TECTONIC, MAGMATIC AND METALLOGENIC EVOLUTION OF THE CAJAMARCA MINING DISTRICT, NORTHERN PERU

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ABSTRACT

In the Cajamarca region of northern Peru periods of peak Tertiary magmatism had a close association with orogenic episodes and high plate convergence rates. New $^{40}Ar/^{39}Ar$ dates show magmatism in the region had commenced by late Palaeocene times, some 15 m.y. earlier than suggested by previous geochronological studies. Palaeogene (57-43 Ma) intrusive and volcanic rocks are intermediate in composition with flat REE profiles and primitive isotope compositions. These magmas were derived from an immature sub-Andean mantle dominated by pyroxene and olivine. This magmatic interval coincided with development of an early fold-thrust fabric in deformed sedimentary rocks.

Early Miocene onset of high plate convergence rates triggered the generation of oxidised hydrous melts from the breakdown of a sub-Andean amphibole-rich upper mantle to lower crust. These melts rose into large magma ponds deep within the crust. Sr, Nd and Pb isotope compositions indicate synmineralisation magmas and metals were derived from a common deep source and that magmas underwent minimal upper crustal contamination. During brief changes in the tectonic stress, primitive hydrous-rich magmas were released from these chambers and ascended rapidly along deeply tapping faults. Dioritic intrusions with HREE-depleted profiles were emplaced during periods of extension in a highly fractured upper crust. New $^{40}Ar/^{39}Ar$ dates indicate this occurred from 23.2 to 16.5 Ma. Mineralised stocks are commonly located in the hanging wall of a regional thrust fault and situated at structural intersections, such as oblique secondary structures superimposed on pre-existing regional-scale faults. Mineralisation-controlling structures, e.g. fault, vein and fracture arrays, at the porphyry deposits have subparallel NNW and NE-NNE trends that suggest they were directly controlled by a regionally extensive stress regime. The physiochemical conditions that prevailed during early stage hypogene mineralisation strongly influenced the Au enrichment at the various porphyry deposits. Au-rich deposits are typically hosted in carbonates, tend to have well-developed potassic alteration zones, high temperature and oxygen fugacity hypogene sulphide mineral assemblages (bornite + chalcopyrite) and abundant hydrothermal magnetite. In contrast, mineralised stocks in contact with fractured quartzites ± carbonates are Cu-Au-Mo deposits with lower temperature

hypogene sulphide assemblages of chalcopyrite and pyrite, and potassic alteration zones overprinted by low-grade pyritic phyllic alteration.

Late Miocene high-sulphidation deposits (~11 Ma) near Cajamarca formed during the cessation of intense crustal thickening and uplift that was associated with shallowing of the slab dip angle. Location of ore bodies at the Yanacocha mine was largely controlled by WNW structures, indicating rotation of the dominant fault orientation from NNE-NNW to WNW with time. A mineralised dioritic-tonalitic intrusion beneath the Yanacocha high-sulphidation system has a steep HREE-depleted profile and more evolved radiogenic Sr-Nd isotope compositions than the early Miocene intrusions. However, a pyrite Pb isotope composition from this intrusion is significantly less radiogenic than sulphides from early Miocene deposits. These features indicate late Miocene magmas were formed beneath a thickened crust, similar to that at the present day, and require a higher garnet content in the source.

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THESIS INTRODUCTION

The Cajamarca district of northern Peru hosts an unusually high number of Tertiary Au-rich porphyry and high-sulphidation deposits for the Andean metallogenic belt. Despite extensive mineral exploration and recent development of the world class Yanacocha Au mine, the tectonic and magmatic understanding of the Cajamarca region has been poorly documented compared to other Au-rich regions in the Andes, such as the 27^{o} to 30^{o}S central Andean transect (e.g. Gustafson and Hunt, 1975; Vila and Sillitoe, 1991; Lindsay *et al*., 1995; Sasso and Clark, 1998; Kay *et al*., 1999; Richards *et al*., 2001).

This thesis investigates tectonic, magmatic and deposit geology controls on the formation of Tertiary mineralised centres in the Cajamarca district. The thesis consists of five sections written in journal format that are intended for future publication. The sections are arranged a logical progression that follow on from the previous section. The first four sections present new geochronological, structural and geochemical data, and a geological description of two porphyry-related deposits. The final section incorporates these results with findings from previous studies in the region and other mining districts in the Andes to develop a comprehensive tectonomagmatic model for the formation of Miocene hydrothermal deposits in the Cajamarca district.

Section A

The first section of the thesis presents a geological introduction to the Cajamarca region. This includes a brief summary and petrological description of the major magmatic units that crop out throughout the region. Ten new $^{40}Ar/^{39}Ar$ dates are also presented for selected magmatic and hydrothermal centres. The section concludes with discussion of the relationship between magmatic-hydrothermal events and tectonic episodes.

Section B

The second section addresses the structural evolution of the Cajamarca region. Data presented are derived from field and aerial photo studies of deformed Cretaceous sedimentary rocks and various mineralised centres. Fault, fracture and vein arrays at the porphyry-related deposits are used to assess the influence of the regional stress field on the formation of these deposits. The section documents a temporal change in the principal fault-fractures trend with time and links these changes to plate convergence direction.

Section C

The third section focuses on petrographical and geochemical data (major, trace, rare earth element and radiogenic isotope compositions) of the magmatic rocks in the region. Different igneous suites are identified and compared. A comparison between mineralised and unmineralised porphyry intrusions is also addressed. Selected samples are modelled using REE and trace element models to estimate possible changes in the residual mineralogy of a developing magmatic arc. The section concludes with a geochemical comparison with mineralised porphyry deposits in Chile and magmatic model for Tertiary igneous rocks in the Cajamarca region.

Section D

Section four gives geological descriptions of two mineralised intrusive-related centres in the Cajamarca district, i.e. the El Galeno and Michiquillay Cu-Au-Mo deposits. The study documents the intrusive history at the deposits, as well as the alteration and mineralisation paragenesis. A geological model for the formation of these centres is proposed. New sulphide Pb isotope compositions from four of the mineralised deposits are also presented. Finally, these porphyry deposits are compared with the well-documented Au-rich Minas Conga prospect and generalised models for porphyry Cu deposits.

Section E

The final section of this thesis unifies new geochronological and geochemical data with structural observations and deposit geology to develop a top-to-bottom tectonomagmatic model for the formation of Miocene porphyry-related and high-sulphidation deposits in the Cajamarca region.