Structural Control, Hydrothermal Alteration Zonation, and Fluid Chemistry of the Concealed, High-Grade Orebody at the Paraburdoo 4E Deposit, Western Australia

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High-grade iron ore of the 4EE orebody of the 4E deposit occurs as a southerly dipping sheet within banded iron formation (BIF) of the Paleoproterozoic Dales Gorge and Joffre members of the Brockman Iron Formation. Structural reconstruction of the 4E deposit shows that reactivation of the 18E fault and development of the NW-striking, steeply SW dipping 4E and 4EE normal faults resulted in preservation of the 4EE orebody below the 4E deposit, 400 m below the modern topographic surface.

Three hypogene alteration zones were observed between low-grade BIF and high-grade iron ore are observed: (1) distal magnetite-quartz-dolomite-stilpnomelane-hematite ± pyrite, (2) intermediate magnetite-dolomite-hematite-chlorite-quartz-stilpnomelane, and (3) proximal hematite-dolomite-chlorite ± pyrite ± magnetite. Hydrothermal alteration is temporally and spatially constrained by NW-trending dolerite dikes that intruded the 4E and 4EE faults prior to hypogene alteration.

An integrated two-stage structural-hydrothermal alteration-fluid flow model is proposed for the transformation of unmineralised BIF to high-grade iron ore BIF. Early stage 1a, hypogene fluid flow in the 4E orebody occurred during a period of continental extension and enhanced heat flow within sedimentary basins to the south of the Paraburdoo Range. Basinal brines sourced from these basins were focused by the NW-striking, steeply SW dipping 4E and 4EE normal faults and reacted with BIF of the Dales Gorge and Joffre members. The warm to hot (160°–255°C), Ca-rich (26.6–31.9 equiv wt % $CaCl_2$) basinal brine interacted with magnetite-chert layers, transforming them into magnetite-quartz-dolomite-stilpnomelane-hematite-pyrite BIF. The brine contained significant iron (up to 2.8 wt % Fe) and likely originated from evaporated seawater that had lost Mg and Na and gained Li and Ca through fluid-rock reactions with carbonate successions and volcaniclastic rocks. The first incursion of deeply circulating, low-salinity (5.8–9.5 wt % NaCl equiv), heated (106°–201°C) modified meteoric water is recorded in late stage 1a minerals. This modified meteoric water had lost some of its Na through wall-rock interaction with plagioclase, possibly by interaction with dolerite of the Weeli Wooli Formation.

Stage 1b involved continuing reactions between the hydrothermal fluids and the previously altered magnetite-quartz-dolomite-stilpnomelane-hematite-pyrite BIF producing the intermediate magnetite-dolomite-hematite-chlorite-pyrite and the proximal hematite-dolomite-magnetite-stilpnomelane alteration assemblages. The intermediate and proximal alteration zones represent the mixing of a hot (250°-400°C), high-salinity, Ca-rich (30–40 wt % $CaCl_2$ equiv), Sr-rich basinal brine with low-salinity (~5 wt % NaCl equiv) modified meteoric water that was heated (~100°–200°C) during its descent into the upper crust.

Stage 1c of the hypogene hydrothermal fluid is characterized by low-temperature (<110°C), low-salinity (~5 wt % NaCl equiv) meteoric water that interacted with the proximal hematite-dolomite-magnetite-stilpnomelane altered-BIF, leaving a porous, hematite-apatite high-grade ore. Stage 2 supergene alteration affected the orebody since the Cretaceous and produced a hematite-goethite alteration assemblage, resulting in destruction of the hypogene alteration zones that are only preserved below the depth of modern weathering.

Discovery of the concealed 4EE orebody demonstrates that structural geology plays a critical role in the exploration for high-grade iron orebodies and structural reconstruction should be considered a critical exploration activity in structurally complex terranes where concealed orebodies may exist.