Timescale of Forming a Giant Porphyry Copper-Gold Deposit – Ok Tedi, Papua New Guinea

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ABSTRACT

We investigated the duration of formation of the giant Ok Tedi porphyry copper-gold deposit in Papua New Guinea using zircon SHRIMP U-Pb dating. The intrusions that host the Cu-Au mineralisation have a maximum age of 1.43 ± 0.22 Ma. Since previously published K-Ar dates on the same intrusion constrain the last thermal event at 1.11 ± 0.05 Ma, we conclude that the magmatic-hydrothermal event that produced the deposit lasted ~0.45 megayears (Myr). A comparison of Ok Tedi's calculated volatile fluxes with those from arc volcanoes and active mineralising hydrothermal systems suggests that the efficiency of metal deposition is a key factor in determining the duration of deposit formation.

INTRODUCTION

Recently published fluid compositional data from deep geothermal systems below the Ladolam Au deposit in Lihir, Papua New Guinea, suggest that giant magmatic-hydrothermal ore deposits can form within a time span of less than 100 kiloyears (kyr) (Simmons and Brown, 2006). However, crystallisation of typical porphyry copper deposits such as Cadia (New South Wales) and Bajo de la Alumbrera (Argentina) suggest that magmatic activity commonly exceeds time spans of several million years (Harris *et al*, 2004; Wilson *et al*, 2007). This discrepancy could imply that ore formation from hydrothermal systems surrounding porphyries is a relatively short-lived process that is not directly proportional to the timescales of magma crystallisation.

We therefore investigate the timescale of forming the giant porphyry Cu-Au deposit at Ok Tedi, Papua New Guinea (PNG). We use high-precision U-Pb SHRIMP dating on magmatic zircon to constrain the crystallisation ages of the magmatic plumbing system and combine this with published age data. Our analytical results show that the Ok Tedi intrusive complex crystallised between 1.5 and 1.0 Ma, whereas published K-Ar data suggest that hydrothermal activity was contemporaneous with magmatic activity within this time bracket. Calculation of the required sulfur fluxes to form the deposit shows that they are consistent with published estimates on S fluxes from volcanic arc systems. This suggests that the fundamental control on ore deposition in these systems is the host rock's permeability and reactivity.

GEOLOGICAL BACKGROUND

The Ok Tedi deposit is situated in the southern extension of the Papua New Guinean fold-and-thrust belt, near the border with Irian Jaya. There is considerable doubt about the nature of the basement

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since it is not exposed, but the overlying sedimentary rocks of the region are 1000 - 1500 m thick siltstone and limestone units. South-directed folding and thrusting occurred in the Late Miocene, during and after which a series of calc-alkaline felsic plutons intruded the fold-and-thrust belt along a NNE-trending lineament during the Pliocene (Hill *et al*, 2002). The Ok Tedi intrusive complex is part of this event.

The stocks and their deposits occur within the regional scale NW-SE trending Ok Tedi Anticline and are closely associated with two north-dipping faults, which cause repetition of parts of the stratigraphy by producing a wedge-shaped structure that dies out away from the intrusive complex. The thrusts are known as the Parrots Beak Thrust and the Taranaki Thrust. These two thrusts were active before magma emplacement, as evidenced by intrusion of the thrust stack by the stocks. Deformation continued after emplacement and mineralisation as evidenced by tectonic breccias containing mineralised clasts and faulting of the intrusive bodies.

The mine area consists of two major intrusive stocks:

1. the Fubilan Monzonite Porphyry (FMP), and
2. the Sydney Monzodiorite (SMD) (see Figure 1).

The FMP is intensely altered to K-feldspar-biotite-magnetite and K-feldspar-sericite assemblages, whereas the SMD shows similar alteration close to the contact with the FMP, decreasing in intensity away from it. The FMP is characterised by stockwork and disseminated chalcopyrite mineralisation and is hosted by siltstone. The SMD is uneconomically mineralised. However, at

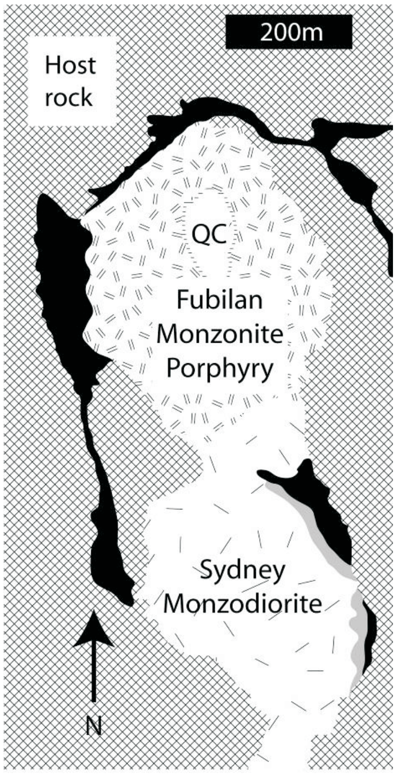

FIG 1 - Simplified premining surface geology of the Ok Tedi mine area. Skarns are indicated in black and grey. Checkered infill represents various sandstone and limestone units.

depth, the SMD is in contact with a brecciated limestone wedge due to the thrust stack geometry. On these contact surfaces a thick magnetite-pyrite ± chalcopyrite skarn developed.

METHODS

We used conventional zircon separation techniques on selected rock samples from the Ok Tedi intrusive complex. Zircons were imaged using cathodoluminiscence electron microscopy and petrographic microscopy. We noted that many zircons contained inherited cores. We therefore targeted the analytical beam at homogeneous zones on the rims of the zircons to infer the crystallisation age of the magma. SHRIMP-II U-Pb analyses were performed at the Australian National University, Canberra and calculated and processed through concordia diagrams following standard procedures.

DURATION OF MINERALISATION PROCESS

Our calculated concordia intercept ages of two SMD and two FMP samples are within the range 1.02 - 1.36 Ma and are temporally indistinguishable within the 2σ error. A sample from the southeast of the Ok Tedi intrusive complex has an intercept age of 1.43 ± 0.22 Ma, suggesting intrusive activity occurred between ~1.5 - 1.0 Ma. The zircon results contrast with previously published ages that infer that the SMD is ~2.6 Ma (Page, 1975). Published K-Ar ages for samples from within a ten kilometre radius of Ok Tedi show that magmatic activity occurred between three and 1 Ma, consisting of gabbroic and monzodioritic intrusions, whereas hydrothermal activity occurred until 1.11 ± 0.05 Ma, as inferred from K-Ar analysis of hydrothermal biotite in the FMP (Page and McDougall, 1972; Page, 1975).

MINERALISING VOLATILE FLUXES

Our zircon ages show that the time span of intrusive activity in the Ok Tedi mine area was less than 0.5 Myr. We have evidence that the intrusions acted as permeable pathways for mineralising volatiles because they have been hydrothermally altered and veined and are enriched in Au and Cu. Since the youngest K-Ar age on hydrothermal biotite from the FMP is 1.11 ± 0.05 Ma and these ages are commonly affected by thermal resetting, we infer that the total time span of hydrothermal activity cannot have been more than 0.45 Myr. This allows the calculation of the volatile fluxes associated with the formation of the deposit.

The Cu resource of Ok Tedi is 8.51 Mt Cu and the estimated overall Cu:S ratio of the ore is 1:5 to 1:8, based on mineralogy and blasthole data (OTML, 2007). This implies that 42 - 68 Mt S was deposited in the Ok Tedi area (before mining), yielding an S flux of ~93 - 151 Mt/Myr. Andesitic magmas typically carry 1300 ppm S (Wallace, 2005) and have a density of 2650 kg/m^3. At the typical magma flux of 4 to 20 km^3/Myr (Carmichael, 2002), we calculate a typical S flux in arc volcanoes of 14 - 68 Mt/Myr. This number is approximately half but comparable to that of Ok Tedi. Given the broad uncertainties in the entry parameters, this implies that a typical volcanic systems could produce an S-concentration like Ok Tedi, if the S transfer from the magmatic system to the deposit is highly efficient.

At the Ladolam deposit on Lihir Island, Papua New Guinea, the calculated time span to form the Au resource of 1300 tons was ~55 kyr, based on the measured concentration of Au in the fluids (Simmons and Brown, 2006). Using the fluid composition of Simmons and Brown (2006), we estimate, using the SO_4 contents of ~16 000 ppm, fluid flux of 50 kg/s and disregarding the 19 ppm of H_2S gaseous species, that the S flux at Ladolam is 25×10^3 Mt/Myr. The three orders of magnitude difference between fluxes at Ladolam and Ok Tedi and arc volcanoes is likely a result of the extrapolation of the fluxes measured on a scale of seconds to days (Ladolam) to a time scale of Myr (arc volcanoes). Our results show that the hydrothermal systems associated with porphyry copper deposits act similarly to arc volcanoes on the timescale of Myr.

CONCLUSIONS

This study concludes that whilst fluid and S flux rates averaged across the duration of magmatic activity may be capable of producing deposits, Ladolam has much higher flux rates. This comparison suggests that hydrothermal systems could be comprised of short duration intense mineralising pulses (an order of ten thousand years). Integration of detailed studies of alteration evolution in mineralising systems with highly precise dating is required to determine timing and duration of intense hydrothermal activity.

Furthermore, in order to efficiently transfer S and metals from magmas to a small volume of intensely altered rock, the system must behave in a particular way. We therefore also conclude that ore deposition in these systems is caused by a combination of host rock permeability and chemistry, which provides the necessary gradients in P T and redox conditions to cause metal deposition. This is consistent with the 3D distribution of permeable and reactive rock units and evidence for syn-mineralisation deformation at Ok Tedi.

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