THE GEOLOGICAL SOCIETY OF AMERICA®
Thompson FIELD FORUM

Old or Young?: The Topographic Evolution of the Sierra Nevada, USA

Conveners: Craig Jones, Christopher Henry, Elizabeth Cassel, John Wakabayashi

Participants: Mary Grace Albright, Snir Attia, Mark Brandon, Isabelle Bristol, Cathy Busby, Owen Callahan, Russell Callahan, Joella Campbell, Robinson Cecil, Odin Christensen, Helen Dow (née Beeson), Becky Flowers, Jackie Giblin, Allen Glazner, Emma Heitmann, Mike Hren, Chelsea Hutchens, Jeff Lee, Erin Marsh, Scott McCoy, Matt O'Neal, Chris Pluhar, Sophie Rothman, Joel Scheingross, Greg Stock, Holli Swarner, Haley Thoresen, Dean Tonenna, Alex Tye, Elijah Werlyklein. Jaclyn Hager, Michael Ort, and Fred Phillips participated remotely due to medical issues. In addition, Manny Gabet, Jim Wood, and Jeff Schaffer provided stop suggestions and text for the field guide.

After more than 150 years of geological investigation, the topographic history of the Sierra Nevada remains contentious. Is the range a continuation of a high-elevation Cretaceous Sierran arc? Or is the range a young phoenix, rising from the lower, eroded remnants of the earlier range? A pre-late Cenozoic range indicates Cenozoic erosion has little altered bedrock relief. Likewise, an absence of uplift as a thin crust over a hot upper mantle replaced thicker lithosphere in the eastern Sierra would indicate that foundering of the lower lithosphere is not a significant driver of elevation change here. If the range is young, repeated measurements of paleoelevation proxies are in error or, at minimum, biased high, bringing their broader application into question. A young range rising in a transtensional regime would be an unusual orogenic event. A lower mid-Tertiary elevation to the Sierra impacts interpretations of the Nevadaplano of Nevada-Utah, expanding implications into the interior of the Cordilleran orogen.

This Field Forum (FF) focused on disputed geologic features across much of the northern and central Sierra Nevada that create the observational basis for the large extent of surface uplift and elevation estimates. Sites visited included those with key geologic relations and significant implications for the analytical results of thermochronologic, isotopic-climatologic, paleobotanical, and detrital zircon (DZ) analyses. A variety of specialties has been employed to address this problem, reflecting broad scientific interest in the Sierra Nevada.

Westward-flowing paleorivers that crossed the Sierra Nevada, their channels, and their sedimentary deposits (the "auriferous gravels" and overlying volcanic rocks) were a major focus because (1) the deposits are the only Cenozoic rock record in the Sierra Nevada, even though sedimentary ages are incompletely constrained, (2) the channels record the erosional history, although their initiation and evolution are not well known, (3) when rivers connected the Sierra and the Nevadaplano to the east is a related and debated key question, (4) steeper gradients of transverse versus parallel channel segments in the Sierra have long been used to interpret late uplift (Lindgren, 1911; Hudson, 1955), (5) apparent tilting of late Miocene lava flows in three channels is some of the strongest evidence for late uplift, and (6) the dramatic change from the older, regional, wide, aggrading drainages headed on the Nevadaplano to the modern deep, narrow canyons restricted to the Sierra Nevada must be explained.

Figure 1. Sierra Nevada Field Forum 2022 group photo. Back row, left to right: Cathy Busby, Becky Flowers, Matt O'Neal, Odin Christensen, Joella Campbell, Russell Callahan, Greg Stock, Allen Glazner, Scott McCoy, Craig Jones, Owen Callahan, Jeff Lee (in mask), Emma Heitmann. Middle row, left to right: Liz Cassel, Joel Scheingross, Mike Hren, Jackie Giblin, Mary Grace Albright, Mark Brandon, Chris Henry, Snir Attia, Alex Tye, Sophie Rothman. Front row, left to right: John Wakabayashi, Robinson Cecil, Chelsea Hutchens, Elijah Werlyklein, Isabelle Bristol, Helen Dow, Erin Marsh, Haley Thoresen, Holli Swarner, Chris Pluhar, Dean Tonenna. Photograph by Jennifer Kent, University of Nevada, Reno.

Timing is a critical aspect, considered at many locations throughout the Forum, but only well established for development and initial erosion of the Cretaceous batholith and for Oligocene and younger volcanic and sedimentary deposits. The batholith intruded between ca. 120 and 90 Ma, younging eastward into western Nevada. Low-T thermochronology and Great Valley Group sedimentation demonstrate that the batholith underwent coeval major erosion. Attendee Robinson Cecil reviewed her previous publication documenting the cooling of batholithic rocks to ~180 °C between 90 and 70 Ma and to ~65–70 °C between 70 and 60 Ma (Cecil et al., 2006). The paleorivers probably developed at least as early as Late Cretaceous and certainly existed by 70–60 Ma.

Events between late Cretaceous batholith cooling and the deposition of well-dated, ≤32 Ma volcanic and sedimentary rocks remain poorly dated. During this interval, erosion shifted to deposition in the paleochannels. The largest of the giant, paleoplacer Sierran gold deposits accumulated in the bottoms of paleovalleys. Forum participants paid special attention to these rocks because inferences based on these deposits have led to support for both young and old Sierran uplift models. Auriferous gravels were long considered middle Eocene (ca. 50 Ma; MacGinitie, 1941) based on floral assemblages only present in upper parts of the gravels and incomplete stratigraphic correlation.

Examination of the gravels at several locations, DZ dates (Cassel; Cecil), their clay mineralogy (Wood), and dates of overlying ignimbrites (Henry), as well as reevaluation of the leaves (Hren), revealed that some upper gravels are no older than 41 Ma and as young as 32 Ma (Schorn, 2012). The lowest gravels may be ca. 50 Ma based on clay mineralogy, timing of the Early Eocene climatic optimum, and probable correlation with Ione Formation (Hren, Henry, Cassel, O'Neal, Wood [FF]; Creely and Force, 2007).

Continuity of Sierran rivers eastward into Nevada through time is variably interpreted and was examined on several days. The evolution of overall drainages is significant for interpreting the Sierran deposits as well as providing a broader context for the rivers. What sediment sources were available, the size of drainage basins, and if and how divides were breached all affect interpretations of Sierran erosional and depositional history. Additionally, the connection of Sierran rivers to highlands to the east requires some continuity of topography and structure that expands the constraints on interpretation of Sierran topography as well.

Expanding on published data by Cecil et al. (2006), van Buer et al. (2009), and Sharman et al. (2015) on batholithic and pre-Mesozoic DZ U-Pb ages in auriferous gravels, Cecil (FF) and Tye and Niemi (FF) place an Eocene drainage divide in the modern high Sierra. In contrast, Cassel et al. (2009) and Henry et al. (2012) place a divide in central Nevada at least by the Eocene–early Oligocene partly based on an interpreted 3–4-km-high Nevadaplano (DeCelles, 2004). Detrital zircons as old as 41 Ma might indicate early river continuity from east of the Sierra (Cassel et al., 2012), but the possibility of airborne transport (Tye and Niemi) leaves open a possible late Eocene divide. Henry showed ignimbrite sections that correlate along paleovalleys from central Nevada to the western foothills of the Sierra Nevada, demonstrating river continuity by 31.5 Ma and ending the era of uncertain dates and unresolved drainage areas.

Gold deposits in the aptly named auriferous gravels also play into questions about river continuity. Marsh presented evidence for purely local reworking from Mother Lode veins, which would not require

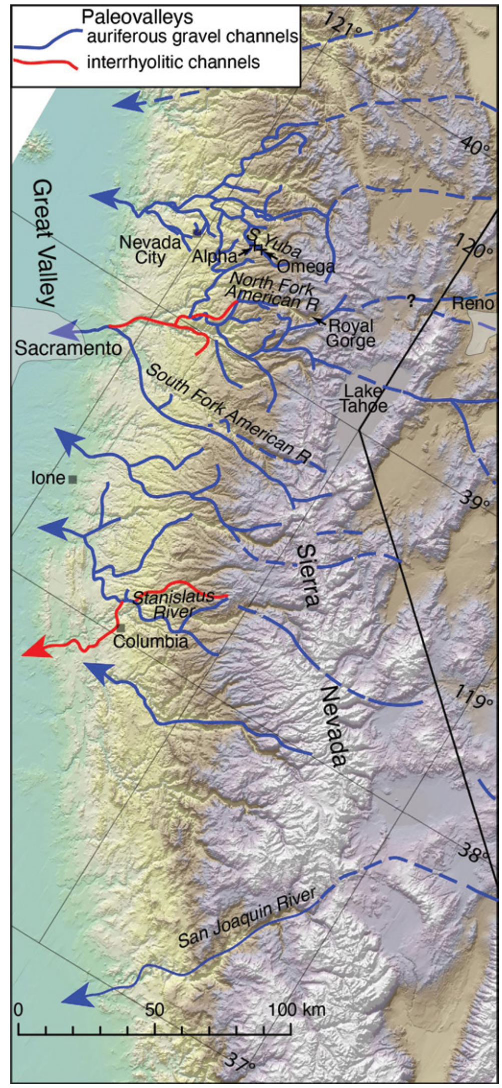

Figure 2. Map of paleochannels in the Sierra and placenames from the text.

rivers continuing beyond the modern Sierra. Christensen previously suggested a significant contribution from Nevada, implying early continuity, but now interprets erosion of epithermal systems above the batholith to be more likely, which does not imply early continuity.

The Forum visited materials preserved in the paleochannels in several localities. Some deposits potentially preceding erosion of the deepest channels might be at the Alpha and Omega mines, where Cassel showed extremely large boulders (rarely up to 8 m diameter) left on strath terraces that appear to demand fast-flowing rivers, not ones consistent with lower grades that a young tilt would seem to require. Observation of the gravels, including deposition of higher gravels on older stream-polished strath terraces at Omega, suggests that the older gravels could have a cut-and-fill history, which would mean that gravels deposited on bedrock do not correlate and instead represent different rivers at different times.

Why did these gravels accumulate? Two possibilities are (1) that the river system was overwhelmed with sediment (Tipp and Gabet, 2020) or (2) that the river gradients (or at least some channel reaches) or flow levels had relaxed enough to permit sedimentation (Cassel and Graham, 2011). The Ione Formation near its type locality alternates between shallow marine and subaerial deposits. As Field Forum participants examined the rocks near the edge of an inferred delta from the paleo–Calaveras River, the failure of the fan to prograde rapidly into the marine environment suggested to one convener that, at least at the time of deposition of the Ione, Sierran river channels were not too overfull of sediment. But, as Lindgren (1911) recognized and the Forum examined around Nevada City and Columbia, the paleorivers were overwhelmed and locally realigned by the great influx of sediment at the ca. 37–32 Ma onset of major volcanism in Nevada.

The Forum also visited younger markers of possible uplift. Twice they examined Miocene lava flows that have been controversial measures of range uplift, one capping a series of table mountains along the San Joaquin River (Hildreth et al., 2022) and the other topping the Stanislaus Table Mountain (Pluhar and Mitchell [FF]). Work at both flows suggests about 1° of tilt since ca. 10 Ma. Noteworthy was a visit to an unexhumed part of the Stanislaus Table Mountain Latite, where preserved channel walls strongly indicate that meanders were primary and not accidents of erosion.

Many studies explicitly or apparently posit that modern rivers partly to mostly re-excavated the paleorivers (Wakabayashi, 2013; Beeson and McCoy, 2022; and Gabet, 2014, 2020, all of whom contributed to the Forum); the depth of incision below the paleorivers would be greater the less the paleorivers and modern rivers coincide. Based on several locations, Henry and O'Neal independently found that modern rivers generally do not coincide with and were not re-excavated from paleorivers. Incision of modern rivers is also contentious. If tilting and uplift are substantial, why are many modern rivers only incised a short distance below the base of the Eocene(?) channels? Dow and McCoy answer that most northern Sierra rivers are not in steady-state equilibrium, and only the very lowest parts of these rivers now reflect the current tilt of their drainages. In many places the migration of knickpoints up drainages appears to be slowed by the underlying geology, leading to the mild incision of the South Fork of the American River where the Forum visited, compared to the far deeper incision of the North Fork we visited near Royal Gorge. A key difference for those skeptical of this analysis is whether the inferred migrating knickpoints are actually lithologic knickpoints (i.e., Gabet, 2023; Beeson and McCoy, 2023). In the southern Sierra, knickpoints associated with the stepped topography of Wahrhaftig seem stuck (Callahan and Riebe [FF]; update of Jessup et al., 2011), while other knickpoints might develop within otherwise uniform bedrock (Rothman and Scheingross [FF]), both potentially complicating river network analysis.

Summary. The Miocene table mountains provided some of the most compelling evidence in favor of a westward tilt of the range in the last 10 Ma. This seemed in good agreement with the Dow and McCoy analysis of the evolution of the drainages, which might be strengthened by specific examination of knickpoints unrelated to bedrock strength variations. Challenges in determining the geometry of the Eocene river system leave ambiguity in the magnitude of tilt of these features, if indeed they have tilted at all. The strong evidence for post–10 Ma uplift of the Sierra conflicts with the strong evidence from paleoaltimetry studies, using stable isotope ratios, paleoflora, and sedimentologic measures, for an Eocene Sierra as high as modern and an even higher Nevadaplano. Accepting both suggests an unrealistic steep topographic gradient between the two near the California-Nevada border. This dichotomy further suggests some apparently reasonable data sets are wrong or misinterpreted.

Looking forward, the Forum spent the morning of the last day digesting their observations and discussions with a goal of identifying work to resolve the evident differences. Additional geo- and thermochronology are particularly needed to help resolve timing of the troublesome Eocene gravels and the complex incision of Eocene and modern channels. Are the channels much older than the gravels, and did lower and upper parts of the Eocene drainages exhume at different times, which would confirm that the channels evolved through upstream migrating knickpoints that separated aggrading downstream segments from incising upstream segments? Geochemical characterization of detrital zircons and analysis of exotic chert clasts, detrital gold, and other heavy minerals would help determine the geometry and evolution of the drainage network. Expansion of paleohydrological analysis to more of the NNW-SSE–trending channel segments might clarify whether these channels have been tilted.

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