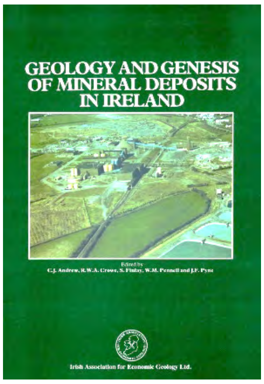

Pb-Zn-Ba ore deposits in the Sardinian Cambrian: a comparison with the Irish Carboniferous.

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Pb-Zn-Ba ore deposits in the Sardinian Cambrian: a comparison with the Irish Carboniferous.

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Abstract

There are many similarities between the Cambrian ore deposits of SW Sardinia (the Iglesiente and Sulcis districts) and the mineralization in the Irish Carboniferous. Both were formed during geological epochs between two orogenic phases, were subject to instability phenomena due either to incipient rifting or to shear systems, and are related to a fairly complex palaeogeographic setting in which the position and role of the basements are problematical. Both are in areas which underwent the classical tectonosedimentary evolution of a carbonate platform. This began with a blanket of shallow-water carbonates covering terrigenous sequences (Nebida Sandstone Formation in SW Sardinia; Old Red Sandstone in Ireland), and was followed by deposition of thicker carbonate bodies, which locally became dissected by synsedimentary and syndiagenetic faults and which were then submerged, although minor areas stood out as structural highs.

The Sardinian ores have been interpreted, since the sixties, mostly as being syngenetic-syndiagenetic, and free of any volcanic or magmatic influence. Irish ores, on the contrary, are mostly considered to be exhalative-sedimentary, with the metals being brought to the depositional areas by feeder channels from depth, and mixing with lower temperature saline fluids.

This paper considers the most important points supporting the similarities between the two mineralized districts, and briefly discusses their genetic and economic importance.

Introduction

In the Iglesiente and Sulcis mining districts in SW Sardinia numerous lead-zinc and barite deposits are known and have been partially exploited. They are extremely variable in appearance, size and geologic setting, and thus probably represent the products of several genetic processes. Most lie within the Lower Cambrian Gonnesa Formation, which comprises shallow-water sediments deposited in different subenvironments of a carbonate platform subjected to synsedimentary tectonics of a tensional nature. The diversity of ore types results from their original different depositional and diagenetic environments, as well as from further phenomena of reworking and redeposition related to tectonism (two compressive tectonic phases have been recorded after the Cambrian), and from later recycling processes. They can be summarized under the following types:

(a) Stratabound, partly stratiform, Zn-Pb-Ba deposits in the Lower Cambrian carbonate sediments (Boni, 1985);

(b) Palaeokarstic ore deposits, related to emersion surfaces. There are many palaeokarstic cycles (Padalino et al., 1973); among the more important are those related to the Cambro-Ordovician unconformity (Boni, 1984) and to the Permo-Triassic post-Hercynian peneplane (Boni and Amstutz, 1982);

(c) Mineralized veins (Salvadori and Zuffardi, 1973; Boni, 1984);

(d) Metamorphic ores at the contact with the Hercynian granites (Benz, 1964).

We will refer in this paper only to the Cambrian stratabound ores (Fig. 1). They are contained mostly in the carbonates, and consist of Zn-Pb sulphides and lesser barite, the last occurring especially in the dolomites, and form several distinct horizons in the sequences of the so-called "Dolomia Rigata" and "Calcare Ceroide". The presently known exploitable reserves contain about 30Mt, with an average ore grade of 5.5% Zn+Pb. The total ore reserves of the carbonate series, including the ores already exploited over past centuries, have been calculated to be at least 120Mt for the whole district. The barite reserves from the stratabound Cambrian deposits are much lower (< 5Mt), the exploitation of $BaSO_4$ being chiefly from late- and post-Hercynian palaeokarst and vein deposits.

General geologic sequence in the Lower Cambrian of SW Sardinia and related ore deposits

The Cambrian sequence in SW Sardinia (Fig. 2) can be summarized, from bottom to top, as follows: Nebida Formation (Lower Cambrian), Gonnesa Formation (Lower Cambrian), Cabitza Formation (Middle-Upper (?) Cambrian) (Cocozza, 1979). The Nebida and Cabitza Formations both consist of detrital sediments. The stratabound ore deposits in the Lower Cambrian occur in the carbonates of the Gonnesa Formation. Smaller occurrences are located in the carbonate intercalations at the top of the Nebida Formation.

The Gonnesa Formation is subdivided into two main dolomitic members (the Laminated Dolomite and the Massive Grey Dolomite) and one calcareous member (the

Ceroide Limestone). Its total thickness can range from 100-200m (Sulcis area in the south) to 500-600m (Iglesiente area). The dolomitic members are thought to have been deposited in tidal flat environments and the limestone member in prevalently lagoonal environments. In all the members throughout the whole area, there is quite frequently evidence of slight syndiagenetic tectonic instability, shown by slumping and brecciation.

The Laminated Dolomite Member ("Dolomia Rigata") and its ores

The "Dolomia Rigata" consists mainly of loferitic dolomites, doloarenites and dolorudites, with local intercalations of chert layers and nodules. The more common facies are algal boundstone and dolomitic mudstone containing desiccation cracks and pseudomorphs of evaporitic minerals, with subordinate fenestral mudstone and peloidal grainstone. Fossil remains are rare. The depositional environments of the Laminated Dolomite, following the clastic tidal shelf of the Nebida Formation, consisted mainly of isolated tidal flats under an arid climate, in which almost pure carbonate deposition took place in several subenvironments varying from lagoonal to intratidal and supratidal. Stratigraphically equivalent to the Laminated Dolomite Member is a sequence made up of deeper-water limestones, with major slump features (from slump-fold to debris-flow). This facies, first found in eastern Sulcis, and representing slope deposits that border the more shallow-water facies, is known to occur also on the western margin of the platform in the Northern Iglesiente district (Planu Sartu Member, Bechstädt et al., 1985, Fig. 2). The platform therefore, at the beginning of the Gonnesa Formation, already ceased to have an epicontinental character and became fairly isolated and cut off from any silici-clastic incursion. It was bordered, at least at its eastern and western sides, by intracratonic (?) basins. No orebodies occur within the slope sediments.

As far as mineralization in the shallow-water Laminated Dolomite is concerned, stratiform barite bodies with zebra structures (Gandin et al., 1974), chicken-wire barite and a few sedimentary breccias are intercalated in the dolomite sequences, especially in the Sulcis area. Sulphide-rich beds, varying from a few centimetres to several metres in thickness occur at various levels in the succession, although generally not in the sequences that contain barite (Fig. 2). The beds usually thin gradually, sometimes overlying eroded surfaces and encrusted and brecciated loferite levels, and pass conformably up into dolomite lithofacies. The sulphides consist of massive pyrite and sphalerite, with lesser amounts of galena. These are often disrupted, locally brecciated and, with few exceptions, deeply altered to a mixture of oxidation products (iron-rich calamine ores and clays) as a result of the many repeated cycles of weathering that the Cambrian rocks have undergone. Because of the strong tectonic lineation that occurs in the area (Hercynian), and because of their tendency to be more easily deformed in regard to the surrounding carbonates, the orebodies appear more stratabound than strictly stratiform, even through there seems to be no doubt about their original concordant position in the dolomite sequence.

The barite mineralization is thought to have been formed by deposition in small high-salinity and high-pH evaporitic basins (sabkha-type) on a tidal-supratidal plain (Gandin et al., 1974). The precipitation of evaporitic minerals, specifically anhydrite and gypsum, could have increased the Mg/Ca ratio and likewise promoted the presence of early dolomite. A schizohaline environment with neoformed dolomite resulted from a periodic contribution of fresh water that caused dissolution of sulphates and development of high-porosity conditions in the sediment. According to Gandin et al. (1974), further precipitation of barite may have followed.

The sulphide bodies seem to be connected more to the sequences that are rich in fenestral mudstone facies and hence those with higher porosity (vadose diagenesis and/or sulphate dissolution?). They remain confined to limited horizons at the base of the Dolomite Member, often showing evidence of sedimentary structures. At present there is no satisfactory genetic explanation of the mechanism of ore precipitation.

The Massive Grey Dolomite Member ("Dolomia Grigia Massiva")

This Member, not always present, is characterized by minute, equally sized crystals of (late diagenetic?) dolomite, and is generally lacking in fossils. It was probably derived from the late transformation of calcareous sediments (Cocozza, 1979). The sedimentary environment was, as in the case of the Laminated Dolomite, intratidal to supratidal. However evaporite and chert nodules are lacking. The Member contains no orebodies, even in the fenestral mudstone which is present in the northern areas.

The Ceroide Limestone Member ("Calcare Ceroide") and its ores

The Massive Grey Dolomite Member passes upward and laterally into the Ceroide Limestone. This typically consists of apparently compact, waxy, sublithographic limestone with a conchoidal fracture and almost no fossils. Recent studies (Boni and Marinacci, 1980; Boni et al., 1984) show that the general term "Ceroide" (waxy limestone) comprises many different carbonate facies, most of which are subtidal, and only some host ore minerals. Slumping, evident at the top of the Nebida Formation and in the Laminated Dolomite, and intraformational matrix breccias at various intervals in the Ceroide (Boni et al., 1981; Bechstädt et al., 1985; Boni, in press), all testify to long-lasting synsedimentary tectonics which resulted in a different evolution of various parts of the carbonate platform. This is also supported by the alternation in the Ceroide of different facies, indicative of at least two sedimentary environments, one intratidal to slightly subtidal, and the other completely subtidal.

At the base of the Ceroide there is nearly everywhere a sequence of black peloidal limestone ("Black Limestone" lithofacies) made up of mudstone-grainstone. Dissolution and cementation episodes are indicated by cavities lined by thick sparry calcite layers. Sometimes this facies is heavily brecciated and cut by sedimentary dykes with dark dolomitic fillings. Higher in the series the Ceroide generally retains a mudstone to peloidal grainstone facies (locally mudstone-wackestone), with very rare fragments of fossils and some evidence of bioturbation (the "spotted" limestone, Boni and Marinacci, 1980). This facies can interfinger with, or give way to, grey or white mudstone with rare intercalations of dolomitic layers, pink chert and sparry calcite nodules and clasts, which could represent replacement of sulphate minerals. All these facies host stratabound and/or stratiform sulphide ore bodies.

At many different stratigraphic levels in the limestone series, especially in the peloidal mudstone lithofacies, there are the already mentioned "horizons" of synsedimentary

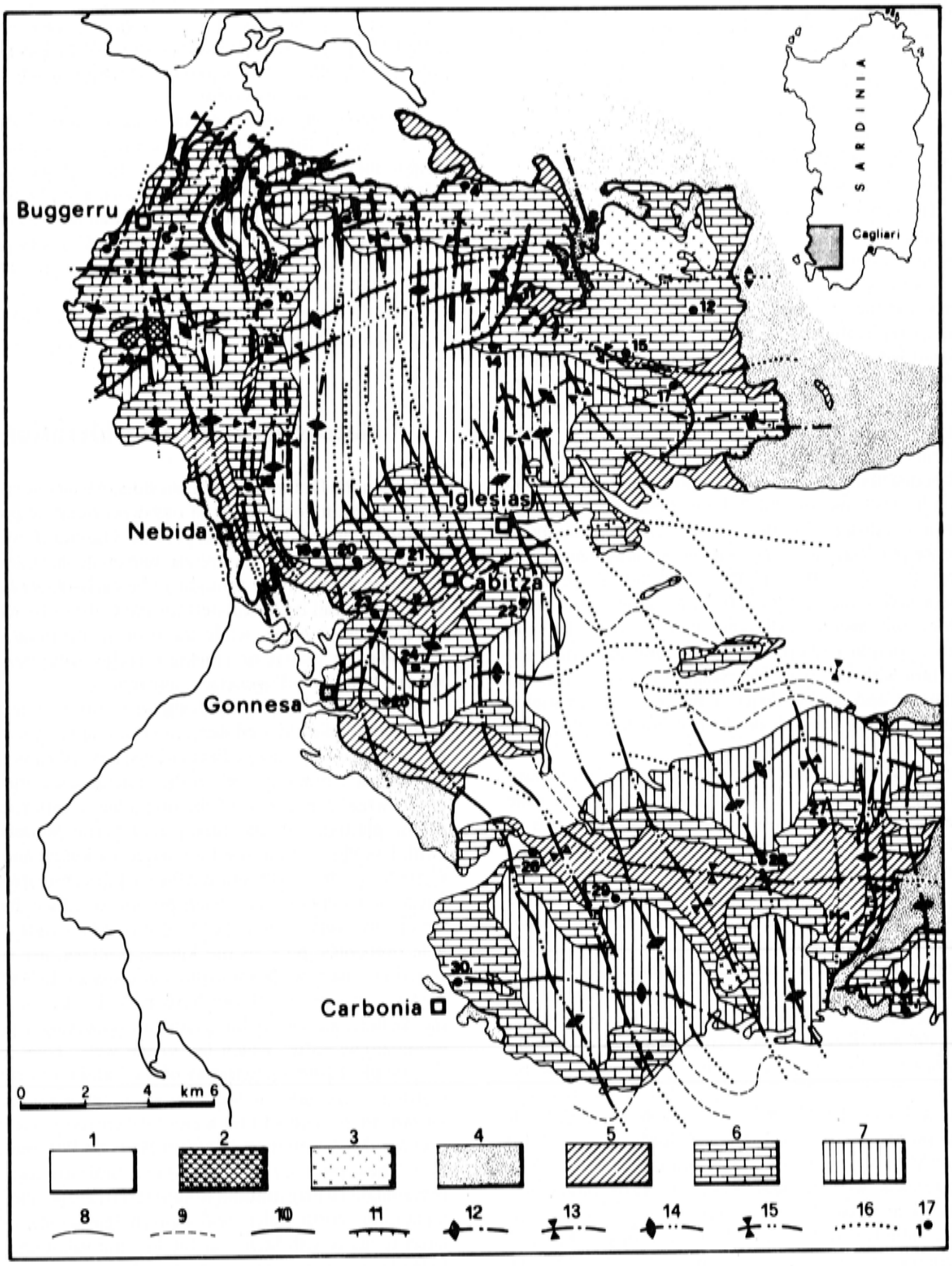

Figure 1. Geological-structural map of the Iglesiente (N of the town of Gonnesa) — N Sulcis (S of the town of Gonnesa) areas with the location of the major Cambrian and Ordovician orebodies.
(1) Post-Hercynian sediments; (2) Permian: Porphyry; (3) Carboniferous: Late Hercynian granites; (4) Silurian and Ordovician: Slates and Limestones with *Orthoceras,* conglomerates and slates; (5) Middle Cambrian: Cabitza Formation; Lower Cambrian: (6) Gonnesa Formation; (7) Nebida Formation; (8) Stratigraphic boundary; (9) Inferred stratigraphic boundary; (10) Cambro-Ordovician unconformity; (11) Main tectonic contacts; (12) Axial planes "E-W" phase: anticline; (13) Syncline; (14) Axial planes "N-S" phase: anticline; (15) Syncline; (16) Inferred axial planes; (17) Main orebodies: 1. Nanni Frau; 2. Su Sollu-M. Segarino; 3. Bau Mannu; 4. Gutturu Pala; 5. Candiazzus; 6. Buggerru-Malfidano; 7. Antas; 8. Arenas; 9. Planu Sartu; 10. Pira Roma; 11. Baueddu; 12. Barrasciutta; 13. Masua-Acquaresi; 14. S. Benedetto; 15. Genna Ruxitta; 16. Canal Grande; 17. Reigraxius; 18. Nebida; 19. M. Scorra; 20. M. Agruxiau; 21. Monteponi; 22. Campo Pisano; 23. S. Giovanni; 24. Seddas Moddizzis 25. M. Onixeddu; 26. M. Tasua; 27. Orbai; 28. Giuenni; 29. Peppixedda; 30. Barbusi; 31. M. Atzei.

and/or syndiagenetic breccias of varying thickness, to which some of the largest orebodies are related, such as the Guttura Pala, Masua, S. Giovanni and Monteponi mines (Boni, 1983) (Fig. 1). Another noteworthy feature is the occurrence of many clusters, layers and irregular horizons of sparry calcite, which vary from a few centimetres to 20-30m in length in stratiform positions in the Ceroide Limestone. It is now thought (Boni, 1983) that at least some of them may be derived from a diagenetic substitution of subtidal gypsum or from the voids left after collapse following dissolution of earlier evaporites. At any rate, there is a more than casual link between this calcite, the breccias and the proximity of the main orebodies. Some of the sparry calcite "horizons" in the Ceroide may be compared with the "calcitized gypsum" that Swennan et al. (1981) describe in the Lower Carboniferous carbonate sequence in Belgium, with the selenite gypsum in the Messinian evaporites in the Mediterranean (Schreiber et al., 1976), and with the chalcedonized evaporite nodules and layers occasionally found in the Navan orebody in the Irish Carboniferous (Andrew and Ashton, 1982).

The mineralization in the Ceroide consists mainly of sphalerite-pyrite-galena, the galena steadily increasing towards the top of the member. In some areas, as in northern Sulcis and eastern Iglesiente, galena and barite are dominant instead. All types of orebodies, in spite of their apparent random distribution and their frequent association with the main Hercynian tectonic trends, are stratabound, and occur in different horizons with a variable paragenesis which depends on their paleogeographic position (Fig. 2).

The lowest stratigraphic horizon in which zinc-dominant mineralization occurs is the "Black Limestone", at the base of the Ceroide. These ores are mainly concentrated in highly dolomitic, shaly, thin-bedded sediments, showing both slumping and brecciation and whose genesis is still under debate (Boni, 1985). Examples of these kind of orebodies have been found in the S. Giovanni, Masua-Acquaresi and Pira Roma mines.

In a middle to upper-middle stratigraphic position in the Ceroide Limestone is the so-called "Calcare Blendoso", typical of the S. Giovanni (Brusca and Dessau, 1968), Monteponi and Nebida mines. It consists mainly of broadly stratabound diffuse impregnations of yellow sphalerite (with less pyrite and even less galena) in the peloidal mudstone facies. Sometimes it is possible to distinguish clearly microcrystalline sphalerite peloids cemented by micrite and/or sparry calcite. The boundary of this kind of mineralization, which appears to be very early diagenetic, is an economic assay boundary only, because the Calcare Blendoso lithotype can range in grade from the geochemical background of the Ceroide Limestone (150-300ppm Zn+Pb) to 7-8% Zn. Very often, this first generation of limestone and sphalerite appears to have undergone further diagenesis and brecciation. These breccias are cemented by later generations of yellow, red and grey sphalerite. A similar type of mineralization has been described by Rogers and Davis (1977) in the ores of the Buick mine in the Viburnum trend.

In the upper part of the Ceroide Limestone the Calcare Blendoso disappears and the Pb content increases steadily; the highest values are found in the "Contact" orebodies (Brusca and Dessau, 1968), where nests, nodules and larger masses of stratabound sphalerite and galena, associated with sparry calcite and sometimes with barite, lie under the Nodular Limestone Member of the Cabitza Formation. The sulphides are present both in the matrix and in the cement of the thick horizons of breccias which form the host rock for the main ores of Masua, Guttura Pala, Nebida and S. Giovanni-Contatto mines. The Ag content is about 300g/t in the lead concentrates.

It must be underlined again that, in spite of the local abundance of the "Calcare Blendoso" facies, the more important control of most orebodies throughout the Ceroide Limestone is the brecciation phenomenon (Boni, 1983), with resultant formation of both pseudobreccias/crackle breccias and intraformational breccia bodies. The geological factors that caused each kind of brecciation and favoured the enrichment cycles of the metals can only be hypothesized at present; further research is needed to solve this interesting problem.

Palaeogeographic considerations

Both in the Dolomite and Limestone Members there are many different generations of ore deposition, all probably related to several stages of diagenesis. The stratiform barite and part of the Zn-Fe sulphide bodies in the Laminated Dolomite Member are thought to be early diagenetic; the same origin can be postulated for the Calcare Blendoso in the Ceroide Member, while the main stratabound Zn-Fe-Pb bodies in matrix-or crackle-breccias have been considered to be late-diagenetic to epigenetic.

Even if there is a quite uniform distribution of the stratabound orebodies in well-defined stratigraphic horizons of the Nebida and Gonnesa Formations, nevertheless there is an extreme variability both in the mineral associations and in the actual dimensions of the orebodies in different parts of the platform. In the Sulcis area barite predominates (with less Pb), both in the Laminated Dolomite and in the Ceroide. In the north and northeast Iglesiente areas both barite and sulphides are often present together, but they never form very large concentrations. The major exploitable orebodies, 80% of the known reserves, are concentrated in a narrow, NNW-trending, elongate belt which is parallel, at least in its northern part, to the outcrop of the western margin of the platform, bordering a possibly intracratonic basin, which lay to the west. Thus, even if the complete palaeogeography of the Cambrian carbonate platform, especially at the Ceroide time, is not yet well known; there seems to be a clear palaeotectonic explanation for the distribution between Ba (and Pb) and Zn-Pb ores. The former are related to more stable areas (possibly palaeohighs) with intratidal to supratidal (evaporitic?) sedimentation (north Sulcis and eastern Iglesiente), and the latter to areas with higher instability and subsidence, near to the basin margins where repeated brecciation and circulation of late diagenetic fluids enriched in metals could be the major factor in ore formation (Boni and Bechstädt, 1985).

It can be concluded that synsedimentary (possibly tensional) tectonics played an important role in SW Sardinia; its effect was felt in the greater part of the Lower Cambrian on the carbonate platform, lasting possibly also through the Middle Cambrian. It resulted in considerable facies variations in the stratigraphic sequences, and produced a seafloor of slightly pronounced horsts and grabens, which marked the boundaries between the carbonate platform facies, its margins and the contiguous basins. Some of the slumps and debris-flow breccia horizons are probably directly related to the repeated movements along the NNW trends. Along the same directions, further pheno-

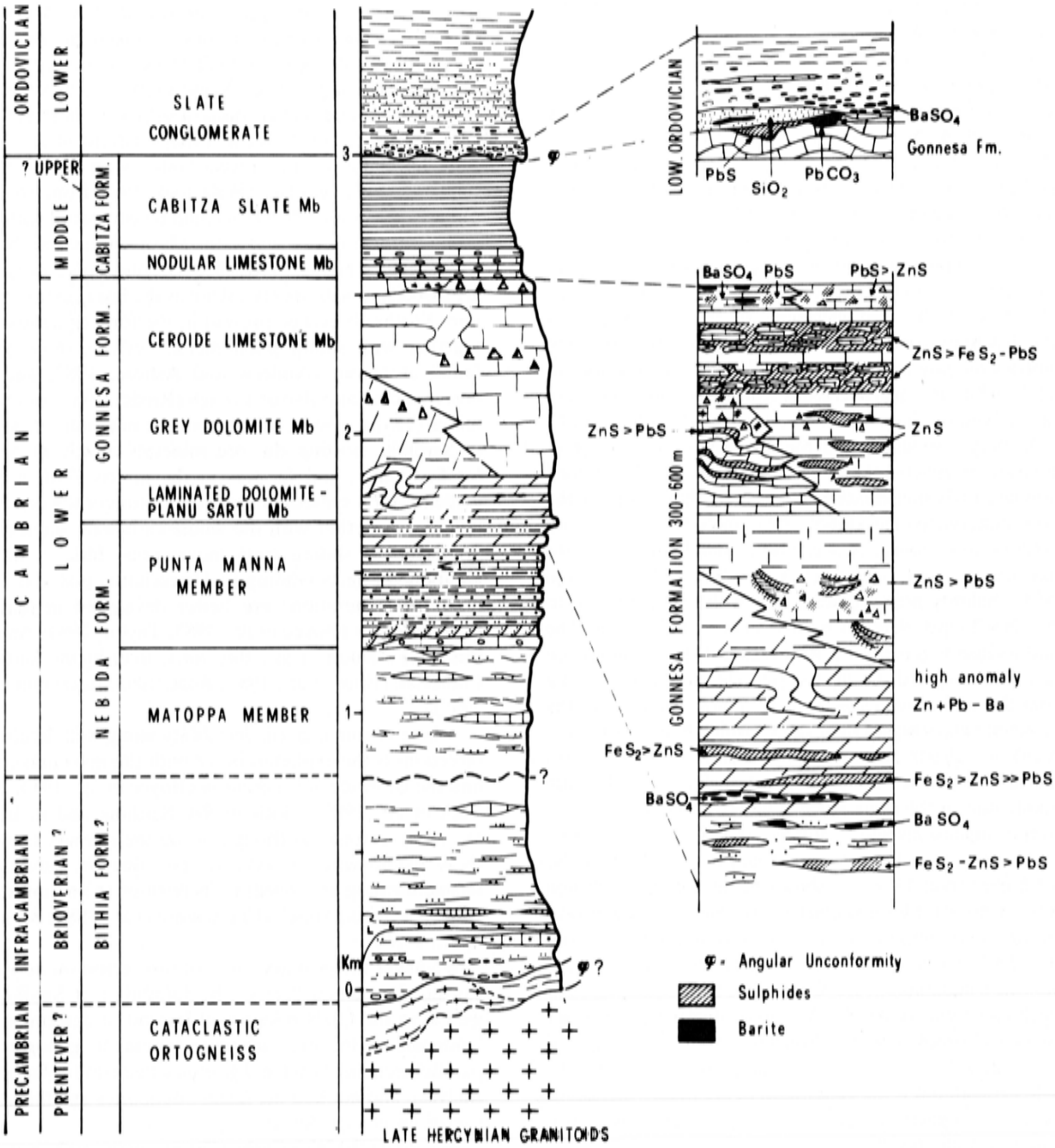

Figure 2. General stratigraphic section of the Cambro-Ordovician in SW Sardinia, showing a composite column of the Gonnesa Formation and of the basal Ordovician, with positions of the orebodies. (From Boni and Bechstädt, 1985).

mena of dissolution, late diagenetic brecciation and internal sedimentation could have taken place.

Isotopic and fluid inclusion studies on the Cambrian ores

Studies on the isotopic composition of the lead in the galenas of SW Sardinia (Swainbank et al., 1983; Boni and Köppel, 1985) have brought forth some interesting results. The isotopic values in the Cambrian ores are similar to the epicontinental "basin and platform" type of deposits (206/204 < 18.5; 208/204 < 38.5, Doe and Zartman, 1979) and show no similarities to the values found in the Mississippi Valley deposits which have high radiogenic leads.

On the whole, the Pb of all deposits (Cambrian strata-bound and later remobilized Upper Palaeozoic-Triassic palaeokarst and vein ores) was derived from the same source in which the U/Pb and Th/Pb ratios evolved in a similar way. The source must be sought in crustal rocks, possibly in the lower crust, that formed in the early Proterozoic or possibly in the Archaean. According to the high μ and W values and to the pattern of the $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{204}Pb$ model ages, the lead belongs to the same isotopic province as the galena-bearing ores of the Southern Alps, the East Alpine nappe units and the Montagne Noire (Boni and Köppel, in press).

The isotopic composition of the sulphur in the sulphides and barite in SW Sardinia has been investigated only by Dessau and Jensen (1966); the revolutionary content of their paper was the argument in favour of a syngenetic origin for the Cambrian ores. The $\delta^{34}S$ values exhibit strong enrichment in ^{34}S and this fact brought the authors to the conclusion that the origin of sulphur was in the form of sulphate, later reduced through bacterial processes. The sulphates could either have originated in evaporitic deposits or, as in the case of the supergene-enriched Permo-Triassic karst ores (Boni and Amstutz, 1982) could have been derived from enriched connate or groundwaters.

Studies on the fluid inclusions of the Cambrian ores revealed homogenization temperatures in sphalerites and fluorites ranging from 80°C to 150°C, with mean values of 115°C, while the quartz crystals from some chert lenses in the carbonates have values between 140°C and 170°C. Particularly interesting are the analyses of sparitic limestone and of sparry calcite that either cements the sulphide breccias, or is intercalated as lenses or thin layers in the more mineralized limestone. These show homogenization temperatures ranging between 80°C and 180°C, with two maxima, the first around 115°C and the second around 155°C. Salinity measurements are in the range of 9% to 15% NaCl equivalent for both sphalerite and calcite. The fluid inclusion generations with higher TH are thought to have been formed during the periods of stress resulting from the main Hercynian tectonic phase. Moreover, the scattered values higher than 180°C, which have been found in calcite, quartz and in small occurrences of stratiform fluorite, could be the product of leaking phenomena, mainly due to the same stresses under which some of the primary inclusions were formed. Therefore, the original (late?) diagenetic temperature should be considered to be not higher than 140°C, as shown in the interval common both to the stratiform sphalerite and fluorite, and also to the first generation of inclusions of calcite crystals from the Cambrian limestones. The second temperature peak, showing a maximum at 155°C, could be the result of stretching phenomena common to a great number of primary calcite inclusions, a process which could have also modified the original NaCl content of the inclusions. Another possible explanation is the generation of secondary inclusions formed at higher temperatures reached during the Hercynian tectonic regime.

A comparison between the ore deposits in the Sardinian Cambrian and in the Irish Carboniferous

The mineralization in the Irish Carboniferous shows a similar mineralogy to the Sardinian ore deposits in the first place, and is also related to shallow water carbonate sequences locally grading into deeper water basinal sediments. The Lower Carboniferous in Ireland hosts several mineralized horizons, situated at different stratigraphic levels, but all confined between the Courceyan 3 and the Lower Chadian (eventually Arundian at Navan) (Sevastopulo, 1979). As in the Sardinian occurrences, many generations of ores, related to several diagenetic stages, are seen. Most frequent are the syngenetic-early diagenetic ores, as shown from the main occurrences at Navan, and partly at Silvermines. These can be compared with the stratiform barite and sulphide bodies in the Dolomia Rigata, with the "Calcare Blendoso" lithofacies of S. Giovanni mine, and with some perfectly stratiform, though small, sphalerite concentrations in the Upper Ceroide. In Ireland, contrary to SW Sardinia, the late diagenetic-epigenetic ores of the classical MVT types as void fillings or as cement of crackle breccias are less frequent. Some examples, however, can be seen in the later generations of sulphides, both at Silvermines (Taylor, 1984) and at Tynagh (Boast et al., 1981), and, especially, in the breccia bodies with marcasite and sphalerite in Co. Kildare (Holdstock, 1981; Emo, this vol). The last mentioned breccias could be compared with most of the ore-hosting breccias at the Masua-Acquaresi, Nebida and Buggerru mines, in which sphalerite, pyrite and galena are associated with sparry calcite as the last cement generation. Further breccias, present in the form of debris-flows together with slump phenomena, such as those locally found at Navan (Andrew and Ashton, 1982, and own observations) and also at Tynagh (Riedel, 1980) and Silvermines (Taylor, 1984), differ from the mineralized breccias in Sardinia, hosting the ore minerals mostly in already lithified clasts, and far less in the matrix. This is again evidence for a synsedimentary deposition of the ores, later involved, together with the whole carbonate sequence, in syndiagenetic sliding mass movements. Indeed, the last mentioned effects (sliding and brecciation post-dating the main ore generation) are better developed in the Irish Carboniferous (Boyce et al., 1983; Taylor, 1984; Andrew, this vol.; Ashton et al., this vol.), than in the Sardinian Cambrian (Boni et al., 1981; Boni, 1983; Bechstädt et al., 1985).

A long-lasting tectonic instability along well determined directions is the explanation for both the mass movements and the continuous brecciation (Boyce et al., 1983; Bechstädt et al., 1985). Both in SW Sardinia and in Ireland tensional tectonics is thought to be the primary cause for these phenomena, a tectonic style due, in Sardinia, to incipient rifting as a result of its position in an "intracontinental stretching zone" (Carannante et al., 1984; Bechstädt et al., 1985).

Whatever the primary cause of this tectonism may be, it can not be denied that in the Cambrian of Sardinia, as well as in the Carboniferous of Ireland, it determined the landscape of the pre-carbonate basement, giving rise to parallel-trending horst and graben structures (or basins and shelves), and marked the facies boundaries and the related variations in subsidence.

Regarding the Irish Carboniferous, many authors suggest that some of the tectonic features acted as feeder channels allowing the metals to exhale onto the sea floor (Andrew and Ashton, 1982; Boyce et al., 1983; Taylor, 1984), and mix with partially bacterially-reduced sulphur supplied from the sea-water. A similar genetic explanation has never been taken into account for the Sardinian ores, owing to the lack of evidence for similar processes.

In both the Irish Carboniferous and the Sardinian Cambrian the more important ore deposits, whatever their stratigraphic position, are situated in particularly unstable areas, near the margins of (intracratonic?) basins or smaller troughs. They tend either to deform themselves owing to the instability of these margins, giving rise to mass and gravity flows (more frequent in Ireland, less in SW Sardinia), or they constitute the cement of late generations of crackle breccias (more frequent in Sardinia, less so in Ireland) associated with faulting.

Another feature common both to the Irish and Sardinian ores is the presence of evaporites and evaporite-pseudomorphing minerals. These are well recognized in Ireland, even if in small occurrences, e.g. at Navan (Andrew and Ashton, 1982; and own observations), Silvermines, Ballinalack (Jones and Bradfer, 1981) and Co. Kildare (own observations), but are generally rare in Sardinia (Gandin et al., 1974; Boni, 1983). Their influence could be essential, both for the mechanism of creating space with their dissolution (solution-compaction breccias in both districts have also been suggested, Oreskes, 1981), and for the genesis of part of the ores. On this subject, one of the genetic possibilities is the well-known classical theory of Dunsmore and Shearman (1976), concerning the reduction of sulphates by organic substance in a sedimentary sequence during a multi-stage diagenesis, followed by the fixation of metals (whatever their primary source) released from metastable complexes in carbonates. This mechanism is more difficult to apply to the syngenetic or even very early diagenetic ores, as those of Navan or the "Calcare Blendoso".

Lead and sulphur isotope studies carried out on the Irish Carboniferous ore deposits show results quite different from those from the Sardinian Cambrian, even if still consistent in a purely tectono-sedimentary syndiagnetic model. The sulphur isotope ratios are highly variable (Boast et al., 1981; Caulfield et al., this vol.), but the $\delta^{34}S$ values appear to reflect the depositional environments, and suggest a local source of sulphur also subjected to bacterial fractionation. The lead isotopes, contrary to results from SW Sardinia, suggest at least two different crustal sources (Caulfield, this vol.). Nevertheless, it is still possible, in both areas, that the lead originating from several distinct source rocks, could have been brought to the depositional sites through the normal sedimentary process of weathering and surficial transport.

Because of their high homogenization temperature (up to 250°C, Samson and Russell, 1983), the fluid inclusion data have been one of the strongest arguments in favour of the exhalative-sedimentary hypothesis for the Irish ores. They differ in their upper values with those measured in the Sardinian Cambrian ores. Even if the temperature and salinity data for Sardinia do not represent original diagenetic values, but have rather been influenced by subsequent Hercynian stresses, temperature peaks of 250°C are certainly not typical for pure MVT deposits. There could be many reasons for this rise in temperature in the Irish ores, such as the subsequent igneous activity or, as already ascertained in SW Sardinia, the presence of an incipient metamorphism affecting the Carboniferous lithotypes. In a recent communication during this conference, temperatures up to 300°C have been reported from illite crystallinity and vitrinite reflectance measurements (Sevastopulo, pers. comm. 1985). Moreover, it emerged from post-conference discussion that at least some of the higher temperature data measured at Silvermines by Samson and Russell (1983) originated from some late-Hercynian quartz veins which are not directly related to the mineralization.

Conclusions

It is suggested that mineralization in both the Irish Carboniferous and the Sardinian Cambrian are consistent with a model of tectono-sedimentary evolution related to long-lasting tensional tectonic regimes, which gave rise to more or less pronounced horst and graben structures with variable amounts of subsidence. This model of evolution does not necessarily require an origin for the ores either involving exhalative-sedimentary volcanogenic mechanisms or a genesis by means of hydrothermal fluids rising through extensional fractures. As in SW Sardinia, most of the Irish Pb-Zn-Ba-Fe mineralization might have been part of the normal sedimentary-diagenetic cycle; the primary source of the metals might well have been in the pre-Devonian basement from which they were carried to the depositional sites by supergene processes.

Further comparisons of the Cambrian of SW Sardinia and the Irish Carboniferous may usefully lead to a reconsideration of the primary source of the metals in one or both districts, and also perhaps to a review of the most favourable depositional and/or diagenetic environments for ore accumulations.

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