

Trace element remobilization at the Ok Tedi porphyry Cu-Au deposit, Papua New Guinea.

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ABSTRACT: The Ok Tedi Complex hosts a world-class porphyry copper-gold deposit. Samples from the Ok Tedi Complex and the neighbouring Mount Ian Complex were analyzed for major and trace elements using XRF and HR-ICP-MS, and the isotopic composition of S in sulphides was analyzed by Elemental Analyzer. Major element geochemistry indicates that both complexes are alkaline and contain rocks ranging in composition from picrobasalts to trachytes. Trace element signatures suggest both complexes have a common parental magma. REE values are significantly lower for felsic, mineralized rocks than for both unmineralized equivalents and more mafic rocks in general. This suggests that original magmatic signatures have been lost due to intense alteration, which is complicating the unraveling of the magmatic history. Destruction of monazite, xenotime and possibly apatite were the main cause of REE modification of the mineralized rocks at Ok Tedi.

KEYWORDS: Ok Tedi, porphyry copper, magmatic evolution, REE, sulphur

1 INTRODUCTION

This study investigates the geochemistry of the Ok Tedi Complex and its relationship with the neighbouring Mount Ian Complex. The Ok Tedi Cu-Au deposit of Western Papua New Guinea was discovered in 1968 and mined since the early eighties. Its resources are 854 Mt at 0.64 wt% Cu and 0.78 g/t Au, and production was 2.86 Mt Cu and 706 t Au until 2003. This study provides a detailed geological and geochemical framework for understanding the magmatic genesis of the rocks that are parental to these deposits. This is important because it is unclear to what extent common magmatic processes such as magma mixing occur during the genesis of porphyry copper deposits (Sillitoe, 1997).

2 GEOLOGY

The deposits are situated in the Mio-Pliocene fold-and-thrust belt of Western Papua New Guinea. The deposits consist of chalcopyrite, chalcocite and minor bornite, deposited in quartz veins and stockworks in a central part of a porphyritic monzonite intrusion. This intrusion itself is part of the larger Ok Tedi Complex, which consists mainly of equigranular

monzodiorite. In addition, Au and Cu are found in massive magnetite and sulphide skarns in the adjacent country rock. The area consists of shallowly dipping continental margin marine sediments of Cretaceous to Middle Miocene age overlying stable Palaeozoic metamorphic and granite rocks of the West Papuan platform (Bamford, 1972; Fig. 1).

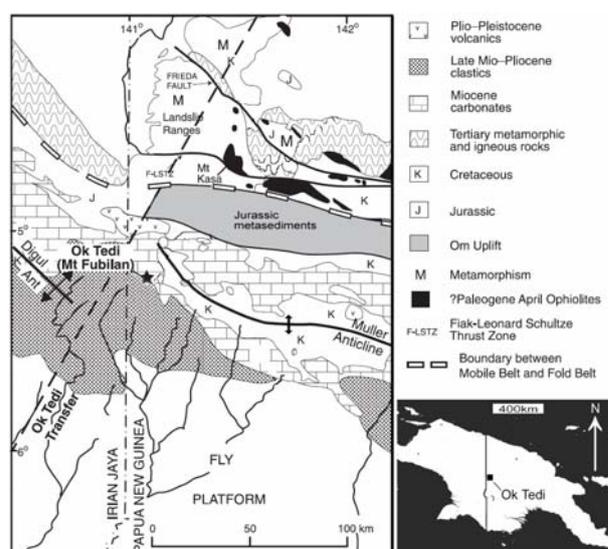


Figure 1. Regional geology and location of the Ok Tedi deposit. Modified from Hill *et al.* (2003).

The sedimentary package comprises Cretaceous marine mudstone and glauconitic sandstone of the Ieru Formation, late Oligocene-early Miocene Darai Limestone and Middle Miocene calcareous mudstone, siltstone and limestone of the Pnyang Formation. Minor tuffaceous sandstone was deposited as part of the Pnyang Formation during the Middle Miocene. Subsequent detrital volcanoclastic sediments, derived from a rapidly eroding stratovolcano during the late Miocene to Pliocene, form the Birim formation. The final sedimentary phase was the clastic and volcanoclastic alluvial flood plain deposits of the Anwin Formation (Rush & Seegers, 1990).

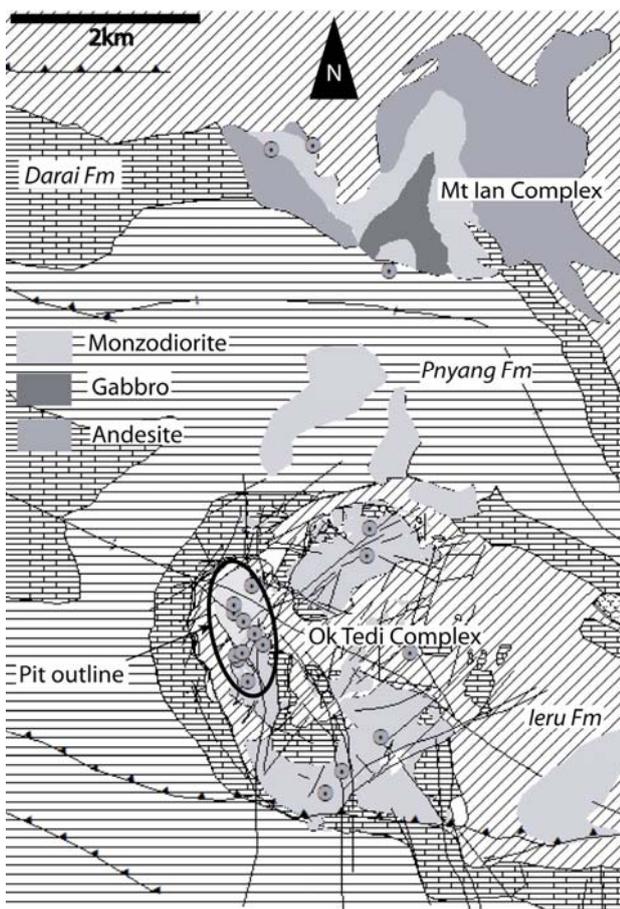


Figure 2. Geology of the Ok Tedi Complex and the Mount Ian Complex.

The Ok Tedi Intrusive Complex (OTC) is Middle Miocene to Pleistocene in age (Page & McDougall, 1972). Two units of this calc-alkaline complex are present at Mt Fubilan (corresponding to the pit outline on Fig. 2). The main stock is the Fubilan monzonite porphyry (FMP), which hosts the Cu-Au vein stockworks. This porphyry intruded sediments and parts of the 2.6 Ma Sydney monzodiorite stock.

Skarns are associated with both intrusions. The FMP is about 850m in diameter, but tapers downward. It has been extensively altered by a hydrothermal event dated by K-Ar in biotite at 1.2-1.1 Ma (Page & McDougall, 1972).

The hydrothermal activity has produced K-feldspar and biotite alteration spatially associated with the main Cu-bearing stockwork veins, within a larger alteration zone characterized by chlorite, pyrite and magnetite. The latter extends over large parts of the OTC, though in varying intensity. Calc-silicate alteration is spatially associated with massive magnetite and sulphide skarns. A leached oxide cap was present (Rush & Seegers, 1990) but has been mined out.

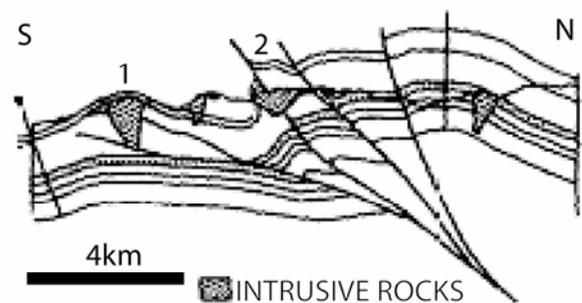


Figure 3. Cross-section modified from Mason *et al.* (1997) showing similarities in structural setting between Ok Tedi Complex (1) and Mount Ian Complex (2).

The Mount Ian Complex (MIC) intruded Darai limestone north of the OTC and consists of a core of Pliocene gabbro, diorite, monzonite and surrounding "intrusive andesite porphyry". K-Ar dating of MIC gabbro resulted in an age of 2.0-1.7 Ma, whereas one "andesite" sample had an age of 12.9 Ma (Page, 1975). Some parts are altered and contain secondary biotite and pyrite (Arnold *et al.*, 1979). Despite its petrological similarities to the OTC, the MIC is not Cu-Au mineralized.

A strong structural control is noted by field evidence from pre-, syn- and post-emplacement slip along fault- and thrust planes and mineralized skarn formation on some of these planes in the OTC.

A comparison of the structural setting between the OTC and MIC (Fig. 3) suggests that their setting is equally favorable for mineralization. Some other explanation is thus required for the lack of mineralization in the MIC.

3 METHODS

Field study consisted of pit wall analysis, core logging and sampling. Samples were analyzed by XRF at CSIRO Land and Water, Adelaide, for whole rock major and trace element geochemistry. Selected samples were dissolved by High Pressure Dissolution with HF. Rare Earth and other trace elements were determined following Elburg *et al.* (2002) using HR-ICP-MS at the School of Geosciences, Monash University. Sulphides of selected samples were separated using tetra-bromide liquid (specific gravity 2.96) and washed with ethanol. After drying, they were combusted with VO₅. The S isotopic composition of the gas was determined using an Elemental Analyzer.

4 RESULTS

Rock samples have been classified using the IUGS TAS classification (Fig. 4), although this is a scheme for volcanic rocks. All samples are from medium-to-coarse grained plutonic rocks. The OTC is an alkaline intrusive complex and predominantly has a chemical composition of trachyandesites to trachytes. Deep-seated alkaline gabbroic dikes and enclaves of basaltic to basaltic trachyandesitic composition are also present. The MIC is less alkaline and less evolved than the OTC. Its intrusive rocks have picrobasaltic, trachybasaltic, trachyandesitic and trachydacitic compositions.

Trends in major oxides with increasing silica show decreasing MgO, CaO, TiO₂ and P₂O₅ and increasing alkali oxides. XRF trace element trends with increasing silica show increasing Rb, Ba and Zr, decreasing Y and Ce, increasing then decreasing Sr and variable S, Th, Cu and Zn.

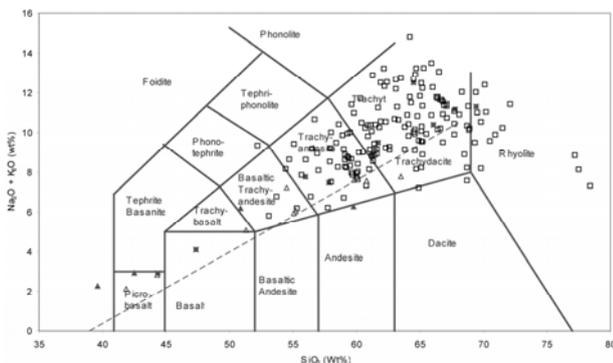


Figure 4. TAS plot showing OTC (filled black squares) and MIC (filled black triangles) rocks and their IUGS classification. Open symbols represent data from Doucette (2000).

Samples are enriched in REE relative to C1 chondrites (Fig. 5), with LREE enrichment, typical of arc andesites. Although MIC samples and the OTC picrobasaltic gabbro have similar signatures, most OTC rocks (near Mt Fubilan) are depleted relative to MIC samples and OTC picrobasaltic gabbro. Most OTC rocks have significant positive Eu anomalies, whereas MIC rocks and the OTC picrobasaltic gabbro have small negative Eu anomalies.

Sulphur isotopic compositions of sulphide separates are between -0.8 and 5.1 (Fig. 6).

5 DISCUSSION

5.1 Whole rock geochemistry

The alkaline character of the rocks in the MIC and OTC (Fig. 4) is characteristic of many major circum-Pacific gold-copper occurrences (Sillitoe, 1997). Incompatible element ratios of Zr/Y and Nb/Y of mafic OTC and MIC are similar, suggesting a common source. The REE values of OTC monzonites and monzodiorites are substantially lower than the other samples. This suggests remobilization by fluids, *i.e.* the effects of hydrothermal alteration (Poitrasson *et al.*, 1995). This decrease in REE can at least in part be ascribed to the disappearance of monazite and xenotime, causing a significant decrease in P, Y and La. Using field relationships and published data, relative ages were assigned to the samples. This produces complex chemical patterns over time that need further examination and interpretation in order to interpret the magmatic evolution of the rock suite correctly.

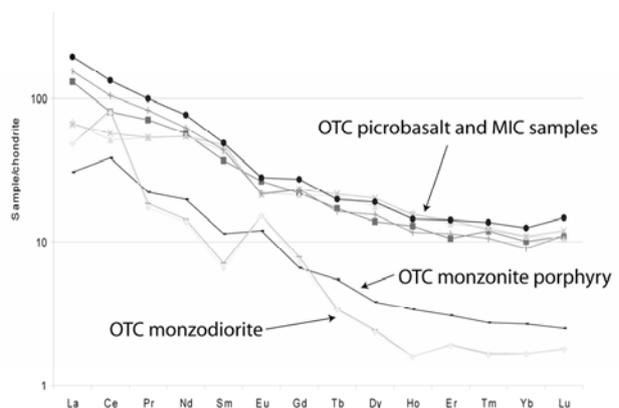


Figure 5. Chondrite (C1) normalized spidergram of REE from the OTC and MIC. Normalizing values are from (Sun & McDonough, 1989).

5.2 Sulphur isotope geochemistry

The range of sulphur isotopic values (Fig. 6) is similar to those of typical sulphides from porphyry copper deposits, although slightly higher. Since sulphide from the mantle has a $\delta^{34}\text{S}$ of approximately zero, a large part of the sulphur is interpreted to have an orthomagmatic source. The slight shift towards positive values may reflect mixing with crustally sourced sulphur, e.g. from surrounding sediments.

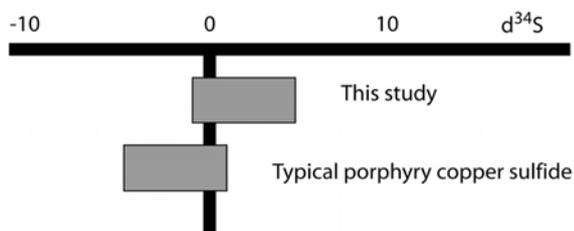


Figure 6. Sulphur isotopic composition of sulphide separates relative to Canon Diablo Troilite. Typical sulphide sulphur isotopic values are from Rollinson (1993)

5.3 Implications for porphyry copper genesis

The sulphur isotope results suggest a largely magmatic source for the sulphur. This could imply that a large part of the sulphur in this system is provided by mafic magma replenishment, which is consistent with the conclusions of Hattori & Keith (2001). In our attempt to substantiate this possibility by means of comparison of REE patterns, we found that REE mobility through destruction of accessory phases strongly disrupts the original signature. Caution should be taken when interpreting geochemical signatures of ore deposits associated with intense alteration.

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