VHMS in the Yilgarn: their genesis and significance for exploration

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Volcanic-Hosted Massive Sulfide (VHMS) deposits within the Archaean Yilgarn Craton represent one of the most primitive phases of economic mineralization, yet explorers are tasked with finding these often small, rich bodies within rocks that have subsequently undergone a very long tectonothermal history. The aim of this paper is to review existing genetic models – including some not so well known and/or accepted – across the Yilgarn and the well-endowed Archaean Superior Province, and discuss how other mineralization events in the evolution of the Yilgarn Craton would complicate VHMS exploration. The overarching exploration goal is to push the existing VHMS models to come up with additional geological concepts to test going forward. The hypothesis to be put forward here is whether skarns were volumetrically significant at the time of VHMS formation.

VHMS deposit morphologies within the literature are typically displayed as idealized sea-floor flow-hosted VHMS deposits that conform neatly to a generalized model (e.g. Gibson & Galley 2007). In contrast, replacement deposits such as lithofacies-hosted VHMS that can occur alongside flow-hosted equivalents are generally atypical and can only be summarized in terms of their tabular habit. Another variation from the classic VHMS model include the first-time recognition of high temperature calc-silicates within the Noranda mining camp that were intimately associated with VHMS formation (Galley *et al.* 2000). The calc-silicates are from the flow-hosted Ansil deposit that is one of the closest to the syn-volcanic Flavrian Pluton out of the 22 deposits within the complex. Magnetite and associated minerals within the sulfide lens and footwall stockwork are the replacement product of a combination of andradite–hedenbergite, ferroactinolite–ilvaite, epidote–albite–quartz and massive sulfide. Nevertheless, this was not the first documented account of calc-silicates related to VHMS within the Superior Province. ‘Skarn-like’ rocks from the Manitouwadge mining camp were interpreted to form from metamorphism of pre-existing metasomatically remobilized Ca-rich fluids derived from sea-floor hydrothermal alteration (Pan & Fleet 1992).

Within the Yilgarn Craton, the protracted tectonothermal history including numerous mineralization events all add to the complexity in revealing diagnostic VHMS signatures. For example, the Nimbus Ag–Zn–Pb deposit demonstrates this ambiguity when it has been genetically assigned. Greisen (Maxwell 1995) and sea-floor exhalative VHMS (Mulholland 1998) models have been used to explain Nimbus mineralization, but when measuring-up the pros and cons including a reversed metal zonation and stockwork paragenesis to that of classical VHMS, a coherent host and a lack of chlorite, the most generalist model of hydrothermal replacement is most representative (Doyle 1998). Structural controls on VHMS mineralization are generally expressed in terms of syn-volcanic faults (e.g. Galley *et al.* 2000), but in highly-deformed environments such as the Murchison domain of the Yilgarn massive sulfides are focussed within bedding flexures caused by non-cylindrical folding, but with individual lenses still retaining classic VHMS zonation of copper-dominant base and zinc-rich cap and flanks (Vearncombe 2011). ‘Post-extensional’ deposits or those that generally formed post peak metamorphism, complicate base metal exploration because they have some characteristics in common with VHMS. The Centurion gold deposit within the Binduli camp is one example where the ‘ECM’ style of mineralization exhibits sub-horizontal layering defined by minerals including pyrite, galena and sphalerite that is similar to some forms of VHMS, but is laterally restricted in this case to the crest of a porphyritic intrusive (Ivey *et al.* 1998). Intrusion-related gold deposits such as Boddington (e.g. McCuaig *et al.* 2001) contain vein stockworks and skarn mineralization that may also be indicative of VHMS.

The paragenetically and geometrically simplest of VHMS deposits have driven exploration models world-wide, but within the intensely deformed and metamorphosed greenstone sequences of the Yilgarn Craton VHMS have proven to be a little more elusive than many Archaean provinces. A need has arisen to emphasize already recognized departures from the classic seafloor exhalative VHMS model including lithofacies-hosted deposits that form some of the largest tonnage deposits such as Horne within the Noranda mining camp (Gibson & Galley 2007). Another syn- to post-volcanic feature of VHMS is skarn development, but because of the general lack of recognized synchroneity between VHMS and high temperature calc-silicates it is unknown how significant this style of alteration may be. Future VHMS research needs to investigate deviations from traditional models and pay attention to geological complications within these deposits that may give clues on additional genetic information. Only through the integration of existing and newly-derived strategies, for example targeting syn-volcanic intrusives and high temperature calc-silicates, can the exploration footprint of these systems potentially be increased. Combining these exploration strategies also maintains the geological context of VHMS anomalies that is essential when faced with the confusion of numerous hydrothermal events, remobilization and deformation.

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