The Teena Zn-Pb deposit: Enlightening the Carpentaria SHMS model

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The Teena shale-hosted massive sulfide (SHMS) Zn-Pb deposit, discovered in 2013 by Teck Australia Pty Ltd (a subsidiary of Teck Resources Limited), has a current inferred mineral resource of 58 Mt at 11.1% Zn and 1.6% Pb (Rox Resources 2016). The Teena deposit is located in the highly-endowed Proterozoic Carpentaria Zn-Pb-Ag province of northern Australia and represents the largest SHMS discovery for the last 25 years (Taylor *et al* 2017). Exposure to this system has provided the opportunity to further research the genesis of this economically important deposit type and contribute to the refinement of exploration and genetic models that will ultimately aid discovery of the next generation of world-class SHMS deposits.

The Carpentaria Zn-Pb-Ag province contains the largest accumulation of shale-hosted base metals in the earth's crust (nearly 120 Mt of zinc and lead: Huston *et al* 2006). Nevertheless, the discovery rate within the province has dropped over the last 25 years due to a combination of relatively low exploration expenditure levels and the need to explore for buried and blind systems. Typically, these systems are under extensive thicknesses of post-mineral cover where conventional exploration methodologies (eg surface geochemistry, shallow penetrating geophysics) are far less effective. Coupled with this detection challenge is that a widely accepted genetic model for SHMS deposits invokes hydrothermal fluids venting to the seafloor, resulting in stratiform sulfides accumulating in exhalative deposits, termed sedimentary exhalative SEDEX deposits (eg Large *et al*., 1998; Ireland *et al*., 2004; Sangster, 2018). This model has implications for the exploration geologist in terms of the size of detectable pyritic haloes associated with this deposit type and the position of economic sulfides within favorable sub-basin packages.

This presentation focuses on the following key aspects of the Teena Deposit: the characteristics of the sulfide assemblages, including the main mineralisation style, and the trace element content and distribution of pyrite. In contrast to the SEDEX model, this research suggests a timing and setting of mineralisation that favors a replacement formation model. We also discuss the presence and recognition of a secondary dolomite alteration (hydrothermal dolomite) that is intimately associated with the mineralising event but not formally described from other Carpentaria SHMS deposits. This research has implications for the size and nature of detectable alteration footprints and emplacement positions within favorable packages, which is critical for discriminating barren sub-basins from endowed sub-basins.

The Teena Deposit is located 8 km west of the world-class McArthur River Zn-Pb-Ag Mine. Both deposits are hosted within the Barney Creek Formation, which forms part of the Umbolooga Subgroup of the Glyde package (Ahmad *et al* 2013) and corresponds with the peak transgressive phase of the package deposited between 1645 and 1630 Ma. The deposits, along with the lower grade Myrtle Zn-Pb deposit, are located in the 3rd order Hot Spring–Emu basin (Duffett *et al* 2007), developed westward of the regionally significant Emu Fault corridor but locally within separate 4th order sub-basins (~2 × 2 km^2).

Mineralisation at Teena consists of a dominant phase of fine-grained, stratiform sphalerite with lesser galena (Zn:Pb ratio of 6.5:1) occurring as two massive sulfide lenses; both the thicker Main lens (up to 30 m) and a thinner Lower lens (~5 m) are hosted within the more dolomitic carbonaceous shale units of the HYC Pyritic Shale Member. Footwall to these two lenses is an extensive zone (<200 m) of low-grade zinc mineralisation occurring in the W-Fold Shale Member (Taylor *et al* 2017). Pyrite is intimately associated with the mineralisation sulfides in the Main lens and generally increases in abundance up sequence with continuation of fine-grained pyrite into the overlying carbonaceous Barney Creek Formation, which represents the maximum flooding surface event of the Barney Creek depositional cycle (Jackson *et al* 2000, McGoldrick *et al* 2010).

Two main phases of pyrite are recognised (Py1 and Py2), each with two sub-types: Py1a, microcrystalline and occasionally framboidal pyrite, which forms laminations; Py1b, >10 um in size and forming on the margins of carbonate (dolomite) nodules; Py2a, typically concentrically zoned in spherical aggregates; and Py2b, more anhedral and containing interstitial sphalerite and galena inclusions (Magnall *et al* in press). Py1a predates dolomite nodule formation while Py1b is consistent with syn-nodular dolomite formation. Py2 formed syn-mineralisation due to inclusions of Py1, sphalerite, galena, and locally replaced dolomite nodules, indicating a post–nodule timing.

Py1 continues into the overlying Barney Creek Formation for several hundred vertical meters and is the dominant species. Py2 extends only around ~200 m above Main lens mineralisation. Similarly, the lateral extent of pyrite decreases to the margins of the deposit, signaling a lack of contribution from the syn-mineralisation Py2. Thus, the pyrite halo attributable to hydrothermal syn-mineralisation pyrite is far more restricted vertically and horizontally than the 10+ km suggested by the SEDEX model (eg Mukherjee and Large 2017).

Extensive lenses of secondary dolomite alteration are present at Teena. They occur predominantly in the footwall W-fold Shale Member but also show evidence of upward transgression into the overly HYC Pyritic Shale Member. Secondary dolomite is distinguishable from primary fine-grained dolomite alteration and early diagenetic nodular growth as it is typically stratabound and texturally destructive of dolomitic sediments, including shales. Lenses can be up to 30 m thick with cores characterised by cavity infill textures. Three main infill textures are recognised: (a) bladed dolomite fans, (b) botryoidal dolomite aggregates, and (c) colloform banded dolomite.

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The bladed dolomite fans are observed nucleating from the void margins and grow in multiple orientations. Although texturally similar to Coxco Needles described within the Barney Creek depositional cycle (eg Pietsch *et al* 1991), the bladed dolomite fans are evidence of void-fill, not seafloor evaporite growth as proposed for Coxco Needles. Commonly infill dolomite is associated with silica (eg quartz), ankerite, sphalerite, with lesser galena, and bitumen.

The replacement of primary dolomite and stratiform sulfide mineralisation by hydrothermal dolomite lenses indicate that they formed late syn-mineralisation. The replacement and dissolution of primary host sediments, void-filling textures, coupled with widespread presence of quartz, suggest alteration by fluids at temperatures higher than the ambient conditions of the host sediments; this is characteristic of hydrothermal dolomitisation (HTD) facies (Davies and Smith 2006).

HTD facies are both major sources of hydrocarbons in North America and are increasingly recognised in association with Mississippi Valley-type sulfide deposits. These observations at Teena bolster a genetic connection between HTD and SHMS systems in the Carpentaria Zn-Pb-Ag province; more importantly, they may offer another detectable deposit footprint.

Conclusion

Observations relating to the genesis of the Teena Zn-Pb deposit suggest that:

- the earliest sulfide phase was a fine-grained stratiform pyrite formed during early diagenesis
- primary matrix and nodular dolomite alteration occurred shortly after Py1 formation during early diagenesis, prior to significant compaction
- in contrast to the more widely accepted view on the genesis of the McArthur River Mine (considered one of the best examples of SEDEX style mineralisation [Large *et al* 1998, Ireland *et al* 2004]), the main mineralising event occurred during mid-diagenesis through sub-seafloor replacement
- Py2 associated with the mineralising event was restricted both laterally and vertically and shows no direct relationship to the Py1 present in the hanging wall Barney Creek Formation above the lenses
- stratabound HDT (silica-dolomite-sulfide) lenses formed through cavity-dissolution and replacement in the footwall sequence, resulting in irregular low grade zinc mineralisation.

The implications for SHMS zinc exploration in the Carpentaria province are:

- Zn-Pb mineralisation is commonly deposited through replacement of dolomitic carbonaceous sediments
- the high volume of fine-grained pyrite typically observed in carbonaceous sub-basins is distinct from the pyrite associated with the mineralising event and likely cannot predict fertility of a sub-basin
- pyrite contemporaneous with mineralisation is far more restricted vertically and laterally than proposed by the SEDEX process
- the recognition of late stage diagenetic hydrothermal dolomite potentially provides a second halo to deposits that may aid with assessing prospectivity.

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