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Southwest Pacific Rim Gold-Copper Systems:

Structure, Alteration, and Mineralization

Editors

G.J. Corbett and T.M. Leach

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SERIES PREFACE

This work by Greg J. Corbett and Terry M. Leach is the sixth volume in the Society of Economic Geologists Special Publications Series, which was begun by former editor Patricia A. Sheahan in 1992. No post-mortem on defunct mining areas, Corbett and Leach's volume reflects current and emerging interests in an important part of the world.

For hundreds of years, miners have been drawn to the Pacific Rim but, until recently, large-scale production has been concentrated on the eastern fringe, on such important deposits as the epithermal precious metal ores of Mexico and the western United States and the classic porphyry copper deposits of the Cordillera. For various economic and political reasons, major exploration and development efforts are now being lured to gold and copper deposits in the southwest Pacific—to Fiji, Indonesia, Japan, Papua New Guinea, New Zealand, the Philippines, and the old standby, Australia. Interest in the southwest Pacific hinges largely on new economic discoveries such as those of the Gunung Bijih (Ertsberg) district which was featured in recent issues of *Economic Geology* and *Geotimes*. Readers will also be drawn by the scientific value of recently formed deposits, such as Tertiary to Quaternary porphyry coppers and by gold values at the Champagne Pool and Osorezan volcano which contain key information about ore genesis although they are unlikely to ever be mined.

Corbett and Leach's review is a direct result of a popular and heavily-attended short course presented by SEG at its March 1996 meeting in Phoenix, Arizona, where William X. Chávez was general chair. Prior to and after the meeting, the authors also conducted short courses and workshops on the topic for mining clients, and at public venues over a four-year period at 29 other locations spread around the Pacific between Jakarta, Manila, Santiago, and Vancouver. A repeat of the Phoenix course was presented under SEG sponsorship in Lima in 1997. Capitalizing on their unique experiences on the road and in the field, Corbett and Leach provide readers with the latest data and interpretation on a wide range of deposits on the southwest Pacific Rim. They are to be congratulated for tackling such a complex topic and for sharing their perspectives with colleagues.

The Society is also indebted to Jeffrey W. Hedenquist of the Geological Survey of Japan, and John Thompson of the University of British Columbia, for intensive formal reviews requested by the SEG Publications Committee. SEG Executive Director John A. Thoms and Lisa Laird deftly handled the production of SEG Special Publication 6, including final formatting and expediting the printing process.

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SUMMARY

This publication classifies and describes differing styles of southwest Pacific Rim gold-copper systems, (Fig S.1) and analyzes hydrothermal ore-forming processes. Investigations of these systems in terms of structure, alteration, and styles of mineralization provide information which may help determine the direction of fluid flow within evolving hydrothermal systems.

Major structures localize magmatic hydrothermal systems in magmatic arc settings and create ore-hosting dilational environments within subsidiary structures, commonly at high angles to the controlling structures. Differing styles of convergence influence the style of major structures and ore-forming environments. Breccias occur in most gold-copper deposits and may be categorized as a guide to understanding the ore-forming environment, as broad correlations are apparent between breccia and mineralization styles.

Temperature and fluid pH are considered to be the most important of many factors which control the types of hydrothermal alteration. Hydrothermal minerals are classified in terms of these two factors to create a meaningful interpretation of alteration data. Possible mechanisms of metal transport and deposition provide a framework to understand the distribution of metals in intrusion-related systems.

Porphyry copper-gold systems develop around intrusions which are localized within volcanoplutonic arcs by regional accretionary (arc parallel) or transfer (arc normal) structures. Cooling of intrusions emplaced at high crustal levels results in the conductive heat loss and initial formation of zoned alteration assemblages. This is followed by the exsolution of magmatic fluids and the formation of stockwork to sheeted quartz-dominated vein systems, generally along the margins and around the carapace of the intrusion. Subsequent mineralization occurs within an environment which is conducive to metal deposition, and it is interpreted that these conditions are created as a result of cooling, predominantly by dilute meteoric waters. Porphyry copper mineralization concentrates in zones of greatest paleo-permeability, commonly along the fault controlled margins of the host intrusion and refractured pre-existing stockwork veins. It is proposed that mineralization mainly results from mixing of meteoric waters with metal-bearing magmatic fluids, possibly derived from larger magma sources at depth. Skarn deposits exhibit similar prograde and retrograde alteration and mineralization in response to the emplacement of intrusions into calcareous rocks.

High sulfidation gold-copper systems are formed from hot, acidic, magmatic-derived fluids and extend from porphyry to epithermal regimes. High sulfidation alteration forms as shoulders and caps to porphyry intrusions, where zonations in alteration reflect progressive cooling and subsequent decrease in fluid pH in response to gradual dissociation of reactive magmatic gases. The high formation temperature of these systems, proximal to the source intrusion, is inferred to inhibit the formation of copper-gold mineralization which occurs in cooler, more distal environments. These systems are classified according to the predominance of either structural or lithological control to fluid flow as members of a continuum. All mineralized systems exhibit characteristic alteration zonation resulting from progressive cooling and neutralization of hot acidic magmatic-dominated fluids by reaction with host rocks and ground waters. Variations in the style of mineralization, metal content, and alteration mineralogy depend upon temperature and fluid composition. A two stage alteration and mineralization model is proposed which suggests that initial vapor-dominated fluids develop zoned, commonly pre-mineralization alteration, which is overprinted and typically brecciated during influxes of mineralized liquid-rich fluids. High sulfidation systems are copper-rich at depth and are gold-rich at higher crustal levels.

Varying styles of low sulfidation gold systems predominate in settings of oblique subduction, where magmatic fluids migrate away from intrusion source rocks into environments which contain meteoric waters of different compositions and temperatures. Metals grade from gold and possible copper-bearing at depth, through gold with base metals at intermediate levels, to gold-silver bearing at highest crustal levels.

Quartz-sulfide gold ± copper systems form proximal to magmatic source rocks, predominantly by the mixing of magmatic fluids with deep circulating cool and dilute meteoric waters. Carbonate-base metal gold

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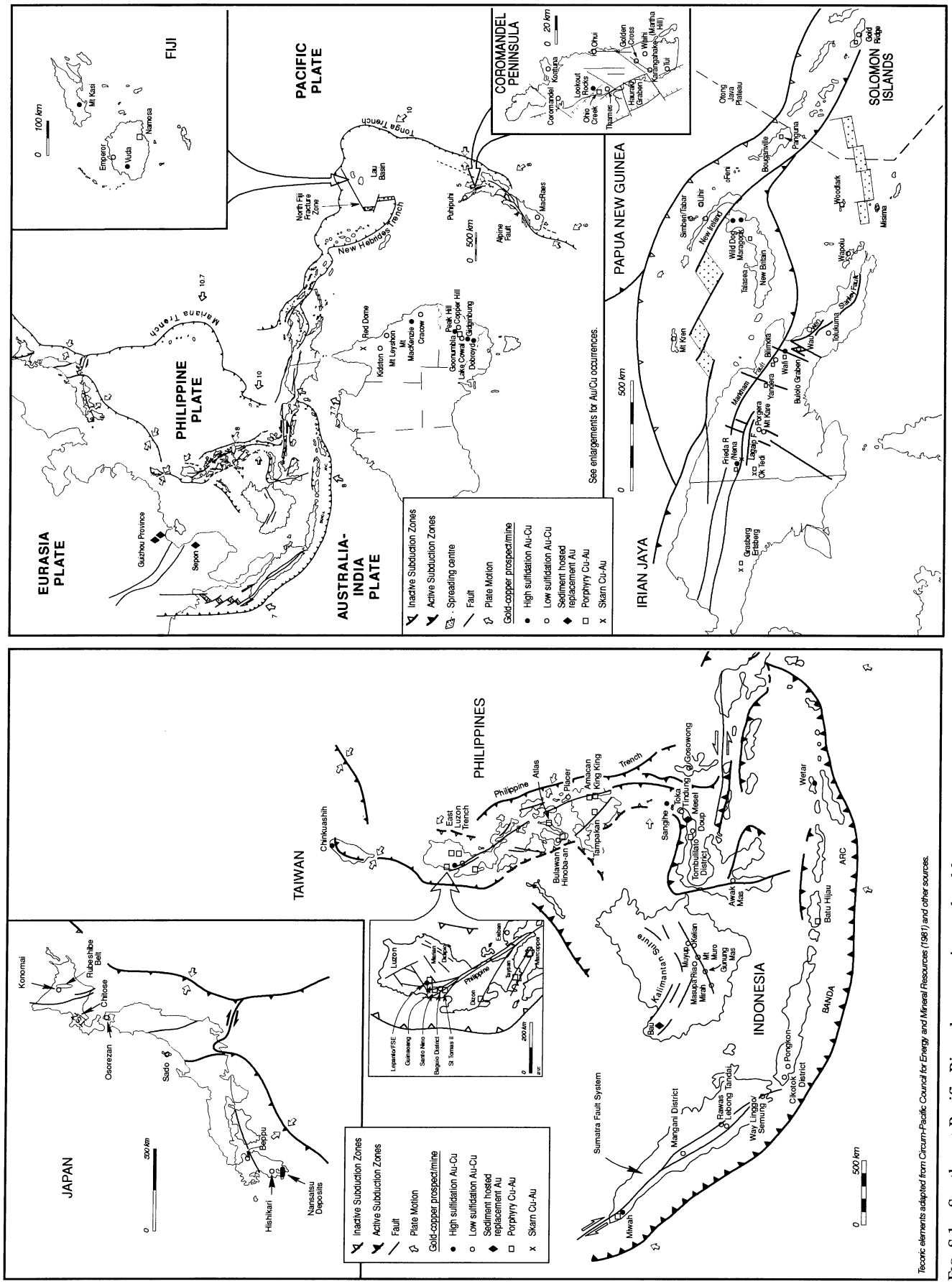

FIG. S.1 Southwest Pacific Rim plate margins and gold-copper occurrences

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systems form at higher levels, mainly by reaction of magmatic-dominated fluids with low pH, CO_2-rich waters. Epithermal quartz-gold-silver systems form at the highest crustal levels and display the most distal relationship to the magmatic source. Bonanza gold grades develop in these systems by the mixing of more dilute, boiling, magmatic-derived fluids with oxidizing ground waters. This latter group of deposits is transitional to the classic adularia-sericite epithermal gold-silver vein systems. Telescoping may overprint the varying styles of low sulfidation gold mineralization upon each other or upon the source porphyry intrusion. Sediment hosted replacement gold deposits are herein classified as genetically related to low sulfidation quartz-sulfide systems, but develop in reactive carbonate rocks.

Adularia-sericite epithermal gold-silver deposits form at elevated crustal settings in the absence of an obvious intrusion source for the mineralization. These systems vary with increasing depth from generally barren surficial sinter/hot spring deposits, to stockwork vein/breccias and fissure veins. Brittle basement rocks fracture well and so represent competent hosts for fissure veins within dilational structural settings. Boiling models account for the deposition from meteoric waters of the characteristic gangue minerals comprising banded quartz, adularia, and quartz pseudomorphing platy carbonate. However, precious and base metals are postulated to be magmatic-derived and are concentrated in thin sulfide-rich bands, commonly with low temperature clay minerals. Mineralization is therefore interpreted to have been deposited mainly by the mixing of upwelling, commonly boiling, mineralized fluids with cool, oxidizing ground water.

The ore deposit models defined herein are useful in all stages of mineral exploration, from the recognition of the style of deposit, to the delineation of fluid flow paths as a means of targeting high grade ores, or porphyry source rocks. The exploration geologist may be aided by the use of conceptual exploration models which are interpretative and vary from the more rigorously defined deposit and exploration models. Conceptual models should not be applied rigidly but modified using an understanding of the processes described herein to develop models which are tailored to individual prospects.