

## **Petrogenesis of the Saindak Porphyry Cu-Au Deposit, Chagai District, Balochistan, SW Pakistan: Evidence from Petrology, Geochemistry, U-Pb Geochronology and Hf Isotopes**

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The Saindak porphyry Cu-Au deposit is located in the western Chagai arc in the central Tethyan metallogenic belt of Pakistan. It is spatially and temporally associated with medium-K calc-alkaline quartz diorite intrusions, formed in early Miocene, and is surrounded by Oligocene andesitic volcanic and siltstone country rocks. Detailed geological relationships, petrography, geochemistry, and geochronology indicate that the intrusive rocks at Saindak deposit are closely associated with tonalite porphyry (quartz diorite porphyry), including three intrusive phases comprising quartz diorite porphyry, early granodiorite, and diorite porphyry. The quartz diorite intrusive phase is characterized by hornblende, biotite, magnetite, quartz, and plagioclase and shows porphyritic textures. It is intensely altered and hosts veins and disseminated Cu-Fe-sulfides. Alteration assemblages are zoned surrounding the Saindak porphyry intrusions from strong to weak potassic, sericitic, and propylitic zones.

Precise U-Pb geochronology, Hf isotope compositions, and trace element distributions in zircon are combined to provide constraints on the petrogenesis and petrochemical evolution of the intrusions associated with the Saindak deposit. New LA-ICP-MS zircon U-Pb dating reveals that ore-bearing magmatism occurred over a period of less than 1 m.y. Initial quartz diorite was emplaced at  $22.54 \pm 0.39$  Ma, followed by early granodiorite at  $22.29 \pm 0.34$  Ma, then quartz diorite porphyries at  $22.17 \pm 0.21$  Ma, and finally to hornblende-biotite  $\pm$  magnetite rock at  $22.06 \pm 0.15$  Ma. All these phases were overprinted by strong potassic to sericitic alteration with Cu-Au and minor Mo mineralization, and this was followed by intrusion of late barren diorite and andesitic porphyry dikes with minor pyrite. In situ Hf isotopic studies on zircon using LA-MC-ICP-MS show that  $\epsilon_{\text{Hf}}(t)$  values of zircon from the quartz diorite samples vary from +4.8 to +6.2 with an average of +4.3, and the Hf data indicate partial melting of mantle components. Intrusions at Saindak with strong to weak potassic alkali-rich characteristics are enriched in LREEs and LILEs and depleted in HREEs. Thus they suggest a shallow mantle source for the magma associated with the calc-alkaline porphyry deposit. These rocks also have variable abundances of  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  with high values for MgO contents, consistent with high magnesium basalt. The  $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$  vs.  $\text{P}_2\text{O}_5/\text{Al}_2\text{O}_3$  plot indicates the effects of hydrothermal K-silicate alteration ( $\text{K}_2\text{O}$ -enrichment) in the early intrusions based on drill core samples and petrographic thin section studies. The hydrothermal fluids in the potassic alteration zone caused the destruction of plagioclase and led to the removal of Sr as indicated by the depletion of Sr content with increasing loss on ignition (LOI) that is apparent in the early mineralized porphyry intrusions. These features suggest that the parent magmas have been directly derived from the partial melting of a sub-arc mantle source.