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Trachyandesite of Kennedy Table, its vent complex, and post–9.3 Ma uplift of the central Sierra Nevada: Comment

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INTRODUCTION

Hildreth et al. (2021) analyzed a set of table mountains near the San Joaquin River that are capped by a 9.3 Ma trachyandesite lava flow and concluded that, since the deposition of the volcanic rocks, the table mountains have been tilted 1.07° due to uplift of the central Sierra Nevada. While Gabet (2014) suggested that, under a limited set of conditions, the size of fluvial gravels under the table mountains would support the hypothesis of postdepositional uplift, the authors claimed that their evidence is more definitive. In addition, the authors proposed that the central Sierra Nevada tilted as a rigid block. However, their analyses rely on inferences and assumptions that are not supported by field evidence.

TILT CALCULATIONS

As Hildreth et al. (2021) noted, the tilt estimate determined from the slope-azimuth relationship (their fig. 6B) of the trachyandesite-capped surfaces of McKenzie Table and Table Mountain is only valid in the case where the lava flow followed a meandering channel (Fig. 1). If these two mesas are, instead, remnants of a much broader sheet-like lava flow, their slope-azimuth relationship is simply a consequence of geometry, whereby the slope (ϕ) of any line drawn with an azimuth α across a plane inclined at an angle θ is calculated as $\phi = \theta \cos \alpha$, where $\alpha = 0$ along the dip of the plane. The tilt results in Hildreth et al., therefore, depend entirely on the interpretation that the trachyandesite flow followed the course of a meandering channel. Several observations challenge this interpretation.

(1) Hildreth et al. (2021, 8th page) concluded that, in the study area, "the river flowed in a moderately incised channel (20–40 m) across a relatively smooth and extensive alluvial plain" and that "the trachyandesite clearly flowed down the low points in the landscape." If so, the elevation of the contact between the alluvial gravels and the trachyandesite flow at McKenzie Table and Table Mountain should be 20–40 m lower than that at nonchannel locations. However, a cross section through Perkins West Table and Table Mountain shows the opposite: The gravel-trachyandesite contact at Table Mountain is ~50 m higher than that at Perkins West Table (Fig. 2). Adjusting the elevations according to azimuth to account for the hypothesized tilt still places the contact at Perkins West Table ~35 m below the contact at Table Mountain. Therefore, the gravels at Table Mountain were not at a low point in the landscape; instead, the gravel surface underneath Table Mountain appears to have been a terrace, with the late Miocene San Joaquin River flowing in a depression to the west of the terrace. (Note that the gravel deposits at Perkins West Table do not represent a tributary to the channel as water cannot flow uphill.)

(2) A topographic profile across McKenzie Table and Table Mountain strongly suggests that these features are remnants of a broader lava flow that advanced down the regional slope (Fig. 3).

(3) For most of McKenzie Table's perimeter, the trachyandesite was deposited directly onto bedrock, not fluvial sediment (Bateman and Busacca, 1982). Moreover, at the southern end of McKenzie Table, the bedrock-gravel contact along the northern "bank" of the hypothetical channel is ~35 m higher than the bedrock-trachyandesite contact at the opposite "bank" (Fig. 4). A river with nearly 20 m of sediment on one side of the bed and a 35-m-deep bedrock depression, devoid of sediment, on the opposite side (implying 55 m of relief) would be unusual. Moreover, what material would have formed the bank that confined the flow at the 100 m gap between McKenzie Table and Table Mountain in Figure 4? The bank would not have likely been composed of fluvial sediment, since none has been mapped between the trachyandesite and the bedrock in the gap. Perhaps a thin bedrock fin jutted up? If so, how could this bedrock fin have resisted erosion over a long period of time before the lava flow, only to be completely eroded away despite being protected by the trachyandesite deposits? The simplest explanation is that McKenzie Table and Table Mountain are remnants of a broader lava flow that buried a patchwork surface of gravels and bedrock, and erosion has since removed the trachyandesite that once filled the gap.

(4) Hildreth et al. argued that the formation of McKenzie Table and Table Mountain by lateral erosion would have had to been "extraordinarily fortuitous." However, their planform shapes can be explained by commonplace erosional processes. The concave western edges of McKenzie Table and Table Mountain have been formed by the expansion of watersheds that debouch into the San Joaquin River; ravines along the rims of these watersheds are signs of active erosion (Fig. 1), and arcuate watershed boundaries are typical in many landscapes (e.g., lat, long: 37.24355°N, 111.16562°W). With respect to the eastern edges of McKenzie Table and Table Mountain, preferential erosion along a lineament aligned with the structural grain appears to have formed the alcove between the two tables (Fig. 1). Finally, C-shaped ridges not formed by topographic inversion can be found elsewhere (e.g., lat, long: 36.91813°N, 111.23375°W).

(5) Hildreth et al. compared the planforms (e.g., meander wavelength) of McKenzie Table and Table Mountain to the modern San Joaquin River to support their hypothesis that the trachyandesite flow followed a river channel. Planform shape, however, varies according to many factors, including discharge, storminess, bank strength, and sediment load (e.g., Schumm, 1967; Stark et al., 2010). Thus, even if the stratigraphic evidence supported the channel hypothesis, a quantitative comparison of the planforms would first have to control for differences in these factors since they would

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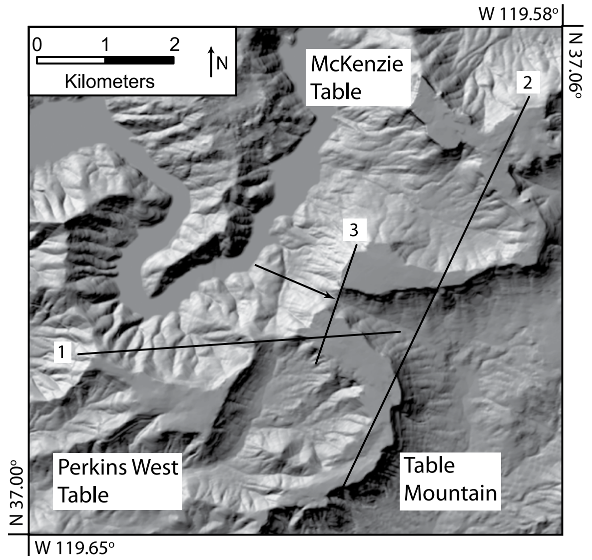

Figure 1. Hillshade map of study area derived from a 10-m-resolution digital elevation model (DEM; U.S. Geological Survey, 2019). San Joaquin River is in the northwest corner. Arrow points to a lineament aligned with the structural grain. Lines 1, 2, and 3 refer to cross-section locations in Figures 2, 3, and 4, respectively.

have formed under different climates. Moreover, a comparison between the modern San Joaquin River and the channel hypothesized by the authors is clouded by the fact that the former is a bedrock river, while the latter would have been an alluvial river; important differences in the patterns and behaviors between bedrock and alluvial rivers have been extensively documented (Bierman and Montgomery, 2020). Finally, the authors used a study of alluvial rivers, that by Leopold and Wolman (1957), to make inferences about the modern San Joaquin River, which is a bedrock river. (Note that Gabet [2014] demonstrated that the meanders in the modern San Joaquin River were not inherited.)

EVIDENCE FOR A RIGID BLOCK

Hildreth et al. (2021) offered two lines of evidence to support the claim that hypothetical tilting at the table mountains would have extended across the width of the range due to rigid-block behavior. First, they found that a straight line approximately intersects the trachyandesite-capped table mountains and the vent that produced the lava (the black line on their fig. 7B), and they posited that the lava followed a river with a uniform slope (i.e., low convexity) across this distance. However, the ~70 km gap between the vent and the nearest trachyandesite deposit indicates that the 95 km straight line is mostly unconstrained by field evidence (and the absence of fluvial gravels associated with the 10.8 Ma volcanic deposit at km 59 on their figure 8B implies that it was not deposited on or near a river). The authors note that uniform slopes are common in the lower reaches of rivers; while this may be generally true for large alluvial rivers, it is not true for bedrock rivers, especially in the granitic Sierra Nevada, where lithologic and structural controls have a dominant influence on channel slope (Gabet, 2020) (note that the Kern River, which follows a fault, is a notable exception). Indeed, gradients vary widely along the hypothetical ancient San Joaquin River profile that Matthes (1960) proposed for the "outer valley," a feature used by the authors to argue for rigid-block uplift (see below). Finally, the irregular longitudinal profile of the modern San Joaquin River (shown in their fig. 7B) challenges the likelihood of a straight profile for the late Miocene San Joaquin River, while an infinite number of more plausible (i.e., not straight) lines could be drawn linking the lower trachyandesite deposits to the vent.

Second, the authors presented the longitudinal profile of the "outer valley," a hypothetical erosion surface that parallels the modern San Joaquin River (Matthes, 1960), and proposed that the lack of deformation of this profile is evidence for rigid-body tilting (their figs. 8A and 8B). However, the jagged profile of this hypothesized "outer valley" indicates that this feature is not a continuous erosional surface; while the dips in the profile could be attributed to recent incision of San Joaquin River tributaries, the presence of many ridges intersecting what was, supposedly, a hydrologically connected feature limits the utility of this hypothesized surface for detecting deformation.

Nevertheless, the lack of evidence for deformation within the range is salient. Numerical modeling using field-based estimates of crustal rigidity has shown that significant deformation would be expected under tilting scenarios (Martel et al., 2014), and so the absence of evidence for widespread deformation is evidence against the hypothesis of

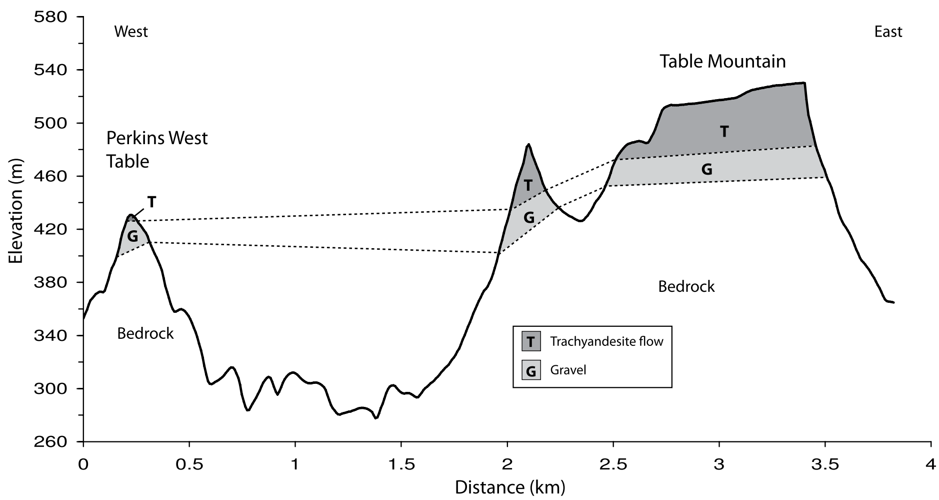

Figure 2. Cross section from Perkins West Table to Table Mountain (line "1" in Fig. 1). Because the gravel-trachyandesite contact under Perkins West Table is at a lower elevation than the same contact under Table Mountain, the volcanic rocks at Table Mountain cannot represent lava that solidified within a confined channel. The orientation of the cross section is ~45° from the azimuth of the hypothesized tilt. Inferred contacts are dashed. Lithology is from Bateman and Busacca (1982). Elevation data are from a 10-m-resolution digital elevation model.

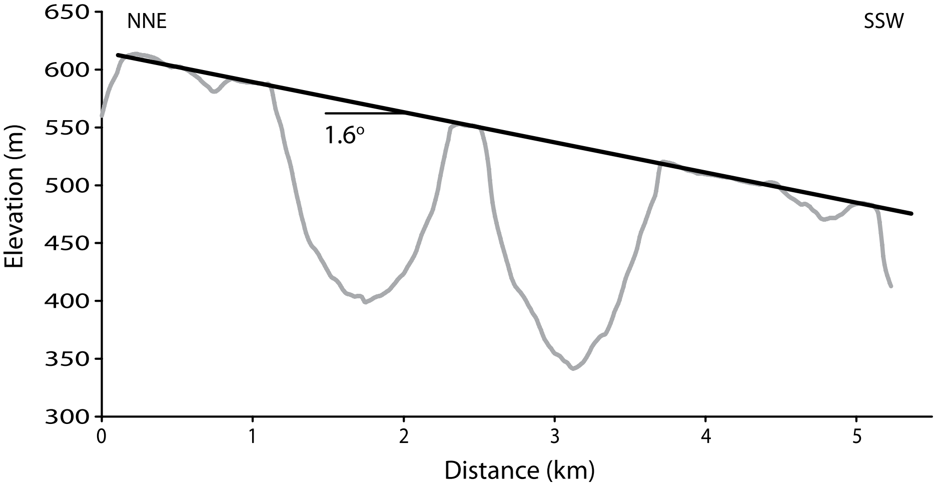

Figure 3. Cross section along the regional slope (line "2" in Fig. 1). A straight line connects multiple surfaces capped by trachyandesite over a distance of 5 km, strongly suggesting that these surfaces are remnants of a much broader flow. Slight deviations from the line are due to local surface roughness of the lava flow.

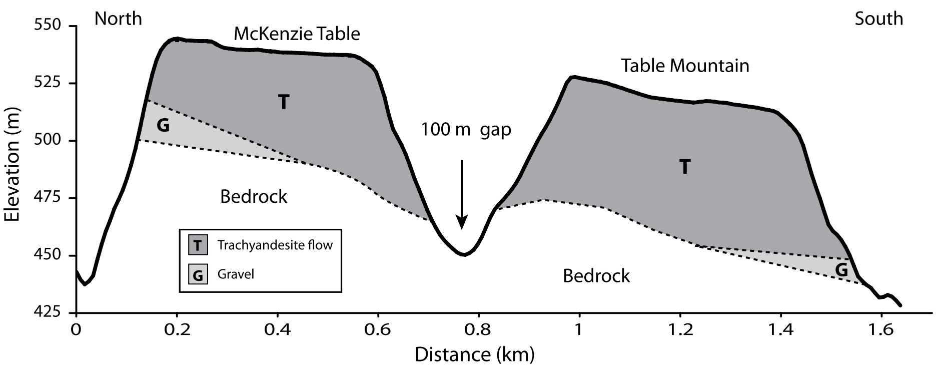

Figure 4. Cross section across the gap between McKenzie Table and Table Mountain, perpendicular to the alleged flow direction (line "3" in Fig. 1). Inferred contacts are dashed. Lithology is from Bateman and Busacca (1982). Elevation data are from a 10-m-resolution digital elevation model.

range-scale tilting. Whitney (1880, p. 510) expressed this idea best: "It is difficult to believe that any considerable general disturbance of such a range of mountains could occur at any time without producing at the same time numerous smaller and local disturbances in the way of faults, dislocations, bendings of the strata, etc."

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