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Behavior of amagmatic geothermal systems: A geochemical and geophysical study of the Agua Blanca Fault, Baja California, Mexico

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Amagmatic orogenic geothermal systems (AMOGS) hosted by steep regional faults in mountain chains are promising renewable energy resources for electricity production. However, quantitative assessment of their potential requires more fundamental insights into the thermal–hydraulic–chemical–mechanical processes controlling their behavior. To better understand these processes, we have conducted geochemical and geophysical studies of seven geothermal systems situated along a 90 km segment of the Agua Blanca Fault in Baja California, Mexico. Waters discharge from these systems at temperatures up to 102 °C (Figure), even though magmatic activity is absent in the region. Solute concentrations and stable isotopes indicate that the thermal waters originate from meteoric recharge at high altitudes (730–1340 m). The resulting high hydraulic head gradients, in conjunction with hydraulic connectivity along 10–20 km lengths of the fault, drive infiltration down towards the brittle–ductile transition at 12–18 km depth, as evidenced by waning of seismicity. The waters acquire salinity along their flow path via water-rock interaction and local mixing with seawater, and their temperatures rise according to the local geothermal gradients (15–24 °C/km). Discharge temperatures correlate inversely with water residence times (inferred from aqueous ^{4}He concentrations) and with ^{3}He concentrations, implying that high upflow rates along permeable structures are a key control on the behavior of the systems. Coupled 3D thermal–hydraulic simulations carried out with TOUGHREACT reveal that thermal waters reach the surface with temperatures up to 100 °C only where permeable upflow zones coincide spatially with the highest hydraulic head gradient below valley floors or at the coast. Such permeable upflow zones along faults control the location, shape, and magnitude of the resulting thermal anomalies in AMOGS. In conclusion, this study demonstrates that under ideal conditions, the temperature threshold for electricity production (120 °C) can be reached in the shallow subsurface of AMOGS. Therefore, geothermal exploration along prospective orogenic faults elsewhere should aim to recognize these conditions and then characterize the underlying thermal anomalies.

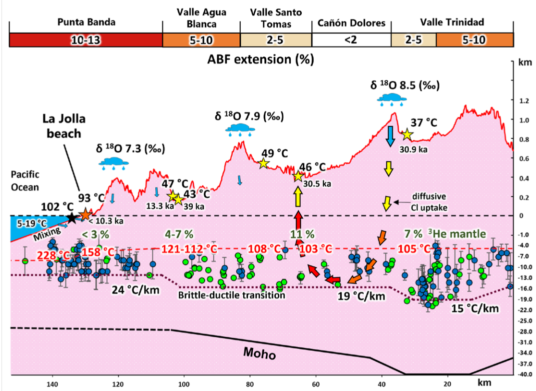

Figure. Conceptual fault-parallel model of amagmatic geothermal systems (stars) along the Agua Blanca Fault, including earthquake hypocenters, Moho depth, and fault extension from the literature.