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Disequilibrium river networks dissecting the western slope of the Sierra Nevada, California, USA, record significant late Cenozoic tilting and associated surface uplift: Comment

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INTRODUCTION

Beeson and McCoy (2022) present several interesting methods for detecting uplift from river profiles; however, these techniques rely on conditions and assumptions that are not met in the Sierra Nevada. Moreover, one of the key predictions from their numerical model, the presence of migrating knickpoints along the Sierra's trunk streams, is not supported by field observations or digital elevation model (DEM) analyses.

TIMING OF UPLIFT

Numerical Model

In the model used by the authors, estimates of the timing of tectonic activity rely on the migration rate of uplift-induced knickpoints. According to their Equation 8, knickpoint location is linearly dependent on *K*, a variable that accounts for bedrock erodibility and climate. In their approach, bedrock erodibility is assumed to be uniform throughout the entire Sierra Nevada. However, in the Sierra, bedrock erodibility is known to change significantly over short distances (e.g., Gabet, 2020); for example, the migrating knickpoint identified by the authors on the North Fork Feather River would have had to travel across at least eight different rock units and two fault zones (Saucedo and Wagner, 1992). Given that *K* can vary by many orders of magnitude according to lithology and fault damage (Gabet, 2020; Stock et al., 2005) and, also, that the knickpoint migration rate is linearly dependent on this variable, estimates of the timing of tectonic activity will be acutely sensitive to errors in properly accounting for spatial variations in bedrock erodibility.

Runoff, which is also incorporated into the variable *K,* is also assumed by the authors to be spatially uniform. However, total annual precipitation in the range decreases tenfold from the north to the south and also varies strongly with elevation (Bales et al., 2006). While Beeson and McCoy (2022) note that snow water equivalent is higher in the south, the streampower formulation depends on runoff, which is correlated with total precipitation. In addition, whereas the authors assume that runoff has not changed throughout the late Cenozoic, it has, in fact, experienced profound climate-driven changes (Phillips, 2008). The importance of accounting for spatial and temporal variations in runoff when analyzing channel profiles within the streampower framework has been emphasized in multiple studies (e.g., Leonard and Whipple, 2021; Roe et al., 2002).

The knickpoint migration rate is also dependent on drainage area, *A*, which the authors assume has not varied with time in the late Cenozoic. However, many of the mainstem rivers over this time period have been beheaded, indicating significant reductions in drainage area (e.g., Busby, 2013; Schweickert, 2009). Moreover, for much of the late Cenozoic, the bedrock surface in the northern Sierra was buried by such thick deposits of volcanic rocks that only the highest peaks rose above them (Bateman and Wahrhaftig, 1966; Slemmons, 1966); for example, Lyon Peak, one of the tallest summits in the American River watershed is capped with 3.3 Ma andesitic lahars (Harwood, 1986, *in* Saucedo, 1992). Lyon Peak and other similar sites demonstrate that, in the late Cenozoic, this portion of the Sierra Nevada was a vast volcanic plain with a drainage network that would have borne little resemblance to the modern system (Fig. 1; Lindgren, 1911; Whitney, 1880). Therefore, the claim that individual trunk streams have maintained the same drainage area throughout the late Cenozoic is not supported.

Finally, the application of the streampower model, which only simulates erosion, assumes that (1) the rivers have been continually incising through basement rock throughout the late Cenozoic, and (2) that the landscape has not experienced aggradation over this time period. However, these assumptions are contradicted by field evidence in the northern Sierra. From the Eocene to the early Oligocene, the accumulation of fluvial gravels was so thick that drainage divides in the Sierran foothills were overtopped by the deposits (Whitney, 1880). From the early Oligocene to the early Miocene, the northern Sierra Nevada was blanketed by rhyolitic ash tuffs, up to 500 m thick near the crest of the range and thinning down to ∼100 m in the foothills, that were conformably and unconformably deposited on the gravels (Henry et al., 2012; Slemmons, 1966). Following these rhyolitic eruptions, andesitic eruptions buried the eastern portion of the range under volcanic deposits that were up to 900 m thick near the range-crest, thinning down to ∼100 m in the foothills (Slemmons, 1966). These andesitic eruptions continued until at least 3.3 Ma (Harwood, 1986, *in* Saucedo, 1992). Therefore, northern Sierran rivers have not been continually incising through basement rock throughout the late Cenozoic. Instead, they were aggrading with volcanic deposits into the Pliocene and even the Pleistocene in some watersheds (Fig. 1). When the rivers began to incise following the end of the Pliocene and Pleistocene eruptions, many of them mostly cut down through volcanic and fluvial deposits, not basement rock (Fig. 2). Pliocene volcanic rocks throughout the Kings River watershed indicate that some portions of the southern Sierra also experienced aggradation in the late Cenozoic (Moore and Sisson, 1987).

Evidence for Migrating Knickpoints

The estimates for the initiation and cessation of uplift rely on the identification of migrating knickpoints on the mainstem rivers and the inter-

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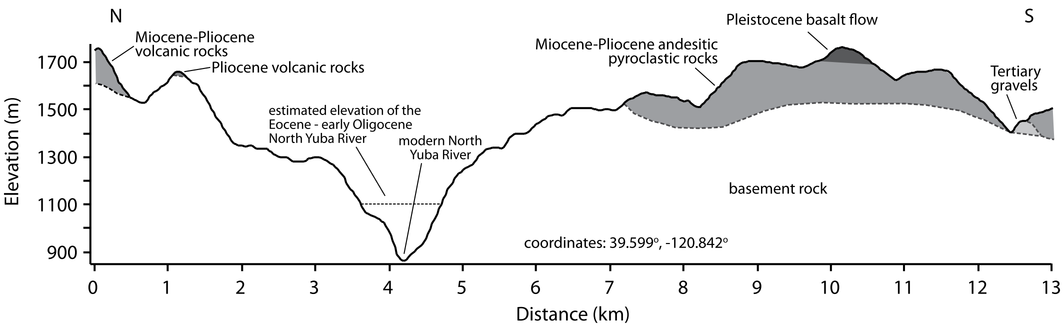

Figure 1. Cross section across the North Yuba River canyon, ~50 km from the range-front (Saucedo and Wagner, 1992). Inferred contacts are dashed; dotted line represents the estimated elevation of the valley bottom during the Eocene–early Oligocene (Gabet and Miggins, 2020). The basalt flow demonstrates that, as late as the Pleistocene, the fluvial system was not incising through basement rock, as claimed by Beeson and McCoy, but was, instead, flowing across a volcanic plain.

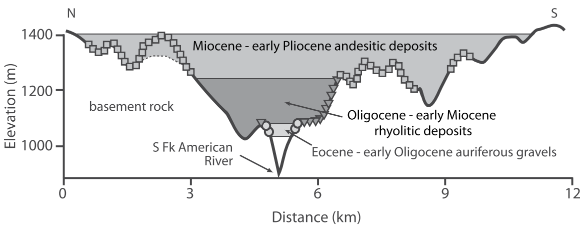

Figure 2. Cross section across the South Fork American River canyon, ~55 km from the range-front (Strand and Koenig, 1965; Wagner et al., 1981). Dotted line is an inferred contact; shaded bands represent eroded valley fill; symbols represent remnant deposits. Auriferous gravel deposits, subaerial and within a mine, indicate that this canyon was within ~160 m of its modern depth by the early Oligocene (Gabet and Miggins, 2020; Lindgren, 1911). The canyon subsequently filled with volcanic deposits which have mostly been eroded away since the Pliocene.

pretation that they were triggered by uplift (Beeson and McCoy, 2022). While the recent bedrock incision claimed by the authors should have left behind strath terraces immediately downstream of the knickpoints (e.g., Crosby and Whipple, 2006), none have been identified (other than those associated with local uplift of the Kern Arch in the southern tip of the range; Saleeby and Saleeby, 2019). Eocene–early Oligocene gravels and Oligocene volcanic deposits on benches throughout the northern Sierra (e.g., Cassel and Graham, 2011; Whitney, 1880) attest to the high preservation potential of strath terraces that would have formed in the late Cenozoic in the northern part of the range. Importantly, we should be able to observe strath terraces forming today, yet such observations are lacking. In addition, if these knickpoints are migrating, hillslopes downstream of them should be steeper than those upstream because of a lag in hillslope response time (Hurst et al., 2013); instead, hillslopes downstream of large knickpoints in the Sierra are often gentler (Gabet, 2020).

In the absence of physical evidence that these mainstem knickpoints are migrating, Beeson and McCoy present a plot of distance versus drainage area for these features (their fig. 15A) as their model predicts a strong power-law relationship between the two. Although they report a high R^2 (0.8) for this relationship when including the data from all knickpoints (mainstem and tributary), the data from just the mainstem knickpoints yield an R^2 approaching zero (Fig. 3), thereby providing strong evidence that the knickpoints are not migrating but are, in fact, stationary.

The breaks-in-slope interpreted by the authors to be migrating knickpoints appear to be, instead, lithological knickpoints (Gabet, 2020); indeed, many of them are at (or very near to) mapped lithological contacts and/or fault zones (note the overlap between the tectonic and the lithological knickpoints in Beeson and McCoy's fig. 15A). For example, the authors conclude that a knickpoint on the Stanislaus River is a migrating knickpoint (their fig. 11); however, it is at a contact between augen gneiss bedrock and the Calaveras Complex, a sheared subduction mélange (Snow and Scherer, 2006) that would be expected to be considerably more erodible (thereby having gentler slopes) than the quartz-rich gneiss (Fig. 4). Other examples where presumed tectonic knickpoints are at lithological and/or structural transitions include the North Fork Feather River, where the base of the knickpoint is in a fault zone juxtaposing metavolcanic and ultramafic rocks; the South Yuba River, where the knickpoint is at a contact between gabbroic rocks and quartz diorite; the Middle Fork American River, where the knickpoint is at a contact between the Shoo Fly Complex and the Calaveras Complex; the South Fork American River, where the knickpoint is at a contact between the Calaveras Complex and granite; and the Merced River, where the knickpoint is at a contact between plutonic and metamorphic units (Bateman and Krauskopf, 1987; Gabet, 2020; Saucedo and Wagner, 1992; Wagner et al., 1981). Note, in my experience, the locations of contacts on the digital map used by the authors, which is a preliminary map (Ludington et al., 2005), often do not coincide with those on the original paper maps.

While the examples above are limited to the northern Sierra where obvious lithological contacts can be identified, the southern Sierra is dominated by batholithic rocks where individual plutons are often not mapped. However, the Kings River presents an important test case for

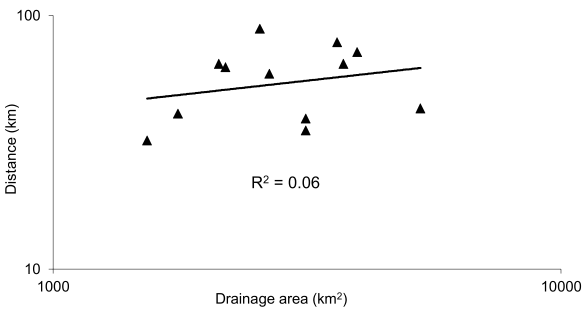

Figure 3. Distance vs. drainage area plot for mainstem knickpoints from Beeson and McCoy's figure 15A. According to the streampower model, if these knickpoints were migrating, there would be a significant relationship between distance and drainage area; the absence of a relationship indicates that the knickpoints are stationary. Processes other than mainstem migrating knickpoints could explain the weak distance-area relationship for the tributary knickpoints (R^2 = 0.45; plot not shown).

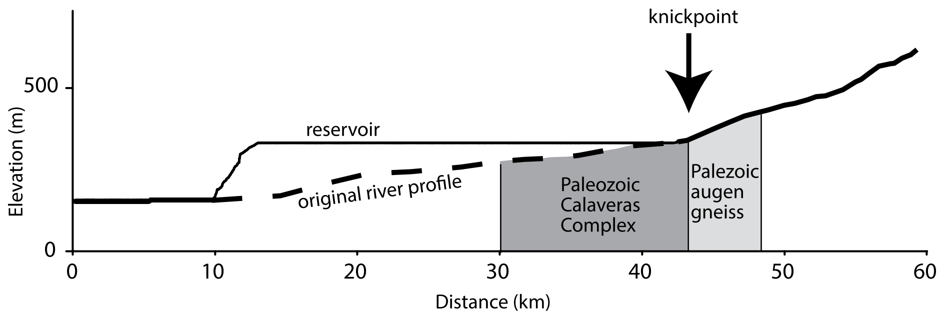

Figure 4. Profile along the Stanislaus River (Wagner et al., 1981). Beeson and McCoy concluded that the knickpoint was a migrating feature initiated by late Cenozoic uplift. This knickpoint, however, is at a lithological transition between two rock types with different erodibilities.

this region. Beeson and McCoy (2022) identify a migrating knickpoint on the Kings River that is ~20 km downstream of a site where the river has already incised deeply through a band of marble 2.7–1.4 Ma (Stock et al., 2004). To explain how this upstream site could have incised before the arrival of the conjectured migrating knickpoint, Beeson and McCoy suggest that tilting of the range led to localized incision within the marble, which they presume to be weaker than the surrounding bedrock. According to

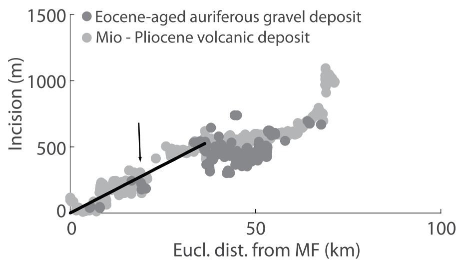

Figure 5. West-to-east increase in incision depths along the North Fork American River used by Beeson and McCoy to estimate tilt angle (modified from their fig. 11). According to the authors, the black line represents the amount of basement incision below a presumed bedrock paleosurface since deposition of the Mio-Pliocene volcanic rocks (light gray dots). For example, at the location shown with the arrow, the authors concluded that there has been ~260 m of basement incision in the late Cenozoic; however, auriferous gravels deeper within the canyon (i.e., dark gray dots below the black line) indicate that there can have only been a maximum of ~170 m of net basement incision from the Eocene–early Oligocene to the present. Finally, the east-to-west decline in incision depths simply reflects a decrease in relief toward the range-front (Gabet, 2014). Eucl. dist. from MF—Euclidian distance from mountain front.

this hypothesis, the reach of river through the marble should now have a lower gradient than the reach below it (their fig. 5C); instead, the marble reach is steeper, challenging their analysis (their fig. S11B). Moreover, hanging tributary valleys, inner gorges, and truncated spur ridges in granitic bedrock downstream of the marble indicate that the wave of incision traveled up to the marble and did not originate within it (Stock et al., 2004).

TILT ESTIMATES

Beeson and McCoy (2022) estimate the amount of late Cenozoic tilting presumably experienced by the Sierra Nevada on the basis of a west-to-east increase in canyon depths below Mio-Pliocene volcanic deposits, which they interpret to be a result of basement incision since the deposition of the volcanic rocks (their fig. 11 insets). The assumption underpinning this interpretation is that the base of these Mio-Pliocene deposits represents a late Cenozoic pre-uplift bedrock surface. However, Oligocene ash-flow tuffs and Eocene–early Oligocene fluvial deposits underneath the Mio-Pliocene deposits demonstrate that the bedrock paleosurface was significantly lower and, therefore, the base of the Mio-Pliocene deposits do not provide information on basement incision (Fig. 2). The presence of these older deposits deeper within the canyons can be seen in the authors' plots of incision depths (Fig. 5). The authors suggest that reorganization of the drainage network could lead to variations in incision depths (their fig. S8); this observation, which has been made by others (e.g., Lindgren, 1911), emphasizes the importance of making measurements of net basement incision from the oldest and deepest deposits (Gabet and Miggins, 2020). The authors also suggest that faulting could be responsible for these older, deeper deposits but do not identify the affected deposits or the faults that would have offset them.

Another technique used in Beeson and McCoy (2022) to detect uplift involves analyzing channel profiles as they pass over a band of weaker rock sandwiched between stronger rock (their fig. 5). This approach, based on a numerical model detailed in Beeson and McCoy (2020), relies on several specific conditions. First, the authors assume that, in addition to presumed late Cenozoic tilting, the Sierra Nevada has experienced uniform uplift (fig. 5 in Beeson and McCoy, 2020), which is a novel claim unsupported by evidence. Second, this technique assumes that the erodibility of the weaker rock is, in every case, an order of magnitude less than the stronger rock; however, no evidence is presented to support this assumption. Finally, some of the reaches analyzed do not conform to the condition of a single weak unit sandwiched between two stronger units; for example, a reach on the Middle Fork Yuba River incorporates granitic rock (a typically strong lithology) into the weak rock (their fig. 11).

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