Structure, Alteration and Mineralisation of the Nifty Copper Deposit, Western Australia: Implications for Ore Genesis

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Sea Fever

I must down to the seas again, to the lonely sea and the sky,
And all I ask is a tall ship and a star to steer her by,
And the wheel's kick and the wind's song and the white sail's shaking,
And a grey mist on the sea's face, and a grey dawn breaking.

I must go down to the seas again, for the call of the running tide
Is a wild call and a clear call that may not be denied.
And all I ask is a windy day with the white clouds flying,
And the fling spray and blown spume, and the seagulls circling me.

I must down to the seas again, to the vagrant gypsy life
To the gulf's edge, and the whale's way, where the wind's like a whistled whistle
And all I ask is a merry yarn from a laughing fellow rover.
And a quiet sleep and a sweet dream when the long trick's over.

Alfred Lord Tennyson
1809-1892
For Elizabeth
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Bruce Anderson
16 Dec 99
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Date 16 Dec 99
Abstract

The Nifty Cu deposit is located approximately 450km east of Port Hedland, Western Australia in sub-greenschist grade rocks of the Proterozoic Paterson Orogen. The deposit consists of a secondary oxide resource of 12.2 Mt @ 2.52% Cu and a primary sulphide ore body of 94Mt @1.63% Cu (0.5% cut-off).

Mineralisation is hosted in plunging syncline of carbonaceous and dolomitic shales of the upper Broadhurst Formation. The depositional age of the Broadhurst Formation is constrained to between 1132±21 and 816±6Ma. A reinterpretation of the local stratigraphy proposes that the mine sequence consist of the footwall beds, Nifty member, pyrite marker bed, and hangingwall beds. The footwall beds consist of chloritic and pyritic shales. The Nifty member is sub-divided into the lower unit, intermediate shale, upper unit and upper shale. The lower unit contains 40-70m thick package of interbedded fine-grained, pale grey, dolomitic mudstone and blue-black, carbonaceous shale. Separating the lower and upper units is a prominent 1-4 metre thick bed of dark-grey to black, very fine-grained, chloritic shale. The upper unit (25-60m) has a similar composition to that of the lower unit and consists of alternating beds of laminated carbonaceous shale and dolomitic mudstone. The upper shale (20-40m) consists of dark-grey to black, laminated, carbonaceous shale with thin to massive framboidal pyrite seams and blebs, disseminated very fine-grained framboidal pyrite and minor dolomitic mudstone. Overlying the Nifty member is the pyrite marker bed, which consists of 1-22m of framboidal pyrite in carbonaceous shale. Above the pyrite marker bed is a 20-60m thick package of carbonaceous and pyritic shales of the hangingwall beds and 5-60m finely laminated dolomitic and calcareous silty shale of the upper carbonate bed.

Five deformation events are recognised. D1 includes rare variably oriented folds of unknown significance. D2 produced regional folding and cleavage during north-east to south-west compression. Folds tend to be doubly plunging with axes trending north-east, south-west. D2 deformation has been at dated at Maroochydore as occurring at 717±6Ma (Reed, 1996). D3 is an upright folding and faulting event that folds S2. Associated with D3 is a north-north-east striking, slaty cleavage that is less well developed than S2. D4 is a complex folding event with sub-horizontal axial planes and fold axis coaxial to D2. A brittle deformation event, D5 has also been recognised and this event has resulted in fault offsetting of the ore body. There is significant structural complexity in the Nifty syncline area but most of the complexity is due to small scale, local, fault related events.

The Nifty Cu deposit occurs as a structurally controlled, chalcopyrite-quartz-dolomite replacement of carbonaceous and dolomitic shale. The main phase of Cu mineralisation occurred during D2 deformation and is associated with a zoned hydrothermal alteration system. Six mineralisation textures were observed; veins, vein networks, breccia matrix, and a progressive sequence of isolated chalcopyrite spots and blebs, to bedding parallel bands, and finally replacement of host rock. Early framboidal pyrite with later chalcopyrite, euhedral pyrite, sphalerite, and galena are the dominant sulphide species. Sphalerite and galena occur in isolated zones in siliceous and pyritic beds of the pyrite marker bed and deposit footwall.
Minor diagenetic alteration occurs as E1-Fe-Mg Carbonate in several prominent bands in hangingwall shales 2-5m above the pyrite marker bed. Two main stages of alteration occur at Nifty. A pre-D2, unmineralised, siliceous alteration, E2-Green Quartz, with minor chlorite + pyrite + hematite + sericite + stilpnomelane, replaces interbedded carbonaceous shale and dolomitic mudstone beds of the upper and lower unit of the Nifty member. The second phase (syn-D2) of alteration is associated with Cu mineralisation and occurs as a zoned quartz-dolomite system. Distal alteration consists of S2-Silicified Pyritic Shale where quartz + sphalerite + galena + chalcopyrite and euhedral pyrite overprint framoidal pyrite beds in the pyrite marker bed and immediate deposit footwall. Inward is a progressive sequence of interbedded/banded S3-Hydrothermal Quartz-Dolomite and unaltered shale beds. The S3-Hydrothermal Quartz-Dolomite alteration first appears as spots and veins with 2-4mm light grey alteration margins in the footwall followed by coalesced spots. An Fe-rich variant of hydrothermal dolomite occurs where minor S1-Chloritic Shale was observed on the distal margin of Fe-rich quartz-dolomite altered rocks. Further inward and proximal to the highest ore grade is S4-Silicified Dolomitic Shale (dolostone) that grades into S5-Black Silica in the centre of the ore body. S5 alteration consists of fine-grained quartz + chalcopyrite + apatite + carbonaceous material and replaces host rock and earlier siliceous alteration. Cu grade has a strong positive correlation with intensity of alteration. Minor concentrations of Pb and Zn are associated with bedding parallel quartz flooding + chalcopyrite + euhedral pyrite of S2-Silicified Pyritic Shale. Sphalerite and galena replace pyrite framboids.

A new method of calculating mass balance change in compositions during alteration has been developed. This method uses a log transform of the element of interest divided by an immobile element. The logratio method is scale invariant and therefore avoids the unit sum problem. This method has been applied to Nifty multi-element data from host rock lithologies and alteration phases. Mass balance calculations suggest that during intense alteration (S4 and S5) the central core of the deposit was enriched in Cu, SiO₂, As, Zn, Pb, Sn, Ni, U, Fe₂O₃ and Y. Depletion has occurred in Ba, Sr, and Rb. The outer halo of the deposit experienced similar additions but of a smaller magnitude. An implication of the mass balance analysis is that there has been a significant volume change during alteration and mineralisation. The highest concentration of Cu occurs within hydrothermally altered rocks of the upper and lower units of the Nifty member while Pb and Zn occur in silicified pyrite shales in the pyrite marker bed and footwall beds. High concentrations of Zn also occur in shale above the upper carbonate beds. This distribution of base-metals has resulted in a vertical metal zonation of Cu→Pb→Zn.

New galena Pb isotope data from the Nifty Cu deposit and other regional prospects have been combined with existing galena data to constrain the source of Pb. Pb isotope data from Throssell Group deposits and prospects plot as a linear trend in ²⁰⁶Pb/²⁰⁴Pb vs ²⁰⁶Pb/²⁰⁴Pb space. The Warrabarty Pb-Zn prospect plots at the least radiogenic end, Maroochydore Cu deposit at the most radiogenic end, and the Nifty Cu deposit plots towards the least radiogenic end of the trend. The Throssell Group linear trend suggests mixing between two Pb sources. Potential sources of Pb are 1) Rudall Complex, 2) Pilbara Craton, or 3) internally sourced Pb leached from Throssell Group sediments. The Rudall Complex Pb signature is
poorly defined as shown by initial Pb-Pb ratios of K-feldspars separates. Galena Pb isotope data from deposits in the Pilbara Craton plot on a Pb evolution trend similar to the growth curve of Cumming and Richards (1975). A source-mixing model is proposed where Pb from a magmatic source ($\mu=9.88$) is mixed with crustal Pb ($\mu=10.55$). The position of deposits and prospects along the linear trend suggests that the Pb in the Warrabarty Pb-Zn prospect was dominated by magmatic Pb and that Pb at the Maroochydore Cu deposit has a crustal source. Pb in the Nifty Cu deposit appears to have a mixed source.

Syn-mineralisation fluid inclusions are small (commonly <5-10µm) and consist a simple two phase petrology of liquid and vapour. Fluid inclusion trapping temperatures of mineralising fluids at Nifty range between 270-457°C (median 358°C) and salinity of 8-27 eq. wt.% NaCl (median 15 eq. wt. % NaCl). Post mineralisation inclusions have trapping temperatures between 181-269°C (median 190°C) and salinity of 11-15 eq. wt.% NaCl (median 13 eq. wt.% NaCl).

Sulphur isotope data from framboidal pyrite ranges between $\delta^{34}S_{CDT}$ of $-27$ and $+16\%o$, suggesting that the source of framboidal pyrite sulphur is a combination of reduced seawater sulphate and evaporite sulphate. Chalcopyrite $\delta^{34}S_{CDT}$ ranges between $-6$ and $+6\%o$ and $\delta^{34}S_{CDT}$ for euhedral, syn-mineralisation pyrite ranges between $-12$ to $+12\%o$. The range of syn-mineralisation sulphide data suggest that source of sulphur at Nifty was homogenous and that syn-mineralisation sulphides did not utilise existing sulphur from sedimentary pyrite. The $\delta^{34}S$ range of $-6$ to $+6\%o$ for chalcopyrite also suggests a reduced magmatic hydrothermal source of sulphur. Carbon and oxygen isotopic data from host rock carbonates, pre-, syn-, and post-mineralisation vein stages have lighter oxygen and carbon values than other deposits in the region. Results from the various vein stage carbonates overlap, with $\delta^{13}C_{VPDB}$ values from approximately 6 to $-13\%o$ and $\delta^{18}O_{VSMOW}$ values from approximately 15 to $20\%o$. Carbon and oxygen isotope trend modelling suggests that fluid mixing and fluid/rock interaction are potential precipitation mechanisms.

A model for the formation of the Nifty Cu deposit is proposed whereby compression associated with the Miles Orogeny caused the expulsion hydrothermal fluids from deep in the Yeneena Basin. Fluid expulsion was driven by lithostatic loading due to overriding thrust sheets. Hydrothermal fluids travelled along a basement decollement and then ascend $D_2$ thrust faults toward zones of low pressure. During tightening of the Nifty syncline thrust faulting penetrated carbonaceous and dolomite shales allowing hydrothermal fluids to enter the Nifty member. Early fluid pulses were weakly oxidised and contained low concentrations of base metals. These fluids altered the host rock and precipitated E2-Green Quartz. Later hydrothermal fluid changed, increasing the concentration of base metals, became hotter, more saline, reduced and moderately acidic. On encountering the Nifty member, hydrothermal fluids reacted with dolomite-dominated beds forming the dolomitic alteration textures and in turn, siliceous replacement of carbonaceous shale and dolomitic mudstone. Chalcopyrite precipitation was controlled mainly by changes in pH and $fO_2$ caused by the reaction of acidic, hydrothermal fluids with the dolomite-bearing host rock.
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