Zn-Pb-Cu massive sulfide deposits: Brine-pool types occur in collisional orogens, black smoker types occur in backarc and/or arc basins

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ABSTRACT

Volcanic-hosted, massive sulfide deposits of Zn-Pb-Cu type were derived either from seawater-dominated, buoyant fluids that built mounds on the seafloor, e.g., the ores of the Hokuroku Basin, Japan, or from saline fluids that reversed buoyancy on mixing with seawater and filled basins on the seafloor, e.g., several ores of the Iberian pyrite belt and the Mount Read province in Tasmania. The Hokuroku ores formed above subduction zones during protracted periods of regional extension, but both the Iberian pyrite belt and the Mount Read province formed under extensional stress during continent-continent (Iberia) or arc-continent (Mount Read) collision and orogenesis. In the Iberian pyrite belt oblique convergence resulted in transcurrent faulting, and this may also be the case for the Mount Read province. Transcurrent faulting may have allowed easy vertical access for the ore-related magmas, some of which were sourced in the asthenosphere, as well as the blueschist and eclogitic facies emplaced in adjacent terrains, and possibly also saline fluids exsolved from the magmas.

Keywords: massive sulfides, brine pools, collisional, orogens.

INTRODUCTION

Volcanic-hosted massive sulfide deposits can be divided into three types: Zn-Pb-Cu-, Zn-Cu-, and Cu-dominated (Solomon, 1976). This study relates to the first type, for which fluid-inclusion data show that the ore-forming fluids had salinities either less than, or greater than, 8 wt%. The less saline fluids were responsible for forming the Tertiary ores of the Hokuroku Basin in northern Honshu, which, like many of the Zn-Cu and Cu types, were deposited from buoyant, seawater-dominated fluids that mixed with seawater to form sulfate-sulfide mounds on the seafloor (Ohmoto, 1996; Lydon, 1996). In contrast, fluids with >8 wt% salinity reversed buoyancy on mixing with seawater, with sulfide deposition occurring as a result of quenching in brine-filled basins or brine pools. Examples include Hellyer in the Mount Read province, in Tasmania (Solomon and Khin Zaw, 1997), and seven in the Iberian pyrite belt of Spain and Portugal (Solomon et al., 2002), thus including some of the largest and richest of all massive sulfide orebodies. Brine-pool genesis has also been proposed for Rosebery in the Mount Read province (Green et al., 1981) and Tharsis in the Iberian pyrite belt (Tornos et al., 1998), based on geological relationships. Given the tendency for ores of individual provinces to have common characteristics (Lydon, 1996), more examples are likely in each province.

Probably influenced by modern seafloor discoveries, and the Tertiary history of Honshu, most ancient massive sulfide provinces have been assigned to extensional backarc basins or rifted volcanic arcs (e.g., Lydon, 1996). However, the two brine-pool provinces, the Iberian pyrite belt and Mount Read, occur in collisional settings, the related structural history being perhaps the fundamental control over the salinity of the ore-forming fluid, and thereby the manner of deposition on the seafloor.

TECTONIC HISTORY OF THE IBERIAN PYRITE BELT

The Iberian pyrite belt is in the South Portuguese zone of the Iberian Massif, which forms part of the Variscan orogenic belt in western Europe (Leistel et al., 1998; Carvalho et al., 1999; Fig. 1). The Iberian pyrite belt is in faulted contact to the north with, successively, the Pulo do Lobo antiform, the Beja-Acebuches ophiolite complex, and the Ossa Morena zone. The Ossa Morena zone, a para-autochthonous Gondwanan unit, was accreted to the Iberian autochthon in the Neoproterozoic along the transcurrent Tomar-Badajoz-Córdoba shear zone, which was transcurrently reactivated during the Variscan orogeny (Quesada and Dallmeyer, 1994). The Pulo do Lobo unit, early

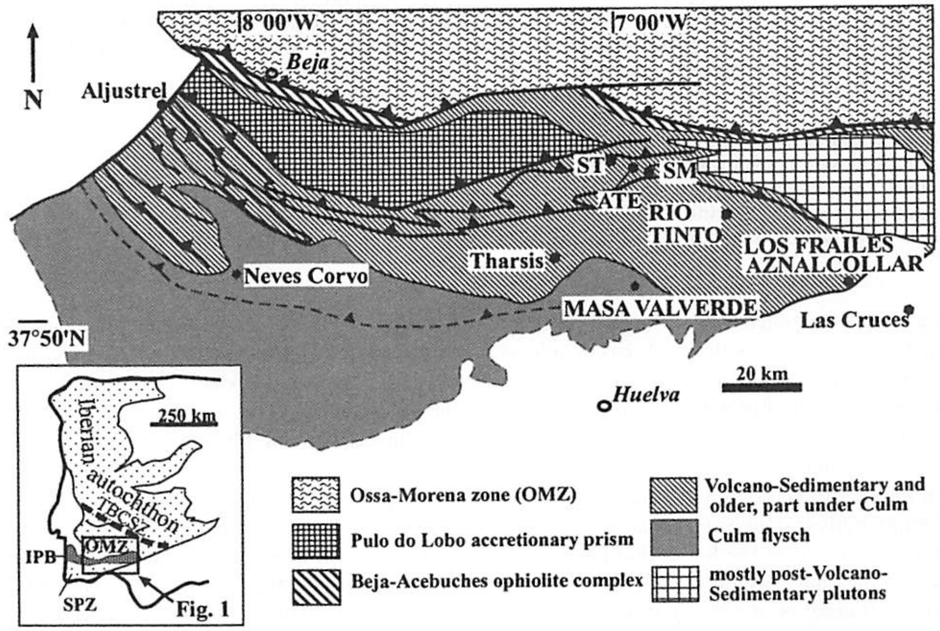

Figure 1. Simplified geological map of Iberian pyrite belt showing major massive sulfide deposits, from Leistel et al. (1998) and Quesada (1998). Those shown in capital letters have yielded fluid-inclusion data. ATE—Aguas Teñidas Este, ST—San Telmo, SM—San Miguel, TBCSZ—Tomar-Badajoz-Córdoba shear zone, IPB—Iberian pyrite belt, SPZ—South Portuguese zone.

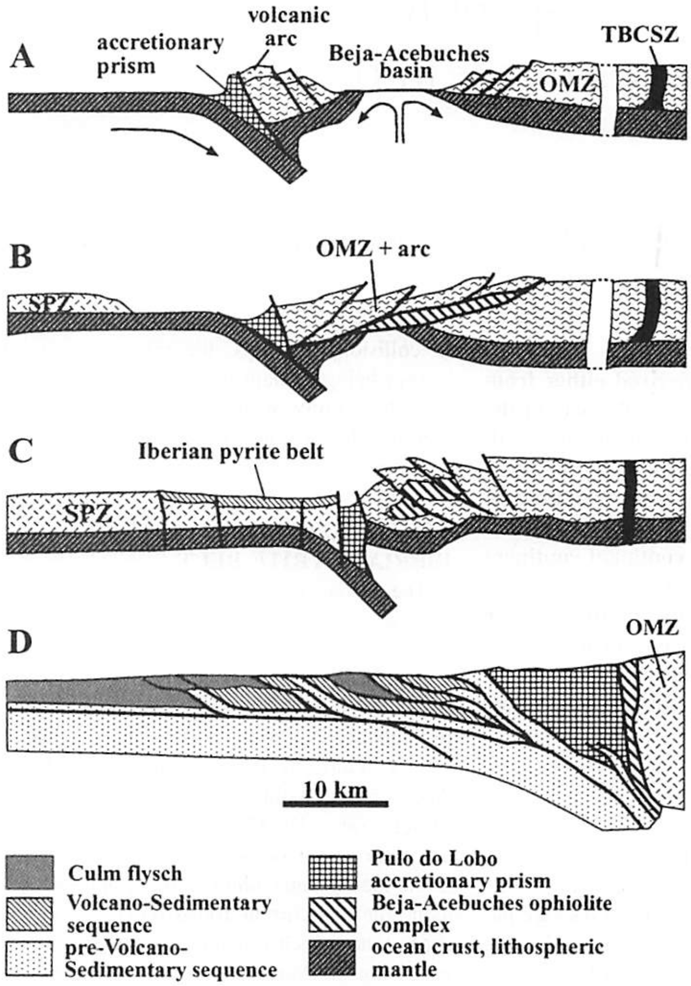

Figure 2. Sections A to C, with left-to-right about south-to-north, illustrating evolution of Iberian pyrite belt during Devonian and Carboniferous, and cross section showing post-Variscan geology. A: Early Devonian opening of backarc basin, faulting of Ossa Morena zone (OMZ), and growth of Andean-type volcanic arc. TBCSZ—Tomar-Badajoz-Córdoba shear zone. B: Middle Devonian northward obduction of Beja-Acebuches ophiolite complex and part of OMZ. C: Late Devonian (Fammenian) closure of ocean, formation of Iberian pyrite belt. SPZ—South Portuguese zone. D: Simplified present structure, showing imbricate thrusts and detachment sole developed during Variscan orogeny. Scale applies to section D only. A, B, and C are largely from Quesada et al. (1994), D is largely from Onézime et al. (2002).

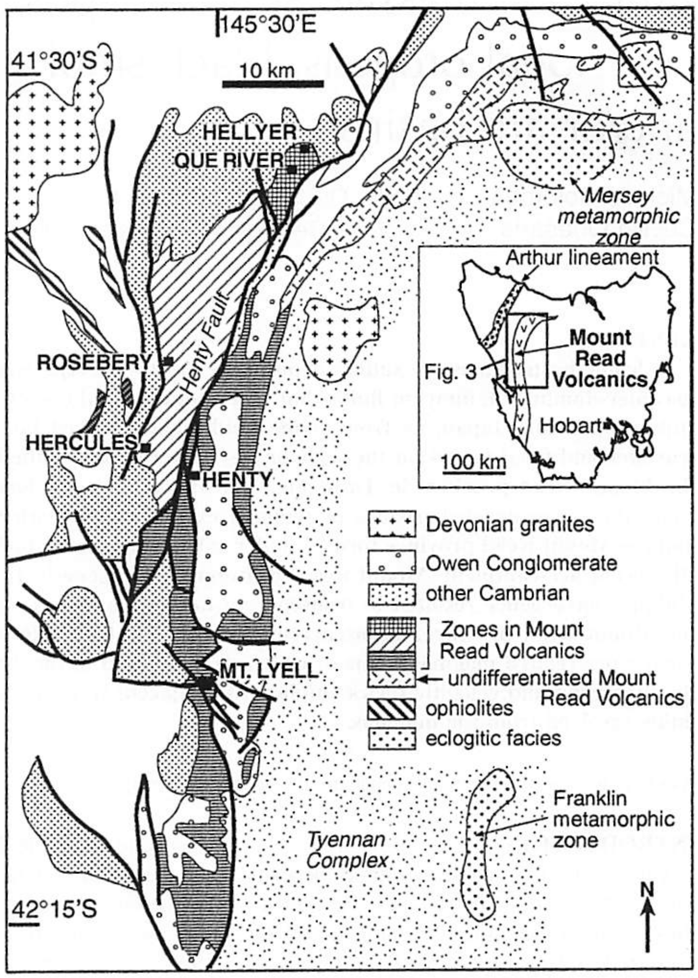

Figure 3. Simplified geological map of western Tasmania showing part of Mount Read volcanic belt, fragments of obducted ophiolite, two metamorphic complexes in Neoproterozoic Tyennan Complex, and Late Cambrian siliciclastic Owen Conglomerate, from Corbett (1992) and Meffre et al. (2000).

Fammenian or older, consists largely of phyllite and quartzwacke, with local basic volcanic rocks, and may be part of an accretionary prism. The Beja-Acebuches ophiolite complex consists of metaperidotites, pyroxenites, metagabbros, amphibolites, and basalts, and may be of backarc basin origin (Quesada et al., 1994). During Early to Middle Devonian time the continental margin of the South Portuguese zone, which may have been part of Avalonia or Laurussia (Leistel et al., 1998), drifted northward by subduction beneath the Ossa Morena zone, developing an accretionary prism, a magmatic arc over the Ossa Morena zone, and a backarc basin floored by oceanic crust (Ribeiro et al., 1990; Quesada et al., 1994; Fig. 2). Oblique collision with Ossa Morena zone promontories in the late Early Devonian resulted in arc and crustal rocks being obducted northward over the Ossa Morena zone, a process accompanied by emplacement of blueschists and eclogites within the Ossa Morena zone and exhumation of deep crustal levels in the Tomar-Badajoz-Córdoba shear zone (Quesada and Dallmeyer, 1994; Fonseca et al., 1999). During the latest Devonian to late Viséan (fauna and zircon U-Pb ages), continuing oblique collision led to transtensional escape of part of the South Portuguese zone margin and development of the Iberian pyrite belt, in which faulting and massive sulfide mineralization occurred in shales and/or volcanic rocks of the Volcano-Sedimentary sequence in en echelon subbasins characterized by individual rock associations (Silva et al., 1990; Dias and Ribeiro, 1995; Oliveira and Quesada, 1998). High-precision U-Pb zircon ages suggest that mineralization occurred between ca. 356 and 350 Ma (Barrie et al., 2002). Continuing convergence during the remainder of the Carboniferous resulted in southward propagation of a south-verging, imbricate thrust complex overlying a shallow detachment, and flysch sedimentation, sourced largely from the Ossa Morena zone (Quesada, 1998; Fig. 2D).

Volcanic and intrusive rocks of the Volcano-Sedimentary sequence are dominantly of basic and acid compositions, with minor intermediate types. Most basalts are continental tholeiites, but a few are slightly alkalic, and the intermediate and acid rocks are calc-alkaline, without suprasubduction characteristics (Mitjavila et al., 1997). Onézime et al. (2003) proposed a second north-dipping subduction zone beneath the Iberian pyrite belt, a proposition that ignores the nonsubduction character. Basaltic compositions reflect mixing between mid-oceanic-ridge basalt–type magmas, fractional crystallization, and crustal assimilation. Intermediate rocks were derived by mixing of mantle and continental crust; the acid rocks were derived by melting of continental crust.

TECTONIC SETTING OF THE MOUNT READ PROVINCE

The Cambrian Mount Read Volcanics unit occurs along the western and northern margins of the Tyennan Complex, which consists largely of multiply deformed quartzites and phyllites of Neoproterozoic age and zones of eclogite-facies metamorphic rocks (Fig. 3). The volcanics overlie Early Cambrian–Neoproterozoic marine quartzwackes, shales, and minor basic volcanic rocks that were deposited on the eastern margin of Proterozoic Australia (Berry and Holm, 2001). The ensuing history is fragmentary, mainly due to the effects of Middle Devonian orogenesis. Berry and Crawford (1988) proposed that in the Early Cambrian the eastward-subducting continental margin collided with an oceanic island arc, initiating westward thrusting in the margin and obduction of forearc crust across western Tasmania (Fig. 4). At least the western parts of the Tyennan Complex, and other metamorphic inliers in northern Tasmania, may also be allochthonous, with early thrusting directed to the southwest and later to the south (Woodward et al., 1993; Berry, 1994). Blueschist assemblages occur in a sinistral high-strain zone in northwest Tasmania, the Arthur lineament, and, like the ecologites in the Franklin metamorphic complex, were metamorphosed and emplaced in the Cambrian (Berry, 1994; Turner et al., 1998; Fig. 3). The collision marks the beginning of the Delamerian orogeny, recognized in mainland Australia and Antarctica, and sinistral strain may be related to oblique terrane convergence. Mount Read Volcanics magmatism, minor marine sedimentation, and massive sulfide mineralization occurred in a belt of middle to late Middle Cambrian age (ca. 505–500 Ma, based on fauna and zircon U-Pb dates; Corbett, 1992; Jago and McNeil, 1997; Black et al., 1997). Berry and Keele (1997) reported synvolcanic and synmineralization normal faults, east-west transfer faults, and faults oblique to the belt (e.g., the Henty fault; Fig. 3). These features, and the apparent fragmentation of part of the volcanic belt into three individual units, each with characteristic rock sequences, Pb isotopic signatures, fault orientations, and ore-deposit styles (Fig. 3), are consistent with a transcurrent component. Deformation continued with east-west shortening prior to local erosion of the volcanic rocks and uplift of the Tyennan Complex, which led to deposition in the Late Cambrian of marginal, molasse-like, siliciclastic aprons (the Owen Conglomerate; Figs. 3 and 4).

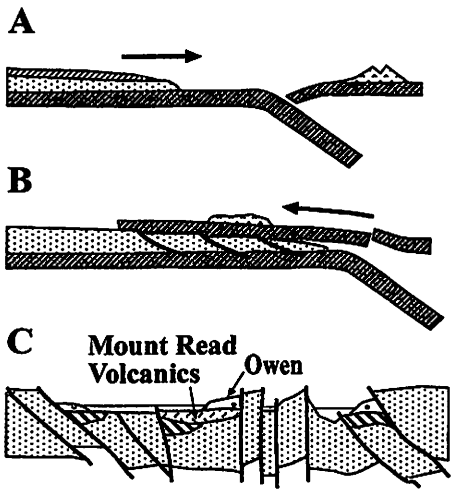

Figure 4. Sections, with left-to-right about west-to-east, illustrating evolution of western Tasmanian during Delamerian orogeny (Cambrian), from Berry and Crawford (1988), Berry and Keele (1997), and Meffre et al. (2000). A: Early Cambrian postulated subduction and volcanic arc. B: Arc-ophiolite obduction and thrusting initiated by arc-margin collision. C: Middle to Late Cambrian erosion of faulted ophiolite and allochthons preceded Mount Read province, and, subsequently, deposition of molasse (Owen Conglomerate). Legend as in Figure 3.

The magmatic rocks of the Mount Read Volcanics include two suites of tholeiitic basalts, and three suites of calc-alkaline to shoshonitic, basaltic, intermediate, and acid rocks, with the acid dominating (Crawford et al., 1992). Acid magmas derived largely from melting of continental crust, and intervening basic-to-intermediate magmas derived from the lithospheric mantle or depleted asthenospheric mantle (Crawford, 1994).

TECTONIC SETTING OF HOKUROKU Zn-Pb-Cu DEPOSITS

The massive sulfide ores of the Hokuroku Basin in northern Honshu, one of several similar basins along the Tertiary volcanic arc of Japan, are believed to have formed between 16 and 11 Ma in a backarc spreading zone (Ohmoto, 1983), or in a rift representing a failed third attempt to open a new basin in the Sea of Japan (Cathles et al., 1983). The volcanic arc overlaid a west-dipping subduction zone, and was under extension from at least 65 Ma. Dudás et al. (1983) found that the associated volcanic rocks have a bimodal silica distribution, but the relationships between basic and acid rocks were obscure; some basalts are relatively unfractionated mantle melts.

DISCUSSION

Mineralization and associated magmatism in the Iberian pyrite belt and the Mount Read province apparently occurred during periods of extension within protracted collisional orogenies. Ore-deposit distribution is closely related to faults that were probably active during mineralization (Large, 1992; Quesada, 1998; Leistel et al., 1998).

Transpressional and transtensional stress regimes favor uplift of deep crustal rocks due to the combination of a wrench component (producing deep vertical faults) and a component of perpendicular shortening (Avé Lallemant and Guth, 1990; Fossen and Tikoff, 1998). The emplacement of eclogitic and blueschist facies in terranes adjacent to both the Iberian pyrite belt and the Mount Read province may be wholly or partly due to wrench movements. Such environments also favor the initiation and rise of magmas generated in continental crust, lithospheric mantle, and the asthenosphere, thus solving the problem of magma genesis in provinces with limited evidence of crustal extension that was raised by both Mitjavila et al. (1997) and Crawford (1994) for the Iberian pyrite belt and the Mount Read province, repectively. Vertical or steep fractures would also allow easy access of highly saline fluids exsolved from the magmas. Solomon and Gemmell (2001) identified a saline magmatic component in the ore-forming fluids at Hellyer, and suggested that it rose to the surface via the vertical Hellyer fault zone. The style of crustal fracturing thus accounts for the relationship between collisional tectonics and brine-pool–type massive sulfide mineralization. In contrast, the structural and/or magma geometry of the Hokuroku-type extensional regimes appears to allow swamping of the magmatic component by convecting seawater. Regardless of whether these interpretations are correct, the evidence suggests that brine-pool–type ores, potentially the richest and largest massive sulfide types, form only in marine basins developed during extension within collisional, and probably transpressional, orogens.

CONCLUSIONS

The massive sulfide deposits of the Iberian pyrite belt and the Mount Read province developed in relatively short lived, tensional, elongate, marine basins during protracted orogenies resulting from continent-continent or arc-continent collisions, respectively. Both provinces contain en echelon subbasins, and massive sulfide mineralization and magmatism were accompanied by extensional faulting. Convergence in the Iberian pyrite belt was clearly oblique, resulting in transcurrent faulting, and may also have been the case in the Mount Read province. Transcurrent faulting may account for the presence of eclogitic and blueshist facies in nearby terrains, the rise of mantle- and asthenosphere-sourced magmas despite relatively limited crustal extension, and, critically, the rise of saline, magma-sourced fluids to the surface to form brine pools and potentially large and rich massive sulfide deposits.

ACKNOWLEDGMENTS

This research was supported by the Australian Research Council's Research Centre's programme, and is a contribution to International Geological Correlation Programme project 453, *Ancient orogens and modern analogues.* We are grateful for discussions with Nick Badham, Ron Berry, Tony Crawford, Cathryn Gifkin, Chris Heinrich, Carlos Inverno, Ross Large, June Pongratz, Mike Russell, and Fernando Tornos. Paulo Fonseca and an anonymous reviewer improved the manuscript.

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Manuscript received 13 June 2003
Revised manuscript received 27 August 2003
Manuscript accepted 29 August 2003

Printed in USA