# Lagunas Norte, La Libertad, Northern Perú: The Metallogenetic Setting of a Major High-Sulfidation Epithermal Au Deposit

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Lagunas Norte (latitude 7° 56′30″ S; longitude 78°14′50″ W), with an oxide reserve of over 13 Moz Au, is the sole demonstrably economic member of a cluster of lower Miocene (16.3–17.7 Ma) high sulfidation epithermal systems associated with the late stages of subaerial Calipuy Supergroup volcanism in the Alto Chicama district. The metallogenetic relationships of this segment of the Pierina (Huaraz)-Yanacocha gold belt are established through integrated petrochemical analysis and $^{40}Ar/^{39}Ar$ dating ($n$ = 81), complementing 1:20,000 geologic and landform mapping of a 400-km$^2$ area surrounding the deposit.

Hydrothermal activity was a product of andesitic to dacitic magmatism recording the initial stages in a regional transition from "normal arc andesite-dacite-rhyolite (ADR)" (hornblende-mediated middle rare-earth element [REE] fractionation; Sr/Y ≤ 40) to high-silica adakitic (garnet-mediated heavy REE fractionation; Sr/Y ≥ 60) chemistry, inferred to reflect melting of a deepening lower crust (≥35–40 km). Crustal thickening, assigned to the Quechua I compressive orogeny, was responsible for the incision of a network of synmineralization, steep-walled, valley pediments (Río Chicama system) into the 25 to 26 Ma Pampa la Julia pediplain generated through Aymará compression. The estimated δD and $\delta^{18}O$ values of meteoric water incorporated in hypogene alunite, montmorillonite, and dickite indicate that local paleo-elevations increased abruptly from ~1,000 to ~2,000 m.a.s.l. during mineralization (16.5–17.4 Ma), whereas supergene oxidation in the late Miocene occurred at elevations as high as 3,500 m.a.s.l. The upper Oligocene, Aymará-age, Tres Cruces low sulfidation Au-Ag epithermal center (25.3 Ma; 1.7 Moz Au) and the large La Arena porphyry Cu-Au-Mo deposit (25.8–26.1 Ma) were associated with normal-arc ADR intrusive activity and formed at low altitude (~500–1,000 m.a.s.l.). The Lagunas Norte deposit was unambiguously emplaced ca. 2 m.y. before subduction of the aseismic Nazca Ridge at this latitude.

The Alto Chicama district lies on the northern margin of a ~20-km-wide, ENE-striking tectonic corridor—the Alto Chicama-Patáz cross-strike discontinuity (CSD). This has constituted a structural high at least since the mid-Cretaceous, when it delimited the northern extent of basaltic volcanism in the Casma Basin and overlay an anomalous deep-lithospheric mantle environment recorded by a small, 105 Ma, ultramafic lamprophyre (aillikite) intrusion adjoining the Lagunas Norte deposit. The strike and plunge of thin-skinned Incaic II (≥46 Ma) structures of the Marañón fold-and-thrust belt exhibit strong dextral offsets across the northern boundary of the CSD, a pattern reflected at Lagunas Norte by a transfer fault which nucleated an intense restraining bend-related pop-up (flower) structure that channeled the considerably younger mineralization during Quechuan reactivation of the Incaic structures.

In comparison to multideposit central Andean Au subprovinces such as Yanacocha and El Indio–Pascua-Lama–Veladero, fertile high sulfidation epithermal activity in the single-deposit Alto Chicama and Huaraz districts occurred over more restricted time spans (1–2 vs. 4–5 m.y.); earlier in the Miocene history of crustal thickening and, hence, at lower altitudes (~1,000–2,000 vs. 2,000–4000 m.a.s.l.); at the outset, rather than following, the transition to adakitic magmatism; and before, rather than during, aseismic ridge/plateau subduction, slab flattening, and arc failure. They share, however, a restriction to long-lived cross-strike discontinuities.

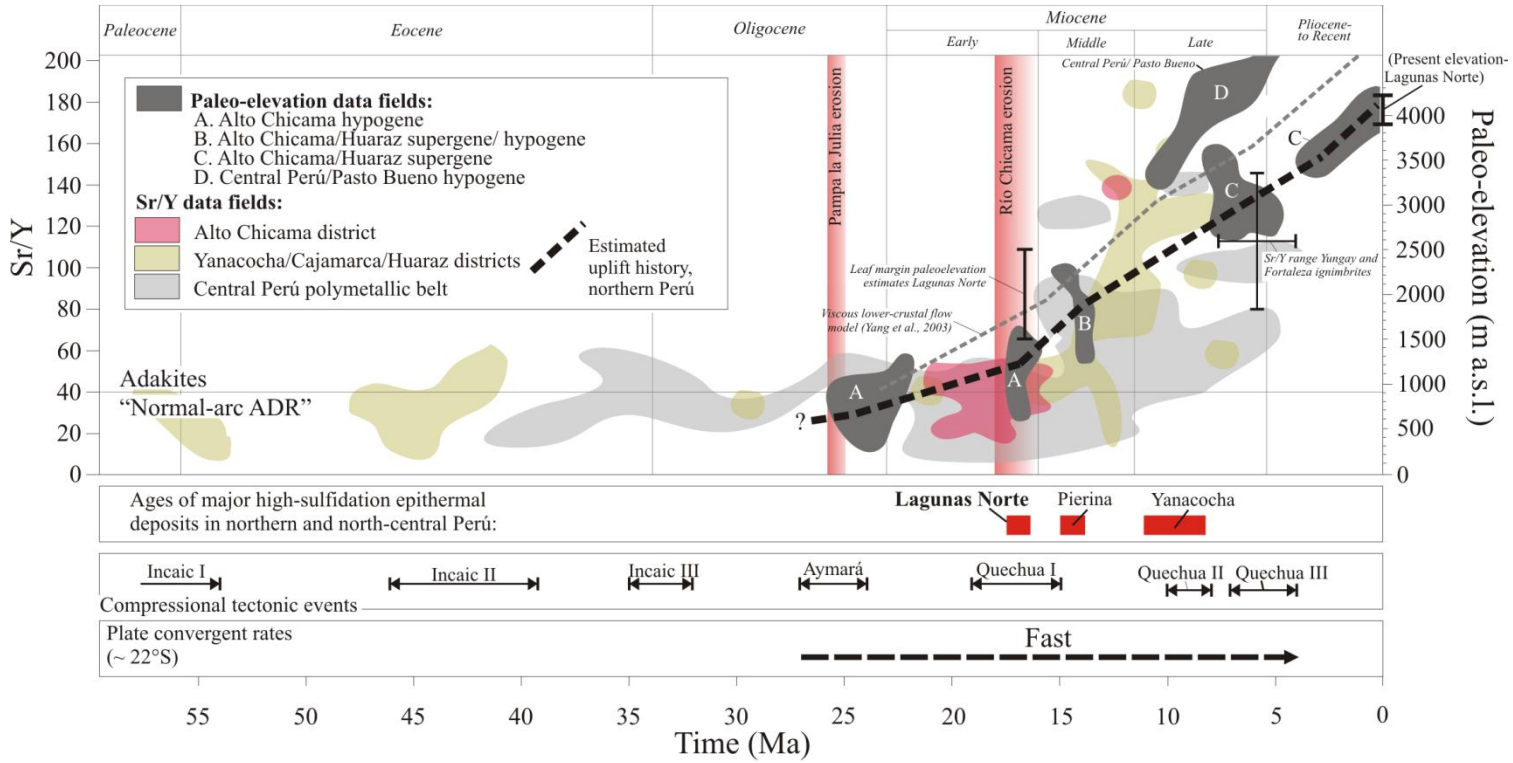


Fig. 1. Estimated late Oligocene through late Miocene stable isotope-based paleo-elevations, northern Perú, and Paleocene to Pliocene Sr/Y geochemistry of Calipuy Supergroup and younger/older magmatic events, northern and central Perú. Data have been compiled from this study (Alto Chicama) as well as studies from the Huaraz district (Strusievicz et al., 2001; Rainbow et al., 2006; Rainbow, 2009), central Perú, and Pasto Bueno (Landis and Rye, 1974; Rye and Sawkins, 1974; Kamilli and Ohmoto, 1977; Norman and Landis, 1983; Campbell et al., 1984; Deen et al., 1994; Bissig and Tosdal, 2009), Yanacocha/Cajamarca district (Davies, 2002; Longo, 2005; Chiaradia et al., 2009), and Yungay and Fortaleza ignimbrites (Coldwell, 2011). Tectonic events referenced from Noble et al. (1990) and Sébrier et al. (1988) and plate convergence data from Somoza (2005).