Structural modification of the Jaguar VHMS Zn-Cu-Ag deposits, Yilgarn Craton, W.A.

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SUMMARY

The Jaguar VHMS camp represents a cluster of small sub-sea-floor replacement style VHMS deposits sandwiched between two closely spaced, craton-scale, shear zones. Despite preserving evidence for growth faults and feeder structures, the country rocks are overprinted by two regional folding events with associated cleavage and reworking by transient shearing. Understandably sulphide mineralisation is substantially modified by structure. This involved local folding and boudinage of banded tectonised ores, and remobilisation into shear zones enriched in high-tenor sphalerite within both the footwall and hanging wall rocks. Studies of ancient VHMS systems need to acknowledge that structural modification can be significant and have major implications for exploration targeting.

Key words: Jaguar Zn-Cu-Ag Mine, VHMS, structural geology.

INTRODUCTION

The Jaguar VHMS camp comprises four sub-sea floor replacement style VHMS deposits hosted within the bimodal rhyolite-basalt sequence of the c.2.96-2.8Ga. Gindalbie Terrane of the North Eastern Goldfields, Yilgarn Craton (Figure 1). Three mines: Jaguar, Bentley, and Teutonic Bore have produced (up to March 2019) 6.5Mt @ 9.35% Zn, 2.3% Cu, 127g/t Ag and 0.27g/t Au. Since October 2014, mining has focussed on the Bentley Deposit where an approximate five year mine life to a depth of 1100m has been outlined. Recent discoveries at Bentley (Bentaga) and the stand alone Triumph deposit are as yet unmined.

Descriptions of ancient VHMS deposits rarely discuss the impact of structural modification of geology and sulphide ores. Lithostratigraphic reconstructions at Jaguar by Bellford et al., (2015), proposes early sub-basinal extensional architecture, however, make no reference to modification by deformation associated with orogenic events during 2.68-2.62Ga.

Reloggining of drillcore at the Bentley, Jaguar, and Triumph deposits and most recently within the Bentayga lens at Bentley, coupled with underground mapping at Bentley has revealed significant structural modification of both the footwall and hanging wall sequences, and sulphide ores has occurred. Teutonic Bore deposit did not form part of these investigations. Structural modification is responsible for terminations and repeats of sulphide mineralisation, internal complexity within sulphide ores, and development of shear zone-hosted high-tenor sulphide mineralisation in the footwall and hanging wall. Documentation of this work is important in understanding what constrains the shape and extents of the sulphide orebodies and assists with exploration targeting in an ancient VHMS system.

LOCAL GEOLOGIC SETTING

The Jaguar VHMS camp is hosted within a 5km wide belt of greenstone rocks sandwiched between two craton-scale shear zones: the Ockebury Fault to the West, and the Keith-Kilkenny Fault to the East. Despite this, previous volcanology oriented studies infer that the VHMS sulphide orebodies and hostrocks at Jaguar have survived the effects of subsequent deformation unscathed.

The immediate mine sequence comprises a thick pile of mafic and intermediate volcanics with rhyolitic volcanic rocks in the footwall, overlain by a thin sedimentary unit which hosts the Bentley and Triumph VHMS deposits (Figure 2). The sedimentary unit consists of chert, shale, siltstone and sandstone. This is overlain by a variably thick sequence of reworked, coarse-grained volcaniclastic deposits of rhyolitic and dacitic composition. Andesitic lava with narrow carbonaceous and cherty interfloow units overlie the volcaniclastics. Overlying the andesite is basaltic lava and then the host unit for the Jaguar and Teutonic Bore VHMS deposits, which consists of a complex package of chert and epiclastic sediments interleaved with dacitic volcaniclastics. Jaguar and Teutonic Bore are overlain by andesitic lava and a thick pile of basalt lava. Therefore, Jaguar and Teutonic Bore are stratigraphically ‘higher’ in the sequence than Bentley and
Primary sedimentary features such as cross-bedding, scours, flame structures and graded bedding indicate that the entire mine sequence consistently youngs towards the West; however bedding-cleavage and fold vergence relationships in the same sedimentary units indicate the youngest rocks core a regional antiform lying to the west (Figure 3). These relationships indicate that this regional fold is an antiformal syncline and therefore must have formed during regional-scale overprinting fold interference. This relationship has major implications for exploration prospectivity. At the mine scale, cleavages that are axial planar to the folds are reworked by shear zones that preferentially localise along interflow sedimentary units, including the VHMS sulphide orebodies.

**STRUCTURAL SETTING OF THE JAGUAR OREBODIES**

Structural geology studies at three of the four deposits, predominantly from oriented drill cores show that each orebody has experienced significant reworking and modification during tectonism. However, there can also be good preservation of primary textures, alteration and early structural architecture. Bedding and volcanic layering dips steeply towards the WSW. Primary sedimentary features such as cross-bedding, scours, flame structures and graded bedding indicate that the entire mine sequence consistently youngs towards the West; however bedding-cleavage and fold vergence relationships in the same sedimentary units indicate the youngest rocks core a regional antiform lying to the west (Figure 3). These relationships indicate that this regional fold is an antiformal syncline and therefore must have formed during regional-scale overprinting fold interference. This relationship has major implications for exploration prospectivity. At the mine scale, cleavages that are axial planar to the folds are reworked by shear zones that preferentially localise along interflow sedimentary units, including the VHMS sulphide orebodies.

The Jaguar VHMS mineralisation is sub-seafloor replacement style, preferentially replacing fine to medium grained siliciclastic sediments at the interface with the footwall rhyolite (Bentley and Triumph), and a footwall of basalt at Jaguar. At the periphery of the orebodies the interflow sediments are mixtures of siltstone, sandstone and chert, with the cherty clast component giving classic durchbewegung ore texture. In the centre of the orebodies, the nature of the mineralisation is dominantly banded sulphide mineralisation with alternating sphalerite and pyrite (and rarely pyrrhotite at Jaguar). A mixture of primary and tectonic processes is responsible for the strongly banded ores. Structures such as folds and boudins are common throughout the orebodies. Ductile shear zones are common along the margins of the banded sulphide mineralisation bodies and play host to significant zones of remobilised sphalerite mineralisation projected out into both the footwall rhyolite and the hanging wall sediments and volcaniclastics. The sphalerite in these shear zones is higher tenor, being orange to honey-coloured (i.e. lower in Fe); different to the brown-black-coloured, higher-Fe, marmatitic sphalerite typical of banded sulphide ores (Figure 4). Shear zones cutting through the banded sulphide cause local enhancement in sphalerite tenor as brown coloured sphalerite is replaced by low-Fe orange-yellow sphalerite. Similarly, high tenor sphalerite is noted adjacent to lamprophyre dykes where they crosscut the sulphide mineralisation. Interestingly, this contrasts with late orogenic quartz veins cutting sulphide ore which frequently contain low tenor black-brown-coloured marmatitic sphalerite.
Sulphide mineralisation in the footwall rhyolite is typically semi-massive pyrite mineralisation with minor chalcopyrite immediately below the zinc mineralisation. However, zones of widespread chalcopyrite mineralisation hosted within concentrations of chloritic feeder structures and replacements of volcanic structure in the rhyolite can occur nearby (i.e. Beetle)

Despite the deformation, footwall structures beneath the sulphide orebodies are reasonably well preserved, especially beneath Bentley and Triumph. Feeder structures here form irregular chlorite-rich breccia ‘veins’ often accompanied by chalcopyrite mineralisation (Figure 6). The chloritic feeder veins are distinctive for their clusters of porphyroblastic carbonate. The orientation of the feeders is at high-angle to the basal contact, however they are overprinted by the two main cleavages, resulting in strong crenulation and local transposition in higher strain zones. Similarly, stringer veins of chalcopyrite-pyrite display the same structural behaviour. At Triumph, significant changes in the palaeotopography of the rhyolite-sediment contact are matched by rapid thickening of wedge-shaped basins, resulting in conglomerates proximal to growth faults, transitioning in to finer-grained siliciclastic sediments away from the growth faults. At both Bentley and Triumph, chloritic feeder structures coincide with inferred palaeo-growth faults.

CONCLUSIONS

Deformation associated with 2.68-2.62 Ga. orogenesis in the North Eastern Goldfields has significantly modified the hostrocks and sulphide ores of the Jaguar VHMS camp. The camp is sandwiched between two craton-scale shear zones and younging and bedding-cleavage relationships suggest that the sequence was refolded by two fold events prior to development of sinistral transcurrent shear zones. Sulphide ores are banded and display evidence of folding and extensive boudinage. Sulphide ores are also remobilised into shear zones projecting into both the footwall and hanging-wall, marked by problems.
development of high tenor low-Fe sphalerite mineralisation. Primary feeder structures in recognised in the footwall rhyolite despite being transposed by folding and overprint by two cleavages. Primary volcanic architecture such as early growth-fault-bounded half-graben appear to strongly influence the initiation of new shear zones and folds during later orogenesis. Studies of ancient VHMS systems need to document all aspects of both early and later deformation overprints and apply this knowledge to truly reconstruct the system and provide more effective targeting in such systems. All too frequently ancient VHMS systems are considered by researchers, volcanologists and VHMS explorationists to be ‘pristine’, with little consideration for the effects of major structural modification.

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REFERENCES
