Mineralisation and geochemistry associated with the Dinkidi alkalic Cu-Au porphyry, Northern Luzon, Philippines

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Summary

The Dinkidi Cu-Au porphyry deposit is located in northern Luzon, Philippines (Fig. 1). The 110 Mt deposit is characterised by high gold grades (ave. 1.2 g/t Au and 0.5% Cu) and is one of only a few alkaline porphyry deposits discovered outside of British Columbia. The deposit is hosted within the multiphase Dinkidi Stock, which is in turn part of a larger alkaline intrusive body, the Didipio Igneous Complex. Whole rock chemistry indicates that the volcanic formations in the Didipio region become progressively more alkaline up stratigraphy, as a result of Late Oligocene rifting intermittently tapping a LILE-enriched mantle source that became progressively more enriched over time. Whole rock and mineral compositions indicate that all intrusions in the Didipio region were sourced from a common magma source, and were related by shallow level fractional crystallisation. High-grade gold mineralisation associated with the alkalic porphyry is linked to a calc-potassic style of alteration associated with the intrusion of a mafic dyke, whereas subsequent quartz-sericite-chalcopyrite alteration is linked with lower grade gold mineralisation. When compared with data from Tertiary rocks of the Baguio District the geochemistry and geochronology of Tertiary magmatism in northern Luzon is consistent with eastward-directed subduction along the western margin of the island arc with Dinkidi having formed in a back arc position.

Introduction

The Didipio Igneous Complex is associated with Late Oligocene to Early Miocene alkaline rocks of the Mamparang Mountains, a northern extension of the Caraballo Mountains that is exposed along the south-western margin of the Cagayan Valley Basin. The Dinkidi Cu-Au porphyry deposit has a resource of 1.8 Mt underground ore at 8.68 g/t Au and 1.28% Cu at a cut off at 5 g/t Au, combined with 600,000 tonnes from an open pit, at 1.92 g/t Au and 1.6% Cu, yielding 540,000 oz Au and 32,000 tonnes Cu. This rare occurrence of an alkalic porphyry system outside of British Columbia offers an opportunity to investigate the formation of an alkalic Cu-Au porphyry system and its relationship to the tectonic evolution of the Philippines arc.

Results

The Didipio Igneous Complex comprises an early dioritic series of clinopyroxenites, clinopyroxene-gabbros, clinopyroxene-diorites and clinopyroxene-monzodiorites that have been intruded regionally by a weakly-mineralised multiphase monzonite pluton (the Surong Monzonite), and by a series of strongly mineralised monzonite stocks at Dinkidi (Fig. 2). All of these units, and the surrounding volcanic rocks, are cut by thin, pyrite-bearing andesite dykes. The Dinkidi Cu-Au porphyry deposit is hosted within the multiphase Dinkidi Stock, which comprises four main intrusions that are, in order of emplacement: 1) The Tunja Monzonite, an equigranular monzonite stock 2) the Balut Dyke, a texturally variable clinopyroxene-syenite dyke 3) the Quan Porphyry, a monzonite to syenite porphyry stock and 4) the Bufu Syenite, a leucocratic, crystal-crowded syenite body. The intrusions of the Didipio region changed from early, comparatively large equigranular plutons that were emplaced with some degree of stoping, to later narrow, structurally-controlled porphyritic intrusions, followed by thin late-stage andesite dykes & sills. This change in intrusion morphology suggests that the overlying volcanic edifice was being activity eroded during the lifetime of magmatism.

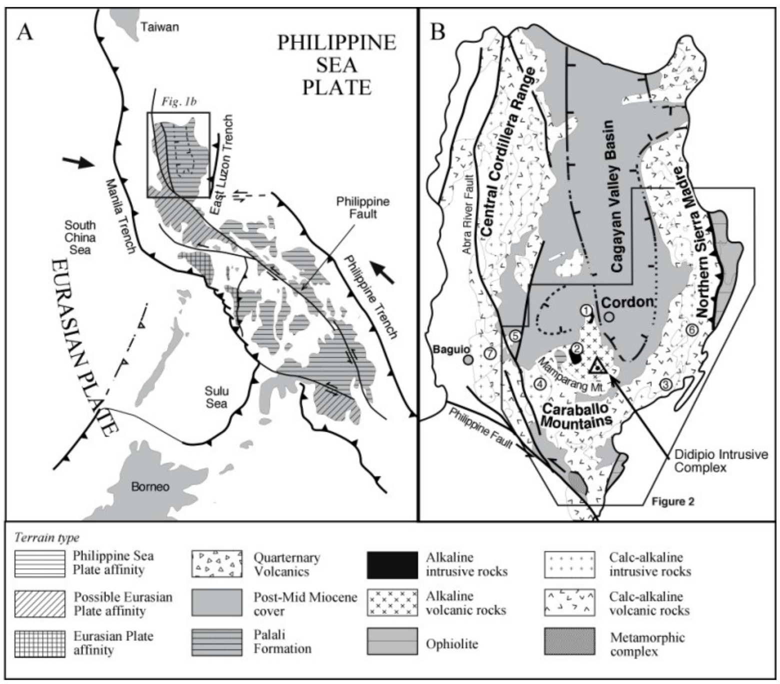

Figure 1: Tectonic setting of the Philippines (A) and physiographic domains of the Northern Luzon Terrain (B). Numbers: 1-Cordon Syenite Complex, 2-Palali Batholith, 3-Coastal Batholith, 4-Dupax Batholith, 5-Bokod Intrusions, 6-Northern Sierra Madre Batholith, 7-Central Cordilleran Diorite Complex (after Lewis and Hayes, 1983; Knittel, 1987; Ranglin, 1991 and Florendo, 1994).

Intrusive rocks of the Didipio area are characterized by elevated alkali contents and lie clearly within the trachybasalt to trachyte fields. Similarly on a plot of K_2O versus SiO_2, the Didipio samples lie within the shoshonite field. Coherent trends in whole rock major, trace and REE element chemistry and similarities in mineral chemistry are interpreted to indicate that the intrusions of the Didipio Igneous Complex were sourced from a single melt that underwent fractional crystallisation. The initial dioritic melt was already depleted in Mg, Cr, and Ni, indicating that substantial fractionation had already occurred prior to the emplacement of the diorite body in the shallow sub-volcanic environment.

The geochemistry and geochronology of the Tertiary magmatism in northern Luzon is consistent with eastward-directed subduction along the western margin of the island arc, supporting the findings of Queano *et al.* (2007). Our model contradicts previous workers who have invoked westward-directed subduction followed by an arc reversal (e.g., Solomon, 1990), the cause of which has been difficult to establish. Eastward subduction is consistent with new geochronological data that demonstrates that calc alkaline to alkaline magmatism in the Baguio District was broadly coeval with rift related magmatism in the Cagayan area (Hollings et al., 2010). This relationship is not consistent with westward subduction as it would place the Baguio District behind the back arc, whereas the geochemical data suggests that the Baguio District formed above the main arc (Hollings et al., 2010).

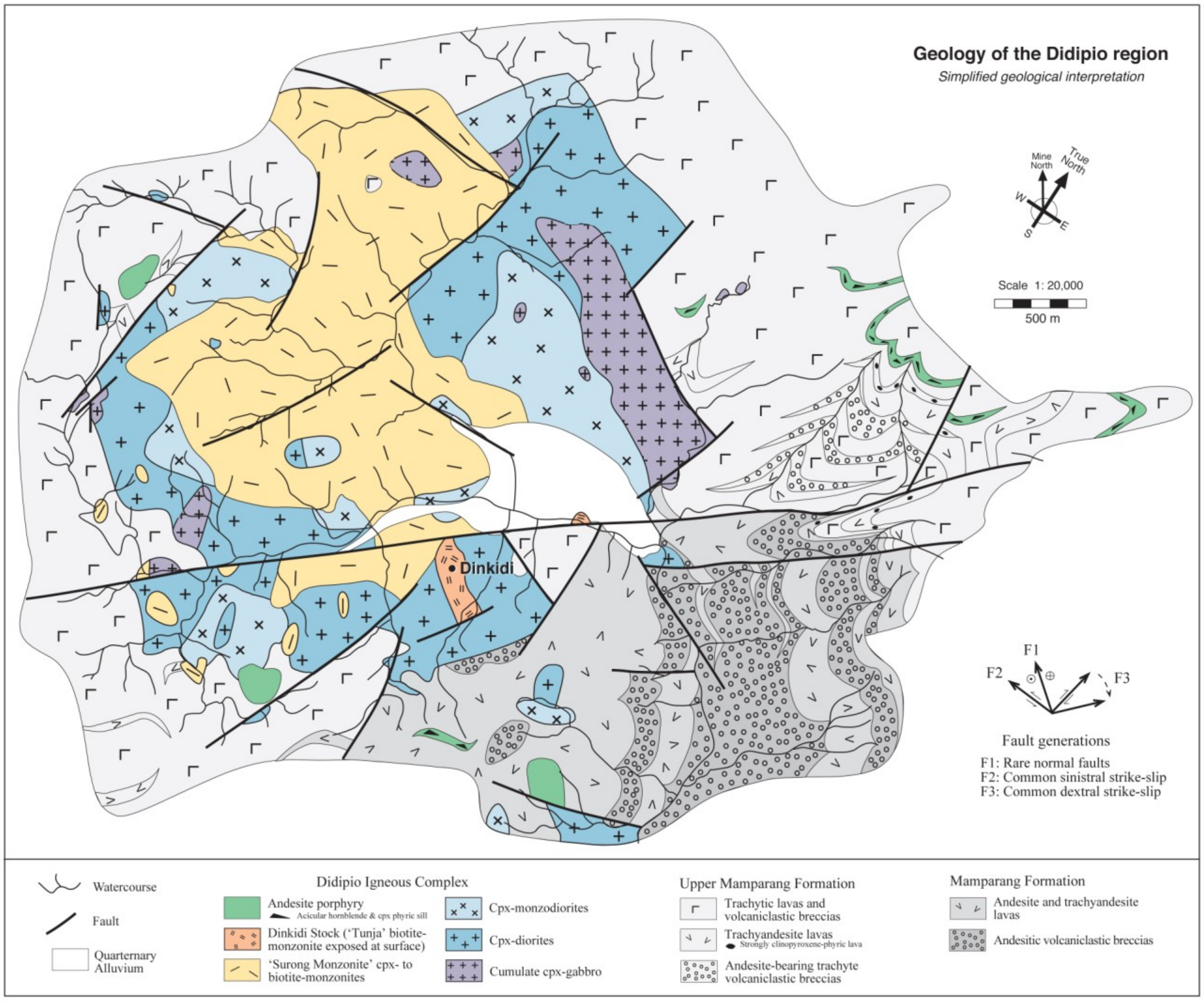

Figure 2: Geology of the Didipio region. Intrusive units of the Didipio Igneous Complex are shown in colour, volcanic units are in shades of grey. Both igneous and volcanic packages are highly simplified: monzonite, monzodiorite and diorite bodies are all comprised of multiple phases; 'lavas' are lava-dominated packages that contain multiple flows and interbedded volcaniclastic breccias.

At Dinkidi, emplacement of the Tunja Monzonite was temporally and spatially associated with the formation of a pervasive biotite-magnetite K-silicate alteration assemblage in the pre-mineralisation diorites. Whereas emplacement of the Balut Dyke (Stage 2) was associated with a diopside-actinolite-K-feldspar-bornite calc-potassic style alteration assemblage and associated vein stockwork. This quartz-free mineral assemblage is associated with high gold grades (2-8 g/t Au) and is typical of alteration assemblages found in quartz undersaturated alkaline porphyry systems. Intrusion of the Bufu Syenite led to the formation of a quartz-sericite-calcite-chalcopyrite stockwork vein and alteration assemblage (Stage 3), which has overprinted the calc-potassic assemblage. The quartz stockwork hosts the bulk of low grade mineralisation (0.5-

3 g/t Au; 0.5-1% Cu) at Dinkidi and is typical of silica saturated alkaline porphyry systems. A coarse-grained assemblage of quartz-actinolite perthite (the 'Bugoy Pegmatite') formed as an apophysis on the Bufu Syenite, and was subsequently brecciated by late-stage faulting. Mineralisation associated with the regional argillic alteration assemblage (Stage 4) consists of a 'high sulfidation' quartz-pyrite assemblage and a 'low sulphidation' quartz-calcite assemblage. 'Low sulfidation' veins are typically 10-70 cm thick, and have crustiform textures. The veins are dominated by quartz and chalcedony and contain local patches of silicified bladed calcite and sub-economic Au-Ag grades.

The calc-potassic assemblage is inferred to have formed at temperatures in excess of >600°C from a silica-undersaturated K-Ca-Fe brine. Fluid inclusion studies indicate that the quartz stockwork was emplaced at submagmatic temperatures (<600°C) from a quartz-saturated Na-K-Fe brine (>68 wt.% eq. NaCl) that contained up to 0.6 wt.% Cu and 4 wt.% Fe. Cooling to ~420°C and neutralisation by wall rock interaction lead to the precipitation of sulphides within the quartz stockwork. The quartz-bearing assemblage was emplaced at 2.9 to 3.5 km paleodepth, and was associated with periods of overpressurisation and quartz growth disrupted by episodic depressurisation to near hydrostatic conditions.

Conclusions

The Dinkidi deposit is hosted in alkaline to potassic rocks with geochemical signatures (low TiO_2 and HFSE; high Al_2O_3), indicative of the final LILE-enriched end product of island arc magmatism. The alkaline rocks are interpreted to have been sourced from the partial melting of the mantle wedge above the stalled, and dehydrating, Eurasian Plate. The alteration and gold mineralisation associated with the intrusion of alkalic porphyries in Luzon is similar to that associated with the alkalic porphyry systems of British Columbia.

Acknowledgements

Climax Mining is thanked for allowing this study on the Dinkidi Porphyry deposit, and for providing the logistical and financial support for this study. The assistance of Ulrich Knittel from the University RWTH-Aachen in Germany is also gratefully acknowledged.

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