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Geological Framework and Evolution of the Saindak Porphyry Cu-Au Deposit, Chagai District, Balochistan, SW Pakistan

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The Saindak porphyry-type Cu-Au deposit, located in southwest Pakistan at the junction of three countries—Iran, Afghanistan, and Pakistan—is the first discovered porphyry-type Cu-Au deposit in Chagai magmatic belt of the Tethyan metallogenic belt. It is an arc structure curving southward, formed by the underthrusting extrusion of the southwest Arabian plate beneath the Eurasian plate. The Chagai belt hosts several porphry copper deposits (PCDs), including the giant Reko Diq, Dasht-a-kain, and Sorbarot prospects. In Saindak, there are a series of Tertiary sandstone, mudstone, and intermediate-basic volcanic rocks, mainly from intermediate-basic volcanic eruption and magmatic intrusion of the calc-alkaline series. Three tonalite porphyry clusters emplaced during the lower Miocene into a Late Cretaceous-Oligocene volcanosedimentary succession are dominated within the orebodies by Oligocene siltstone. The East-South-North porphyry centers, with inferred resources of 412 Mt at 0.450% Cu and 0.34 g/t Au, are characterized by a strong to weak potassium silicate zone surrounded by sericitic (quartz-sericite-pyrite) and outer propylitic (chlorite-epidote) alteration. Mineralization is hosted in the quartz diorite, diorite, and andesitic intrusions and is associated with hydrothermal alteration. The alteration zoning and mineralization are highly controlled by wall-rock lithology tectonic condition characteristics, potassium silicate alteration largely formed within the South-East clusters, and mineralization occurs as disseminated to stockwork styles. U-Pb zircon geochronological data, combined with published U-Pb ages from quartz diorite porphyry intrusions at Saindak, indicate the emplacement of three porphyry Cu-Au centers in the Miocene (~22.02 Ma). Intrusive events in the South-East porphyry cluster began with emplacement of quartz diorite with the low grade of the North porphyry Cu center from 22.02 ± 0.16 to 22.50 ± 0.26 Ma, and the active magmatism peak is more concentrated (crystallization time <0.5 Ma). From the tested data, there is partial zircon Pb loss, but the next intersection of the isotope Pb zircon age is more consistent, and thus does not affect accuracy. Meanwhile, the Pb isotope composition of magmatic zircons basically has a more consistent evolution curve, showing ancient shale formation lead product evolution, reflecting the PCD ore source regions with distinct characteristics of the shell source. Geochemical analysis suggests that rocks of the South orebody represent a shallow mantle source (~50 km) typical of calc-alkaline porphyry deposits. Major and trace element geochemistry show that the enrichment ratio of most incompatible trace elements and REE relative to N-MORB is greatly enhanced, including Zr/Y, Ti/V, Ta/Yb, Th/Yb, La/Yb, and Th/Yb, indicating that the parent magma of both the volcanic groups was derived from an enriched sub-arc mantle source. Overall, the geological framework dataset for the three porphyry intrusive centers suggests short-lived magmatic systems characterized each center, and the available data suggest there is much potential for associated hydrothermal systems at the Saindak.