CADIA ALKALIC PORPHYRY Au-Cu DEPOSITS, NSW, AUSTRALIA

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U-Pb and Re-Os Geochronologic Evidence for Two Alkaline Porphyry Ore-Forming Events in the Cadia District, New South Wales, Australia

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Abstract

The Cadia district, located in the eastern Lachlan fold belt of New South Wales, Australia, comprises four gold-copper porphyry deposits (Ridgeway, Cadia Quarry, Cadia Hill, and Cadia East) and two related iron-copper-gold skarn deposits (Big Cadia and Little Cadia). These deposits formed along a northwest-striking, arc-transverse structural corridor within the intracratonic Macquarie arc. This arc is composed of a belt of Early Ordovician to Early Silurian mafic to intermediate volcanic, volcanioclastic, and intrusive rocks of calc-alkaline to alkaline composition. The Cadia porphyry deposits are temporally and genetically associated with composite intrusive complexes of alkaline monzodiorite to quartz monzonite.

U-Pb dating of igneous minerals from the intrusions and Re-Os dating of hydrothermal molybdenite from the deposits has revealed the presence of two temporally discrete events of magmatism and related porphyry-style mineralization in the Cadia district. The monzonic intrusive complex related to mineralization at Ridgeway and a quartz monzonite porphyry stock that lies immediately southwest of the Cadia Quarry deposit are early Late Ordovician (456–454 Ma). In contrast, the quartz monzonite porphyry stock that hosts the Cadia Quarry and Cadia Hill orebodies and an intermineral quartz monzonite porphyry dike at Cadia East are Early Silurian (~438 Ma). Re-Os molybdenite ages determined for quartz-sulfide veins within the early Late Ordovician quartz monzonite porphyry confirm multiple episodes of mineralization associated with the Cadia Quarry deposit, suggesting a complex history between 460 and 450 Ma. At Cadia Hill, Cadia Quarry, and Cadia East, a widespread event of porphyry gold-copper mineralization is recorded at about 443 to 441 Ma, based on three Re-Os molybdenite ages from sheeted quartz sulfide veins. Similar ages for magmatic zircon from the host intrusions support a link between dated intrusions and mineralization.

These new ages are in general agreement with the ages of other porphyry gold-copper and related epithermal deposits of the Eastern Lachlan fold belt and help to constrain the relationship between the Cadia region and the evolution of the Lachlan fold belt. It is notable that the high-grade Ridgeway deposit is up to 18 m.y. older than any alkaline porphyry deposit yet discovered in the Macquarie arc, a feature that may be important for continued exploration success in this region.
Clay Mineralogy and Zonation in the Campana Mahuida Porphyry Cu Deposit, Neuquén, Argentina: Implications for Porphyry Cu Exploration

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Abstract

Analysis of clay mineralogy and illite crystallinity in the clay-size fraction (<2 μm) of 102 whole-rock samples from 33 drill cores of the Campana Mahuida porphyry copper deposit has identified (1) a central chlorite-rich zone superimposed on the potassic core, (2) a peripheral chlorite-rich zone in the outermost propylitic halo, (3) an illite-rich zone within the south and southwestern quadrangles of the phyllic halo that has overprinted the outer potassic core and inner propylitic zone, and (4) a smectite-rich zone within the northeast and northwest quadrangles of the phyllic halo. Lateral and vertical variations in clay mineralogy and illite crystallinity are attributed to alteration and mineralization such that surficial or remotely sensed mineralogy can be used to see through superimposed supergene alteration.

In the chlorite zones, the chlorite octahedral cations vary between 11.62 and 11.99 per O2(H2O)4 formula unit and the tetrahedral cation composition is between (Si2Al3) and (Si4Al3) with an overall composition of (Al2O3-MgO-MgO-Fe2O3)/3SiO2. Thus, all are trioctahedral chlorites and, based on Fe3+/Fe2+ and Mg/Si contents, can be classified as Fe-Al chlorite and Fe chlorite. The chlorite zone in the potassic core formed mostly by destruction of hydrothermal biotite during sulfide precipitation at temperature decreased and j0 increased. The chlorite contains more Mg than the biotite it replaces and has higher Fe2+/Fe3+ but lower Al2O3 than chlorite formed in the outer propylitic halo.

The phyllic zone that surrounds the potassic core is dominated by illite (K0.17Na0.13Al0.12Si0.62Fe0.83Mg0.23)O2(OH)4. Illite from the centers and selvages of veins has a composition close to muscovite, whereas disseminated illite in altered protoliths contains more Mg and Fe cations in the octahedral sites, although all belong to the 2M polytype. This hypogene alteration resulted from fluids with lower pH, temperature, and salinity than fluids responsible for the potassic alteration, propylitic alteration, chloride formation after biotite, and Cu mineralization. The K content of illite decreases outward from the potassic core and from early, disseminated illite to late crosscutting veins.

A smectite-rich zone occurs in the northeast and northwest quadrangles of the phyllic halo. Based on X-ray diffraction analysis and a structural formula of (CaK0.18Na0.13Fe0.14Al0.12Si0.62Fe0.14Mg0.23O2(OH)4), the analyzed smectites are of the aluminum montmorillonite-beidellite dioctahedral series. Smectites from the deepest parts of the porphyry copper system, either from the potassic core or the phyllic halo, are montmorillonite-type smectite, with high total MgO and interlayer cation contents, and are probably hypogene, whereas shallow samples above the potassic core and phyllic halo contain beidellite-type smectite that has the highest FeO content and Al2O3 contents. This likely resulted from intense leaching at low temperatures as is typical of a supergene environment.

Illite is widespread in the Campana Mahuida porphyry Cu deposit and in the unaltered Tordillo Formation that hosts the deposit. The Kübler index (illite crystallinity) in the clay-size fraction of fresh sandstone (0.7° 2θ) corresponds to the highest degree of diagenesis, whereas in the altered rocks in the uppermost level of the deposit, the Kübler index ranges from 0.5 to 0.2° 2θ, values that are indicative of high temperature and/or high fluid/nrock ratios. Within the deposit, illite crystallinity increases from the outer limit of the phyllic zone toward the center of the deposit, above the potassic core, and with depth, from the leached cap to the hypogene sulfide copper zones. Contours of illite crystallinity from the leached cap roughly delineate the outer limits of the ore zones at depth.

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Abstract

Short sediment cores were examined from the active SuSu Knolls hydrothermal field in the eastern Manus back-arc basin, Papua New Guinea, in order to explain the origin of the currently accumulating metalliferous sediments. The mineralogy and geochemistry of the sediments were studied by X-ray diffraction, scanning electron microscopy, energy dispersive X-ray fluorescence, and instrumental neutron activation analysis. Sediments of the Suzette site originated from the deposition of volcaniclastic material with the addition of a hydrothermal component from the mass wasting of old oxidized chimneys. A strong mass wasting event was recognized at the base of the studied sedimentary succession from the occurrence of chalcopyrite, pyrite, and barite aggregates, similar to those found in chimneys, as well as the presence of atacamite. The metalliferous component is characterized by high concentrations of Cu (up to 2.3%) and Au (up to 3.5 ppm), elevated concentrations of As, Ba, Zn, and Fe, as well as a positive Cu anomaly. The material derived from eroded chimneys was deposited together with abundant glass fragments eroded from the volcanic edifice. The mass wasting was succeeded by deposition of volcaniclastic sediment containing dacite fragments, Ca plagioclase, pyroxene, glass shards, cristobalite, Si-rich amorphous material, alunite, pyrite, barite, and magnetite. The volcaniclastic sediment may have originated from hydrothermal eruptions at North Su and South Su. The present-day plume at Suzette is a likely source of rare barite aggregates, amorphous Cu-containing aggregates, and Cu-Fe sulfides creating geochemical anomalies of Ba and Cu in the uppermost sediments at Suzette. Interbedded volcaniclastic and hemipelagic sediments were retrieved east and west of SuSu Knolls. The enrichment of Mn in these sediments is considered to be a result of settling of Mn oxides from a hydrothermal plume.
Field Relationships and Geochemical Constraints on the Emplacement of the Jinchuan Intrusion and its Ni-Cu-PGE Sulfide Deposit, Gansu, China

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Abstract
Field mapping and petrological-geochemical investigation of the Jinchuan intrusion in north-central China clarifies how the intrusion was emplaced and provides a new model that explains how its large and rich Ni-Cu-platinum deposit deposits may have formed. The intrusion was emplaced into high-grade gneisses and marbles along a disconformity at the base of an overlying cover sequence, indicating that it was emplaced as a sill, not a near-vertical dike, as previously proposed. After emplacement the intrusion was rotated to its present orientation and deformed and metamorphosed under greenschist-facies conditions. Relative enrichment of incompatible trace elements coupled with negative U-Th and Nb-Ta anomalies in all samples from the intrusion provide evidence that the parental magma assimilated granitoid rocks in the lower crust. The presence of abundant marble xenoliths, now decarbonatized to diopside-rich skarns, and chemical indices such as high CaO/SiO₂ indicate that the magma assimilated carbonate on reaching its present site. This contamination may be linked to the formation of the Ni-Cu platinum ores. We propose that the assimilation of carbonate-rich fluids increased the oxygen fugacity of the magma and led to the segregation of metal-rich sulfides.
Platinum Group Element Geochemistry of Andesite Intrusions of the Kelian Region, East Kalimantan, Indonesia: Implications of Gold Depletion in the Intrusions Associated with the Kelian Gold Deposit

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Abstract

Nineteen andesite samples from the Kelian gold mine and two adjacent prospects, Magerang-Imang and Nakan, in East Kalimantan, have been analyzed for Cu, Re, Au, and the platinum group elements (PGE). The aim of the study was to use variations in PGE concentrations to test whether the chalcophile elements became enriched or depleted with fractionation in the igneous suites associated with the Kelian deposit. When the data are plotted on mantle-normalized chalcophile element diagrams, the patterns for the Magerang-Imang and Nakan suites are subparallel over a range of PGE concentrations of about 20 times. Pd/Ir ratios for Magerang-Imang hornblende andesites and Nakan pyroxene andesites are 15 to 54 and 60 to 129, respectively. The lower Pd/Ir ratios for the Magerang-Imang suite are due to a reversal in the slope of the mantle-normalized pattern between Ir and Os that is not seen in the Nakan suite. All PGE concentrations from both the Magerang-Imang and Nakan suites decrease with increased fractionation. Furthermore, all samples, which have not been subjected to strong alteration, are strongly depleted in Au relative to adjacent elements on mantle-normalized chalcophile element plots. Crosscutting relationships show that the gold mineralization at Kelian is younger than the associated Central and Eastern andesite intrusions, so they cannot be the source of the gold in the deposit. The gold was probably derived from slightly younger intrusions, similar in age to the adjacent Magerang-Imang hornblende andesites, which appear to be coeval with the mineralization and which are also depleted in gold. The subparallel PGE patterns preclude the depletion of Cu, Au, and PGE by sulfide fractionation, which would fractionate highly chalcophile PGE from less chalcophile Cu and Re. We suggest that the parallel Cu-Au-PGE patterns are due to mixing between a relatively mafic PGE-rich magma and a more felsic magma with lower PGE concentrations.
The Deposition of Elemental Gold from Gold(I)-Thiosulfate Complexes Mediated by Sulfate-Reducing Bacterial Conditions

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Abstract

The role of sulfate-reducing bacteria in the precipitation of elemental gold through a geologic stratum was investigated using column experiments. The mixed culture, dominated by sulfate-reducing bacteria, was isolated from the Driefontein consolidated gold mine, Witwatersrand basin, Republic of South Africa. Bacterially mediated gold precipitation from the gold(I)-thiosulfate complex was more efficient than the corresponding abiotic experiments. In the bacterial systems, sulfate-reducing bacteria (i.e., Desulfovibrio sp.) deposited gold inside the cells as spherical nanoparticles. Over time, these nanoparticles of gold were released from the cells and deposited at cell surfaces and in the bulk solutions. Ultimately, these nanoparticles of gold contributed to the formation of micrometer-scale octahedral gold crystals, occasional framboidal structures (~1.5-μm diam) and millimeter-scale gold foils, typically surrounding the silicate grains. Spherical gold particles (~1-μm diam) were precipitated in the abiotic experiments, and the formation of octahedral gold, framboidal structures and gold foils were not observed in these experiments. The reduction and enrichment of elemental gold by sulfate-reducing bacteria occurred without the concomitant death of the bacteria, suggesting that in natural systems, this process could go on over geologic time scales, as long as nutrients and gold(I)-thiosulfate were provided to the system.
THE SIGNIFICANCE OF CLATHRATES IN FLUID INCLUSIONS AND THE EVIDENCE FOR
OVERPRESSURING IN THE BROADLANDS-OHAAKI GEOTHERMAL SYSTEM, NEW ZEALAND

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Abstract

The Broadlands-Ohaaki geothermal system is host to an epithermal environment where gold-silver transport and deposition involves deeply derived fluids containing up to 3.3 wt percent CO₂ and 0.1 wt percent Cl. Earlier fluid inclusion investigations show that most microthermometric data reflect boiling and mixing in the upper 2 km of the system under modern P-T-X fluid conditions. Here we report the microthermometric results for a single quartz crystal from 1.259-m depth, well Br 25 in the upflow zone of the geothermal system that reveal the presence of clathrates upon freezing due to anomalous concentrations of CO₂ (7.9 to 14.3 wt %). These inclusions occupy the core of the quartz crystal and have homogenization temperatures from 291°C to >365°C, but the anomalous concentrations of CO₂ are likely artifacts of deep boiling and heterogeneous trapping of the resulting coexisting gas and liquid phases. Only a few fluid inclusions (Tb ~300°C, To of ~1.4°C to ~1.6°C), which lack clathrate, reveal more realistic conditions of early quartz precipitation from a modestly overpressured fluid (~140 bars) relative to the prevailing hydrodynamic boiling conditions (110 bars). Microthermometric data (Tb ~300°C, To of ~0.2°C to ~0.8°C) for fluid inclusions in a later formed overgrowth of the quartz crystal match the modern P-T-X conditions at 1.258-m depth in the well. The overall results of the study show that the clathrates are artifacts of two-phase trapping of steam and liquid and that the deep liquid became overpressured locally, probably due to mineral deposition and scaling of a permeable channel.
The Siscoe mine was one of the richest in the Val d’Or mining camp, producing 27.5 tonnes (t) of gold and 9.5 t of silver from 1928 to 1949. The C quartz-tourmaline vein at the Siscoe mine, which is the youngest auriferous vein on the property, is an excellent example of a high-grade Archean lode gold deposit; it contains an average of 45 g/t Au and locally up to 221 g/t Au. This vein cuts all foliations, the main regional foliation (S2), and several auriferous quartz-carbonate veins, and is interpreted to be a shear structure that formed during the development of a late- to post-D2 reverse fault. The vein comprises mainly alternating tourmaline- and quartz-rich layers, and gold occurs commonly in late fractures cutting the vein. The visible wall-rock alteration is characterized by the occurrence of tourmaline, pyrite, and calcite.

In this study, we report the Pb isotope compositions of hydrothermal pyrite separates taken from the C quartz-tourmaline vein and its wall rock. Pyrite is abundant in the wall rock, where it occurs as grains with inclusions of chalcopyrite, gold, tetradymite, pyrrhotite, rutile, silicates, and carbonates. In the vein, it forms euhedral generally devoid of inclusions. Locally, the euhedra are fractured, and the fractures are filled with native gold, calcite, and tetradymite. Textural relationships suggest that pyrite precipitated synchronously with and/or after gold in the wall rock, but predated gold in the vein. Pyrite separates from the vein and its wall rock yielded similar $^{207}$Pb/$^{206}$Pb, $^{208}$Pb/$^{206}$Pb, and $^{208}$Pb/$^{204}$Pb ratios (13.63–13.83, 14.53–14.62, and 33.42–33.76, respectively), which are more radiogenic than those reported for volcanic supracrustal and syneutogenic plutonic rocks of the southern Abitibi subprovince, but are very similar to those of the late- to post-tectonic S-type granites in the Pontiac Abitibi subprovince and Lacorne block. This suggests that the Pb originated from a reservoir similar to that of the magmas which produced these granites, or alternatively, that it was leached from the latter. The Pb ratios yield a model age of 2.57 ± 0.07 Ga, which is interpreted to date the cooling of the hydrothermal system that introduced and/or remobilized gold into the C quartz-tourmaline vein.

These results, when considered in the context of the evolution of the southern Abitibi, indicate that widespread hydrothermal circulation occurred between 2.64 and 2.55 Ga, after the collision of the Pontiac and Abitibi subprovince, and was caused by dewatering and S-type magmatism in the thickened unstable continental crust. This long-lived hydrothermal system promoted remobilization of gold from earlier veins and possibly introduction of gold from deeper zones, enhancing gold resources in the Siscoe deposit.
THE AGES OF THE KABANGA NORTH AND KAPALAGULU INTRUSIONS, WESTERN TANZANIA: 
A RECONNAISSANCE STUDY

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Abstract

The Kabanga North and Kapalagulu intrusions form part of a >500-km belt of intrusions within the Kibaran orogenic belt of central Africa. Some of the intrusions within the belt host important ore deposits, notably Ni sulfides at Kabanga and Ni laterites at Musongati and Kapalagulu. Despite the economic significance of the intrusions their ages have remained unclear. Here, we present SHRIMP II U-Pb zircon ages, interpreted as magmatic ages of crystallization, for the Kabanga North intrusion (1403 ± 14 Ma) and for the Kapalagulu intrusion (1392 ± 26 Ma). These data, along with other geochronological and petrological data, support a model of a broadly coeval and cogenetic suite of mafic-ultramafic intrusions throughout the Kibaran orogenic belt, from northwest Tanzania through Burundi, and possibly as far south as the Democratic Republic of Congo.