Comment on "Applied geophysics to morphostructurally characterize a hydrothermal system: La Laja, San Juan (Argentina)" by Sottile *et al*. (2026), Andean Geology 53(1): 113-135

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The contribution by Sottile *et al*. (2026) represents a valuable addition to the understanding of the La Laja system (San Juan, Argentina), particularly through the integration of geophysical, structural and geomorphological data. The identification of structurally controlled permeability and reservoir architecture provides an important framework for interpreting fluid circulation.

In this context, it may be useful to further refine the classification of the La Laja system. While the authors refer to it as a hydrothermal system, the available evidence appears to be more consistent with a **low-temperature geothermal system**.

This distinction is not merely semantic, as it involves differences in heat sources, fluid origin, and hydrological functioning. The term "hydrothermal system" encompasses a broad range of geothermal settings, including both magmatically driven systems and those controlled by regional heat flow and hydrogeological circulation (Hochstein, 1990; Dickson and Fanelli, 2004; Sowiżdżał, 2022). In contrast, low-temperature geothermal systems are typically characterized by conductive or conduction-dominated heat transfer, meteoric-dominated recharge, and structurally controlled flow paths, commonly linked to regional groundwater circulation systems and relatively low enthalpy conditions (Ingebritsen *et al*., 2006; Moeck, 2014; Jalilinasrabady *et al*., 2022).

The geophysical and morphostructural results presented by Sottile *et al.* (2026), particularly the role of active faults in controlling permeability and the apparent lack of association with shallow magmatic bodies, are consistent with this interpretation. This view is also in agreement with previous studies (e.g., Orozco Chirino *et al*., 2021), that interpret La Laja as a system where meteoric waters infiltrate at higher elevations, circulate at depth, and are heated under regional geothermal gradients before ascending along structural pathways through the largely Paleozoic and Cenozoic sedimentary pile of the Precordillera, including a thick section of Cambrian and Ordovician carbonates (Astini *et al*., 2005). The regional geodynamic context further supports this interpretation. The La Laja system is located within the Pampean flat-slab segment, where arc magmatism was largely suppressed since the Miocene, and any residual magmatic activity was spatially displaced to the east (e.g., Kay and Mpodozis, 2002; Ramos *et al*., 2002).

Clarifying this distinction is particularly relevant when considering travertine-forming systems, which can be interpreted in terms of two end-member models: volcanic-hydrothermal and artesian-karstic. However, these systems are better understood as the result of three partially decoupled controls: (1) heat source (magmatic vs. geothermal), (2) CO_2 source (mantle, crustal, or biogenic; e.g., Kerrick, 2001), and (3) hydrological regime (meteoric vs. deep circulation).

Recognizing La Laja as a low-temperature geothermal system has important implications. It supports a model dominated by regional hydrology and structural control, rather than magmatic input, and provides a more consistent framework for interpreting fluid sources, CO_2 origin, and travertine deposition. In this context, travertine distribution and dispersal patterns are expected to be primarily controlled by structural pathways and basin-scale hydrology, which, in turn, influence the spatial organization of facies and the resulting heterogeneity of carbonate accumulations (e.g., Pentecost, 2005; Gandin and Capezzuoli, 2014; Mors *et al*., 2019; Astini *et al*., 2025).

In addition, the travertine system at La Laja displays a wide range of mound morphologies (Astini *et al*., 2016; also see figures 5, 7, 9 and 10 in Sottile *et al*., 2026), which may provide further insights into the underlying hydrodynamic and structural controls. Field observations indicate the coexistence of conical subaerial mounds with high aspect ratios and relatively stable central vent positions, as well as broader, low-relief, discoidal bodies with depressed central areas that likely functioned as shallow pools with subaqueous precipitation.

Such morphological variability has been shown to reflect differences in discharge rate, fluid pressure, vent stability, and self-sealing processes driven by carbonate precipitation (e.g., Luo *et al*., 2022). In this context, the integration of geophysical data with detailed morphological and sedimentological observations could help constrain the controlling parameters of mound growth, including the role of structurally focused flow, temporal variability in discharge, and feedback mechanisms between permeability and precipitation. This approach may provide a valuable pathway to link subsurface structure with surface expression in geothermal travertine systems. This has direct implications not only for the understanding of depositional architecture, but also for the evaluation of travertine bodies as industrial carbonate resources (dimension stone and related applications), where facies distribution, porosity, and diagenetic overprint determine their quality and exploitability.

On a broader scale, the same controls govern the spatial organization of facies and the resulting heterogeneity of carbonate accumulations, which are widely used as analogues in reservoir characterization (e.g., Claes *et al*., 2015; Della Porta, 2015; Ronchi and Cruciani, 2015; De Boever *et al*., 2016). In these systems, permeability architecture reflects the interplay between fluid flow, degassing, and accommodation space, leading to strong facies-controlled heterogeneity and multi-scale variability in petrophysical properties (Lucia, 1999; Mancini *et al*., 2019).

This perspective also provides a useful framework to further explore the architecture of the feeding system (plumbing system) and its role in controlling the spatial distribution and dispersal of surface depositional products. In particular, it enables a more robust genetic interpretation of the facies mosaic, linking fluid pathways, degassing processes, and accommodation space to structurally controlled discharge zones. These aspects appear to be closely tied to geophysical signatures associated with active fault systems, highlighting the broader implications of the results presented by Sottile *et al*. (2026). It also has practical implications for resource assessment and hazard evaluation, as low-temperature systems differ significantly from magmatically driven hydrothermal systems in both geothermal potential and associated risks (Dickson and Fanelli, 2004). In contrast, magmatic-hydrothermal systems are more commonly associated with metal transport and deposition due to higher temperatures and more intense fluid–rock interaction, and therefore have a greater potential for ore-forming processes (e.g., Robb, 2005; Simmons *et al*., 2005). Recognizing the geothermal (non-magmatic) nature of La Laja thus constrains both its economic potential and its genetic interpretation.

Building on the valuable geophysical and morphostructural framework provided by Sottile *et al*. (2026), further integration with complementary datasets could help refine the conceptual model of the La Laja system. In particular, the incorporation of hydrogeochemical and isotopic tracers (e.g., $\delta^{13}C–CO_2$, $\delta^{18}O–H_2O$) would allow better constraining fluid sources, residence times, and fluid–rock interaction processes (e.g., Kerrick, 2001; Ingebritsen *et al*., 2006). Likewise, detailed sedimentological and facies analysis of associated travertine deposits currently under study could provide independent insights into fluid pathways, degassing dynamics, and the spatial organization of depositional systems.

The present perspective highlights the importance of integrating geothermal systems within broader basin-scale hydrological models, particularly in arid regions such as San Juan, where groundwater circulation and structural controls play a dominant role. Integrating the structural framework with basin-scale hydrogeological models would contribute to a more comprehensive understanding of recharge areas, circulation depths, and discharge patterns, particularly in the context of the arid Andes. Such an approach may help bridge geophysical observations with surface expressions and improve the predictive understanding of similar systems in the region.

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