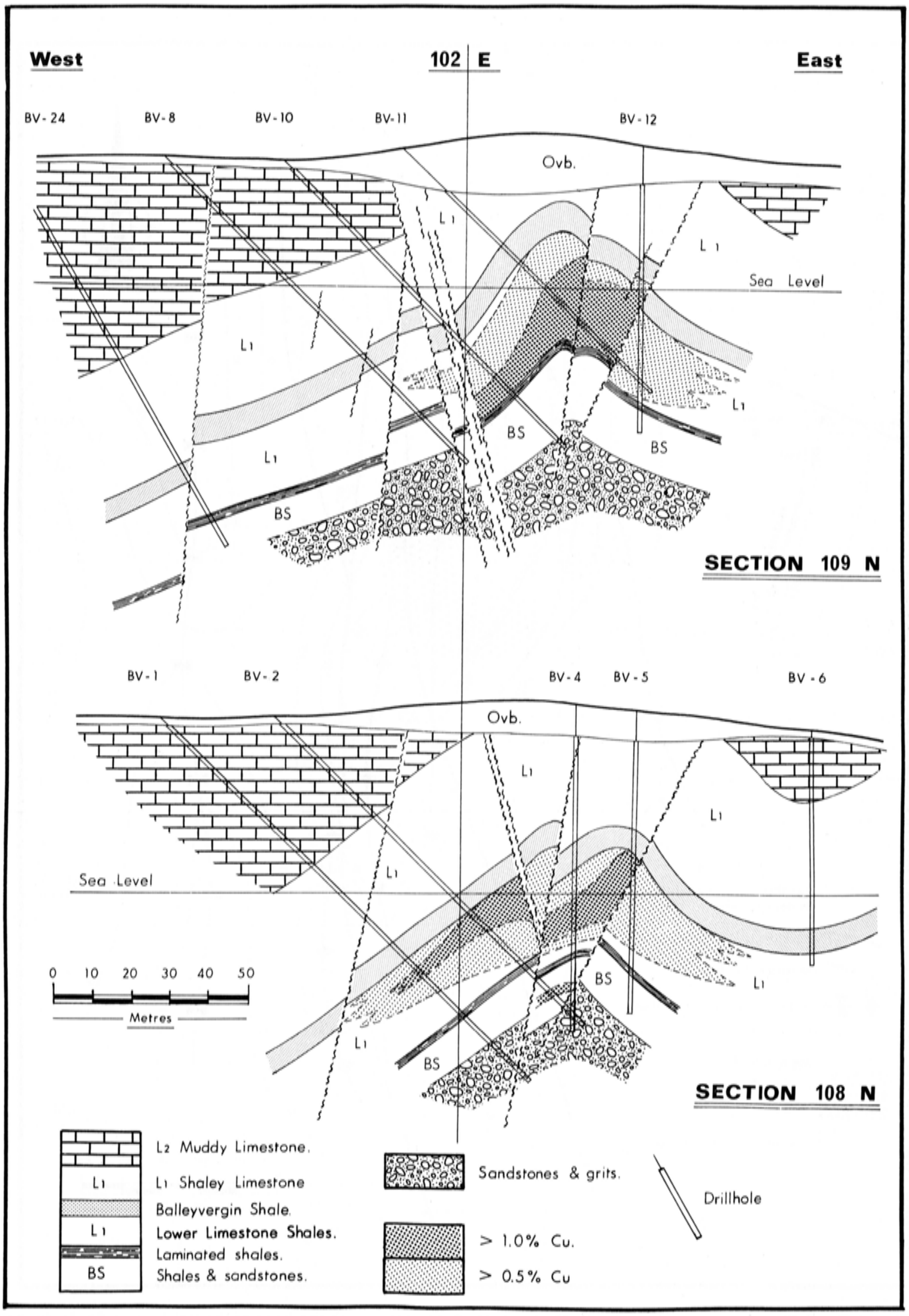

Figure 2. E-W sections through the Ballyvergin deposit.

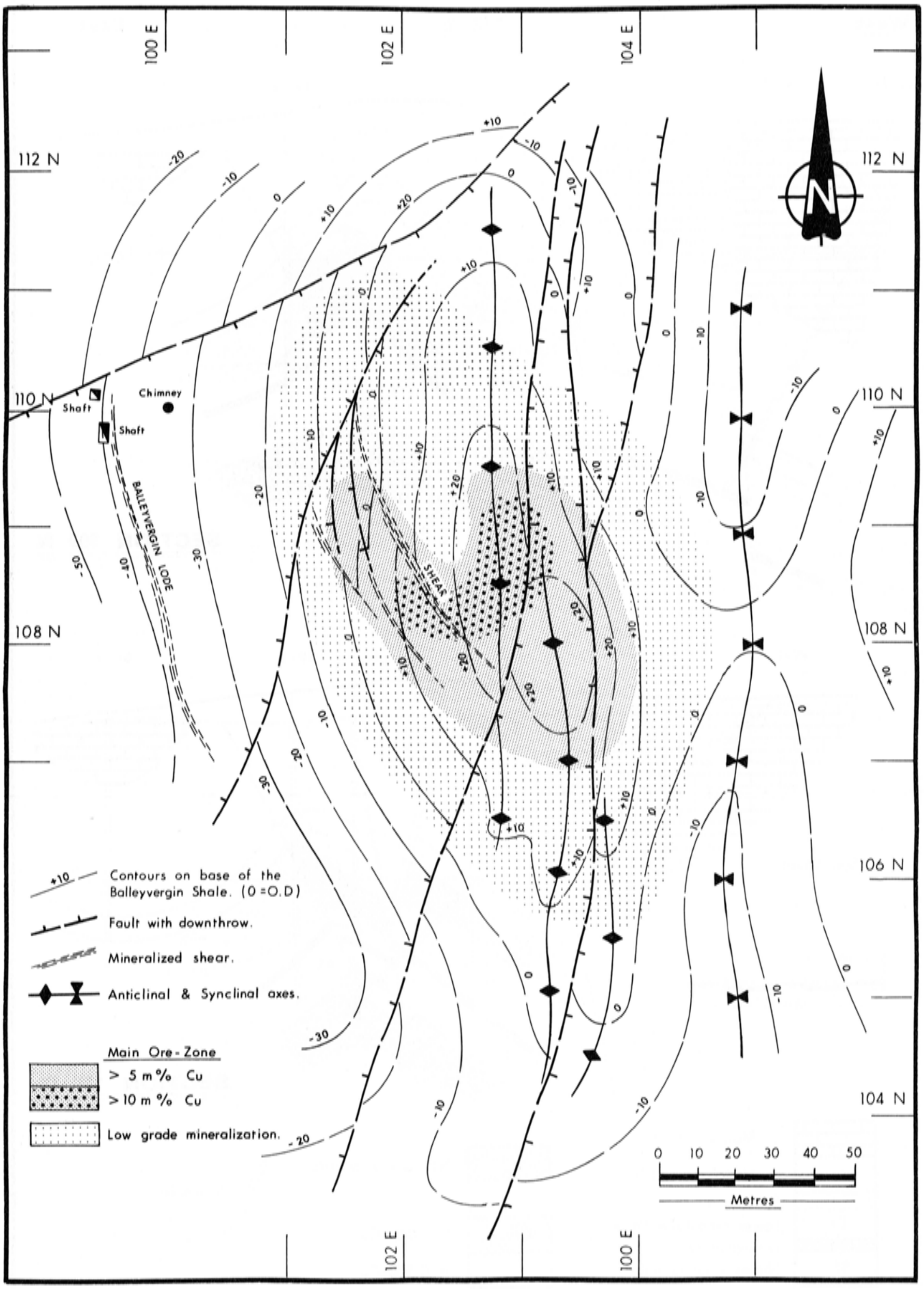

Figure 3. Plan of the Ballyvergin deposit showing structure contours on the base of the Ballyvergin Shale, faults plotted at this surface and the extent of mineralization.'

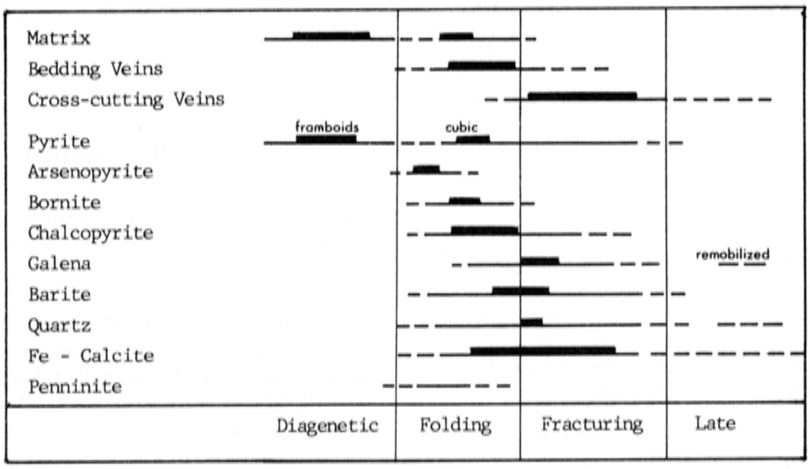

Figure 4. Paragenetic sequence for the Ballyvergin deposit; based on Brown (1967).

Mineralization in both the matrix and in veins is concentrated in the crestal region of the elongate and complex Ballyvergin pericline, and within and adjacent to two shear zones, which display a reverse component of movement. The western shear zone is known as the Ballyvergin Lode and was worked in the 1850s (Fig. 3). Lead grades are enhanced within and adjacent to these shear zones and values up to 15% Pb over 1.5m have been drill intersected in these structures, but elswhere Pb grades are usually in the range 0.10 to 0.50%. Copper grades in the centre of the orebody attain 4.5% Cu over 1.5m sample intervals, but usually average 1-2% Cu with Ag values up to 45g/t. The main zone of mineralization in the Lower Limestone Shales averages 7.5m in thickness at a 1% Cu cutoff grade. This zone is enveloped by a distally diminishing halo of lower grade and trace mineralization.

Genesis

Petrographic and textural evidence reveals that the earliest sulphides in the Ballyvergin deposit comprise bacteriogenic framboidal iron sulphides, presumably formed during early anoxic diagenesis. The main mineralizing event was epigenetic and its onset appears to have pre-dated bedding-parallel vein formation with the local deposition of disseminated sulphides (chalcopyrite, pyrite and arsenopyrite) and barite within residual and secondary porosity (Fig. 4). The locus of deposition was controlled by the initial stages of fold development of the Ballyvergin pericline. Continuing tectonism induced the formation, initially, of bedding-parallel hydraulic jacking veins on the flanks of the developing pericline and of saddle-reef structures in the crestal regions. Ferroan calcite, quartz and barite were deposited in the resultant voids by solution growth mechanisms. Where veins formed in previously mineralized areas, the veins are seen to carry equivalent sulphides, thus suggesting either lateral secretion from the country rock or crystal nucleation on the margins of the veins where they intersected earlier sulphide grains. Later cross-cutting, steeply dipping joints developed systematically to the fold axes and were infilled with ferroan calcite and dolomite. Galena and minor sphalerite with barite and iron-free calcite were introduced during significantly later shearing, and were locally deposited to form the lode structures.

The exact timing of the various styles of epigenetic mineralization is uncertain, but it has been suggested (Coller et al., 1982) that regional deformation during the main phase of the Hercynian orogeny led to the development of the major shear zones and regional folds. Coller et al. (op. cit.) demonstrated that much of the carbonate veining seen throughout the East Clare area can be temporally and spatially related to the Hercynian event. At Ballyvergin, sulphide mineralization within these veins can be shown to be a function of the presence of similar sulphides in the adjacent country rock, and thus Cu ± As ± Ag mineralization pre-dates veining and, conceivably, may be an indepen-dant event. The galena — calcite mineralization of the lode structures occurs widely in East Clare, having been worked at numerous small mines in the last century for lead (Ballyhickey, Carahin, Crowhill, Kilbreckan and Milltown etc.), and currently for calcite (Spancil Hill). It is suggested that this lode style of mineralization is of similar age to the other carbonate veining styles and, therefore, Hercynian. This is significantly later than the Cu ± As ± Ag mineralization at Ballyvergin and is spatially superimposed here by coincident structural controls.

The Ballyvergin deposit is closely analagous in mineralogy and stratigraphic position to the Cu ± Ag deposits at Gortdrum, Aherlow and Mallow (Steed; Romer; Wilbur and Carter; all this vol.). Additionally, the Ballyvergin deposit shows similar structural associations in that the deposit occurs in proximity to, or within, a zone of folding. Deformation is significantly less intense than at Gortdrum where major faulting is also present, but is of a similar intensity and magnitude to that at Aherlow and Mallow.

Steed (this vol.) suggests that the presence of volatile elements (e.g. As, P, Hg) in the Gortdrum ores indicates a genetic relation to the spatially proximal Asbian volcanics of the Pallas Grean area. The presence of a similar trace element pattern in the Aherlow and Mallow deposits and at Ballyvergin points to a similar genetic relation. The Asbian volcanics 10km southeast of Ballyvergin at Steele's Turrett are petrologically similar (olivine basalts) to those in the Pallas Grean area. These volcanics are thought to have provided the heat source to generate hydrothermal fluid flow and to have contributed the volatile elements concentrated in the Ballyvergin deposit. Copper, barium and silver, along with iron and silica, may have been derived by leaching from thick Old Red Sandstone sequences to the south and southwest. Sulphur may have been partially derived from biogenic framboidal pyrite in the sediments or from a primary source; no isotopic data is available on the Ballyvergin ores. Incipient and active faults of Courceyan to Asbian age, possibly overlying deep-seated basement fracture zones, provided the "plumbing system" by which the volcanic-heat-driven fluids rose into the Lower Carboniferous sedimentary pile. Mineralization occurred by massive disequilibration as these brines passed immediately up from a siliciclastic host into argillaceous carbonates. The presence of available biogenic sulphur and reactive carbonates enabled both the necessary void spaces to be created by dissolution in the active tectonic zone and also for the precipitation of sulphides within this zone.

Acknowledgements

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