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Third-Day Road Log: From San Ysidro to Gilman Tunnels and Soda Dam

Karl E. Karlstrom, Laura J. Crossey, Cameron C. Reed, Ben Rodriguez, Spencer G. Lucas, Shari A. Kelley, and Fraser Goff

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THIRD-DAY ROAD LOG:

FROM SAN YSIDRO TO GILMAN TUNNELS AND SODA DAM

KARL E. KARLSTROM[1], LAURA J. CROSSEY[1], CAMERON C. REED[1], BEN RODRIGUEZ[1],
SPENCER G. LUCAS[3], SHARI A. KELLEY[2], AND FRASER GOFF[4]

[1] Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131; kek1@unm.edu
[2] New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801
[3] New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM, 87104 USA
[4] Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, NM 87801

Assembly Point: Southwestern parking lot, Santa Ana Star Casino
Departure Time: 7:30 AM
Distance: 50 miles
Stops: 2

Views, landmarks, and outcrops are given using the clock system. For example, 12:00 is straight ahead, 9:00 is to the left, and 3:00 is to the right. Waypoints are given in decimal degrees [latitude, longitude] and are listed in the waypoint table on page 103 of this guidebook (also available digitally).

SUMMARY

The Third-Day Road Log consists of two ~2-hour stops at Gilman Tunnels and Soda Dam. We drive from San Ysidro into the Jemez Mountains along State Road 4. From San Ysidro, we follow the Jemez River past Jemez Pueblo, turn left on State Road 485, drive to Gilman Tunnels, then back to State Road 4, and make a left to Soda Dam. The goals of this field trip are to look at the oldest and youngest rocks in the Nacimiento nexus area. Stop 1 will discuss the Proterozoic basement of the Nacimiento Mountains uplift exposed in a fault block in the rugged Guadalupe Box of the Guadalupe River near Gilman Tunnels (Fig. 3.1). Stop 2 will discuss Quaternary travertine at Soda Dam, including rocks that are still forming today. An optional stop along the route that could be done on a longer trip is the Jemez Springs Bath House to view geothermal waters.

[Waypoint]
Mileage Description *Distance between stops*

Waypoint 1 [35.325601°, -106.564426°]

0.0 Depart for the field trip from the Santa Ana Star Casino at 7:30 AM. **ZERO ODOMETER** where you turn right onto U.S. Route 550. Follow the First-Day Road Log from Bernalillo to the Cabezon Road turnoff (mile 19.2), then the Second-Day Road Log from there to San Ysidro (mile 21.6) *21.6*

Waypoint 2 [35.555284°, -106.779638°]

0.0 **RE-ZERO ODOMETER** at turnoff from U.S. Route 550 onto State Road 4. Ahead is a closer view of the cliff of Permian Abo Formation, Yeso Formation, Glorieta Formation, Moenkopi Formation, and Triassic Aqua Zarca sandstone interpreted to be on the upthrown side of a Laramide displacement on the San Ysidro fault (Figs. 1.10 and 1.11). *1.0*

1.0 San Ysidro Catholic Church. *0.7*

1.7 Cross the Jemez River. The view up the Jemez River valley shows Zia Sandstone overlain by capping paleo gravels in terraces of the Jemez River. To the north, the highest mountain is Redondo Peak, the resurgent dome in the center of the Valles Caldera. *1.0*

2.7 On the right side of the road are sandstones of the Zia Sandstone overlain by Jemez River terrace gravels (Qt4 of Pazzaglia et al., 1994). *1.0*

3.7 Variably cemented Zia Sandstone is visible in roadcuts on the right side of the road. *0.6*

4.3 The Pueblo of Jemez Medical Clinic and Governor's Office. *0.1*

4.4 Pueblo of Jemez Fire Department. *0.4*

4.8 U.S. Post Office. *0.2*

5.0 Pueblo of Jemez Civic Center. *0.6*

5.6 A panoramic view across the Jemez River valley to the west includes towers of Zia Sandstone capped by Jemez River gravels. These gravels are correlated with the 415-ka terrace at the nose of the Nacimiento uplift near the Tierra Amarilla anticline and are lower than the 630-ka Lava Creek B terrace at the Rio Guadalupe confluence (Rogers, 1996; Reed et al., 2024). The gravels form a resistant cap that has shielded the underlying soft Zia Sandstone from erosion. This is an excellent example of "inverted topography" where the lowest part of the paleolandscape (the 415-ka river bottom and its gravel bedload) now forms some of the highest part of the river valley. This is a powerful tool for dating river incision when gravel ages can be constrained using tephrochronology,

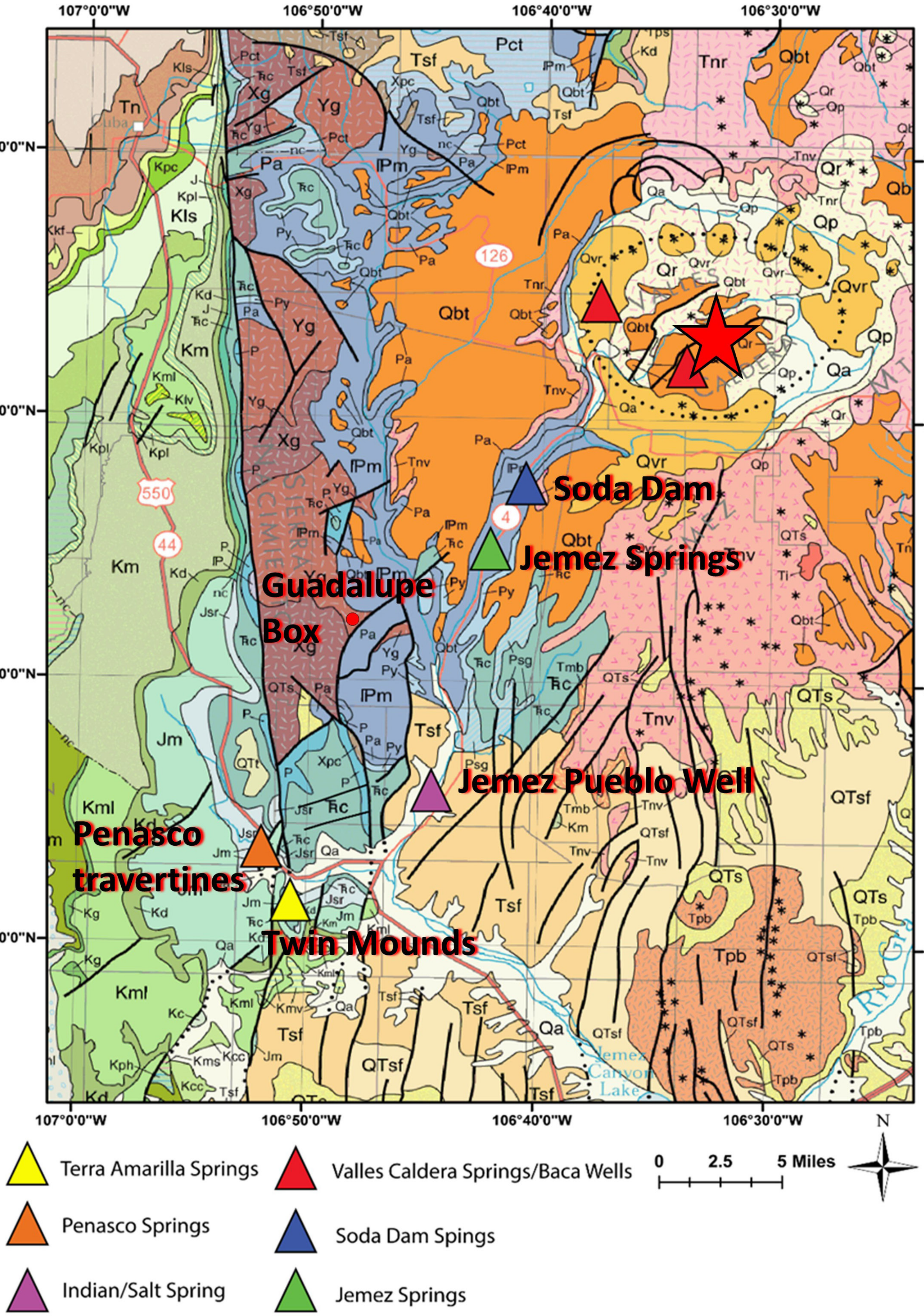

FIGURE 3.1. Geologic map of the Nacimiento and Jemez Mountains (New Mexico Bureau of Geology and Mineral Resources, 2003) showing Third-Day Road Log Stop 1 at Guadalupe Box and Stop 2 at Soda Dam. The geothermal system in the Valles Caldera overlies a shallow magma system beneath Redondo Peak (red star) at 1.9–6.2 mi (3–10 km) depth that may contain melt fractions up ~ 20% (Wilgus et al., 2023). Outflow of geothermal waters follows the Jemez fault system to the southwest, affecting springs and wells shown in colored triangles. Similarly, surface waters from Valles Caldera are funneled down the Jemez River in San Diego Canyon.

detrital sanidine, luminescence dating, and/or ^{40}Ar/^{39}Ar dating of basalt. *0.9*

6.5 The roadcut exposes a strath cut into the Zia Sandstone by the paleo Jemez River gravels. To calculate the average bedrock incision rate of the Jemez River since these gravels were deposited, we need to know their age, then measure the vertical distance between this strath and the modern river. The upper terraces on this side of the highway may correlate with Qt4 of Formento-Trigilio and Pazzaglia (1998), which they report as 6–26 m above river level and give an estimated age of 60–150 ka. *0.7*

7.2 On the left is the Pueblo of Jemez Welcome Center and Museum of History and Culture; it provides information about Towa culture and traditions, and more information is available at http://www.jemezenterprises.com. *1.8*

FIGURE 3.2. Towers of erodible Zia Sandstone are held up by a resistant gravel cap. These gravels are correlated to the Qt2, a 415-ka terrace (Formento-Trigilio and Pazzaglia, 1998). We are in the Rio Grande rift, as shown by Zia Sandstone of the Santa Fe Group that extends west to an eastern segment of the San Ysidro-Jemez fault system.

FIGURE 3.3. Red Rocks area and Walatowa Visitor Center in the De Chelly Formation of the Yeso Group. Note the large-scale eolian cross-beds.

Waypoint 3 [35.667832°, -106.743196°]

9.4 Turn left onto State Road 485 and cross the Jemez River. *0.8*

10.2 The contact between the upper and lower Bandelier Tuff is visible. *2.9*

13.1 At left, Bandelier Tuff flowed out onto Glorieta Sandstone. At right, it flowed onto Yeso Formation. *0.3*

13.4 The basal contact shows that the Bandelier ash flow tuff filled irregular paleotopography, including a paleo San Diego Canyon. *0.8*

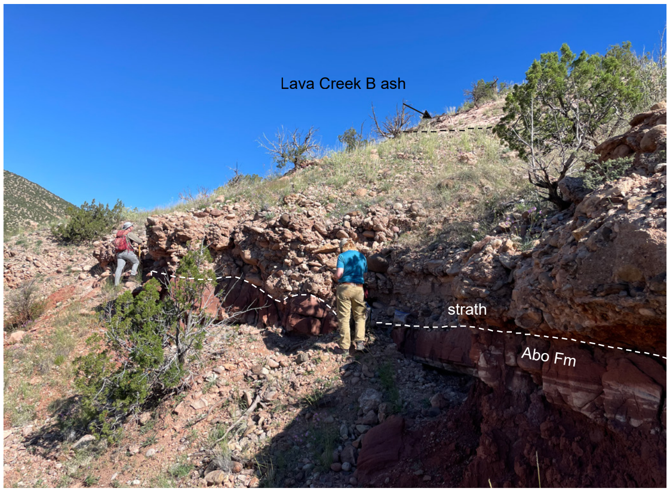

FIGURE 3.4. Guadalupe River gravels rest on a strath carved into Abo Formation and form a thick fill terrace that includes the Lava Creek B ash (light patch in upper part of photo) that erupted from Yellowstone at 630 ka. This is the highest of a flight of terraces (Qt1) near the confluence of the Jemez and Guadalupe Rivers. Incision of both rivers here since that time is 312 ft (95 m) and has taken place at an average rate of 490 ft/Ma (150 m/Ma) over the past 630 ka (Formento-Trigilio and Pazzaglia, 1996; Reed et al., 2024).

FIGURE 3.5. View to the north of Permian red beds (Abo and Yeso formations) overlain by Bandelier Tuff. The lower part of the Bandelier cliff is 1.62-Ma ash-flow tuff (ignimbrite) eruption, and the upper part is from the 1.23-Ma Valles Caldera eruption. Note the irregular erosional surface at the base of the Bandelier Tuff.

FIGURE 3.6. Gilman Tunnels were cut through Mesoproterozoic granite and have a very tall profile to allow the passage of narrow-gauge trains carrying logs from the Nacimiento Mountains to a sawmill in Bernalillo from the 1920s to 1941.

14.2 The view ahead shows a neotectonically active segment of the Jemez fault. To the west is Proterozoic basement; to the east is the Permian section. Bandelier Tuff is offset with 52 ft (16 m) of east-down, post-1.23-Ma normal displacement. *0.3*

Waypoint 4 [35.730140°, -106.759135°]

14.5 Crossing the Jemez fault and driving into the Guadalupe Box. The snack truck will set up in the pullouts here, participant vehicles will proceed, and participants will walk or drive back to this point. *0.2*

14.7 First Tunnel. Gilman Tunnels were cut in the 1920s for narrow-gauge trains carrying logs from the Nacimiento Mountains to a sawmill in Bernalillo. The railroad was shut down due to flooding in 1941. *0.1*

14.8 Second Tunnel. *0.1*

14.9 Vehicles will turn around ahead (at mile 15.4) and come back to park along the road here. *0.2*

15.1 U.S. Forest Service gate. Above the Great Unconformity is a section of Mississippian Arroyo Peñasco Formation overlain by Sandia Formation (see Lucas and Krainer, 2024). *0.1*

15.2 End of pavement. *0.2*

15.4 Very sharp U-turn. Proceed back to park at mile 14.9. *6.0*

Waypoint 5 [35.735203°, -106.765030°]

STOP 1. Gilman Tunnels.

The Proterozoic basement of the Nacimiento Mountains is dominated by granites from two major magmatic episodes. The first includes the monzogranite of Clear Creek (1696±4 Ma) and the San Miguel gneiss (1700±8 Ma). The second includes voluminous granite of 1455 to 1420 Ma, including the monzogranite of Guadalupe Box, which yielded ages from 1432 to 1450 Ma and all essentially within error (Grambling et al., 2015; Premo et al., 2023), and the Joaquin granite (1422±5 Ma from Premo et al., 2023). The 1.7-Ga granites intruded into rhyolitic to basaltic metavolcanic rocks and quartz-mica schists that occur mainly as inclusions within the granites. This stop is an opportunity to review models for multiple orogen-

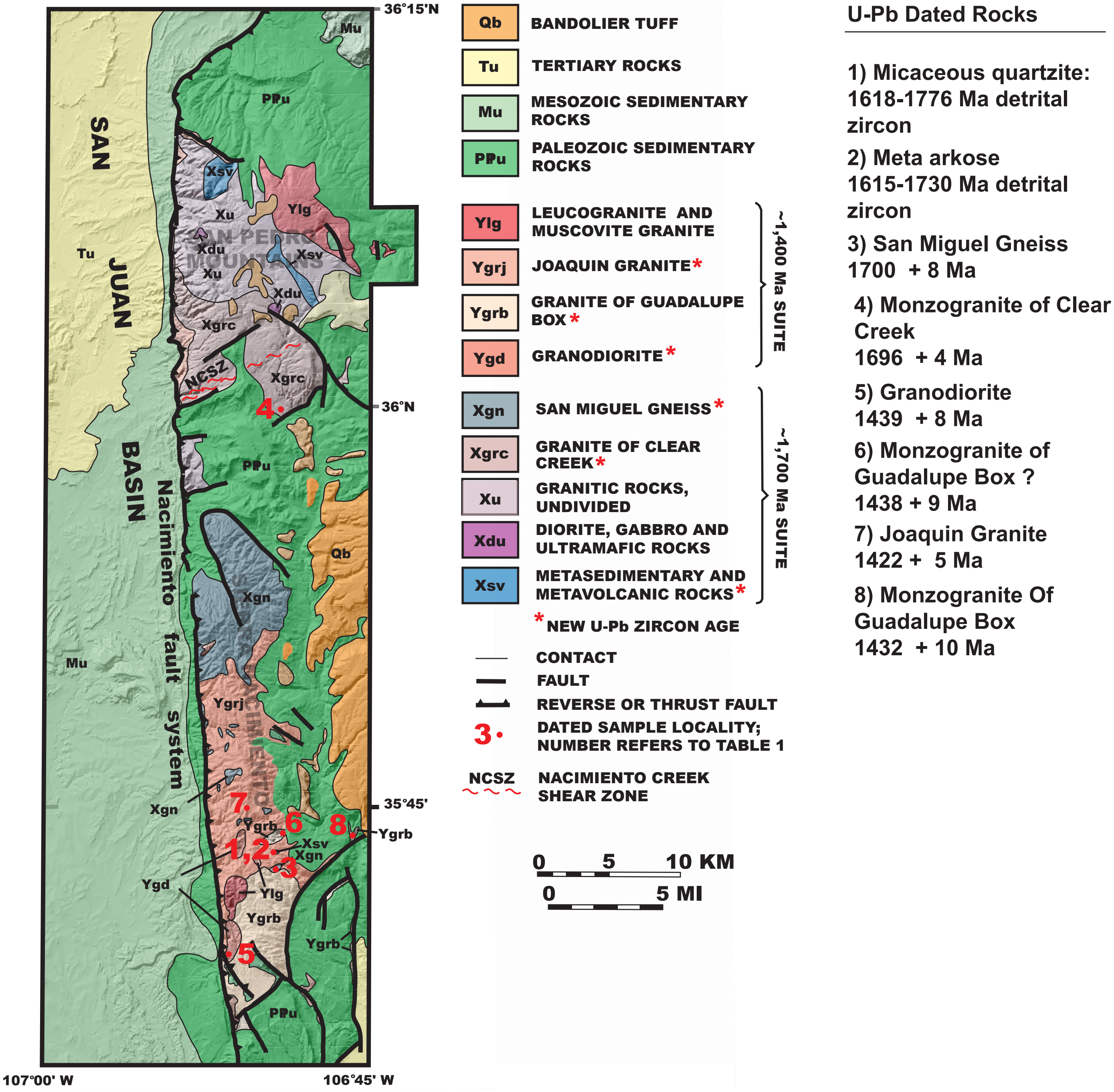

FIGURE 3.7. Basement map of the Nacimiento Mountains showing the locations of U-Pb-dated samples (from Premo et al., 2023). The Proterozoic core of the mountains is made up predominantly of granite. New U-Pb zircon dating shows that Paleoproterozoic granites (~1700 Ma) dominate the San Pedro block, whereas Mesoproterozoic granites of 1410–1450 Ma dominate the southern part of the Sierra Nacimiento block. Guadalupe Box granites (location 8 on this map) yielded a range of U-Pb dates from 1430 to 1450 Ma, which most likely reflects protracted magmatism and difficulty in resolving ages within the ±10-Ma precision of the different dating methods.

ic episodes recorded in Proterozoic rocks of New Mexico and southern Colorado (Hillenbrand et al., 2023a, 2023b, 2024).

Walk back down the road and examine the basement granites. The Guadalupe Box granite has yielded a U-Pb zircon date for the monzogranite phase of 1438±9 Ma that is within error (Premo et al., 2023) of Grambling et al.'s (2015) reported age of 1449±12 Ma. As we walk along, do you think these are all comagmatic phases of the same pluton? And examine the nature of foliation in the granites that may record aspects of ~1.4-Ga middle crustal tectonism and/or flow during magma emplacement. Magmatic foliation is defined by aligned tabular feldspars and still-equant (not strongly strained) quartz between feldspar megacrysts. Penetrative solid-state foliation of quartz and feldspar occurs in some ~1.4-Ga plutons, especially pluton margins, but much of the granite was not penetratively foliated in the solid state during the Picuris orogeny. The "room problem" for granites asks the question, what made room for the magma? Circa 1.4-Ga granites across New Mexico intruded into older crust that ranges in age from 1740 Ma in the Tusas Mountains to 1600 Ma in the Manzano Mountains. In the Nacimiento Mountain block, the 1.4-Ga Mesoproterozoic granites intruded mainly into older ~1.7-Ga Paleoproterozoic granite. A take-home point is that the orogenic middle crust of New Mexico displays both 1.7- and 1.4-Ga major crust formation episodes at 6.2–9.3 mi (10–15 km) depths based on regional metamorphic studies (Williams et al., 1996, 1999; Daniel and Pyle, 2006; Aronoff et al., 2016). The ~1.4-Ga magmatism is interpreted to have been related to basaltic underplating that caused lower crustal melting (Frost and Frost, 2013), and evidence for this can be seen in the dark, dioritic, comagmatic enclaves that are common features of the ferroan ~1.4-Ga granites of the southwestern United States, including the Sandia granite.

Recent "mohometry" studies (e.g., Luffi and Ducea, 2022) provide geochemical methods to estimate the thickness of the crust at the time a magma was generated in the lower crust. Application of these methods to southwestern Laurentia are summarized in Hillenbrand et al. (2023a) and are shown in Figure 3.8. These papers provide a new dataset within which to consider and begin to reconcile models for Proterozoic crust-

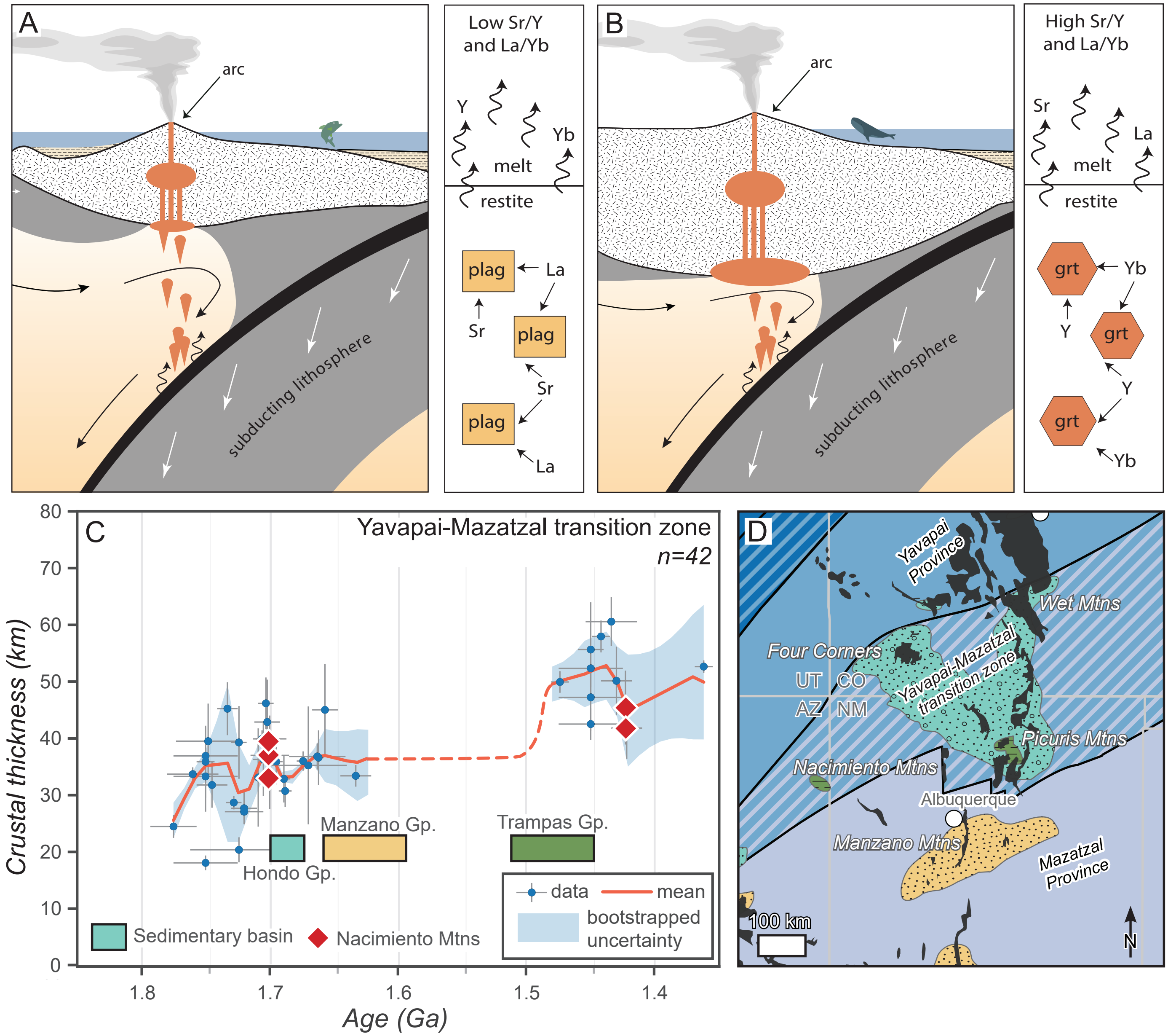

FIGURE 3.8. Crustal thickness at the time of lower crustal magmatism can be reconstructed using geochemistry of arc- and syn-collisional magmas. In thin crust <28 mi (<45 km), La and Sr are partitioned into feldspar, leaving the melt low in Sr/Y and La/Yb. In thick crust >34 mi (>55 km), Y and Yb are partitioned into garnet, leaving melt high in Sr/Y and La/Yb. These and other "mohometers" are summarized in Luffi and Ducea (2022). Application of these techniques to plutons of southwestern Laurentia done by Hillenbrand et al. (2023a) includes data from the northern New Mexico region (lower left) and from the Nacimiento Mountains (red triangles). These data show major orogenic events: formation of high mountains and thick crust during the 1.7-Ga Yavapai orogeny, demise of mountains and crustal thinning by 1.68 Ga, renewed local crystal thickening during the Mazatzal orogeny ~1.65 Ga, a tectonic gap from 1.6 to 1.5 Ga, and formation of 28-mi-thick (45 km) crust within the Picuris orogenic plateau ~1.45 Ga.

al evolution of the Four Corners region. The mohometry data suggest that 1.72–1.69-Ga plutons of the Yavapai orogeny were part of a 124-mi-wide (~200 km) mountain belt of 31–37-mi-thick (50–60 km) crust that extended from the Grand Canyon to northern Colorado. In northern New Mexico, the Needle Mountains of Colorado, and the Nacimiento Mountains, ~1.7-Ga plutons formed within 22–25-mi-thick (35–40 km) crust on the south flank of this mountain range. These plutons are about the same age as the 1.7-Ga Uncompahgre-Vadito-Ortega quartzite-rhyolite basin (Hillenbrand et al., 2023b; Premo et al., 2023) that may have developed on thinned (thinning) Yavapai crust. Subsequent 1.68–1.60-Ga tectonism of the Mazatzal orogeny is not yet recognized in the Nacimiento Mountains, but in areas of the Zuni and Santa Fe ranges, it involved additional granitic magmatism that records 19–25-mi-thick (30–40 km) crust. From 1.60 to 1.50 Ga, there is no record of magmatism, deformation, or metamorphism in the region, and this interval is referred to as a tectonic gap (Karlstrom et al., 2004).

Similar to much of the Southwest, the Nacimiento Mountains have an extensive record of ~1.4-Ga granites that were emplaced broadly within a regional ~1.45-Ga contractional event (e.g., Nyman et al., 1994) called the Picuris orogeny (Daniel et al., 2013). Mohometry data suggest these magmas were derived by lower crustal melting within 25–31-mi-thick (40–50 km) crust in the Nacimientos. This was a regional crustal thickening event across much of the Southwest that is interpreted to have resulted from collision of a 1.4–1.5-Ga terrane to the south (Whitmeyer and Karlstrom, 2007; Bickford et al., 2015). This orogenic event involved upper and middle crustal shortening (Daniel et al., 2013), but crustal thickening was also accomplished by the addition of about 6.2 mi (10 km) of a basaltic underplate (Shaw et al., 2005; Hillenbrand et al., 2023a). One plate tectonic model for this involves lithospheric delamination and asthenospheric return flow during slab roll-back-type thinning of the older crust of the Yavapai and Mazatzal provinces (Karlstrom et al., 2016). Advective heat from the emplacement of ferroan granites in the mid-crust likely contributed to elevated geothermal gradients and rheologically weakened the crust. The extent of the crustal thickening at about 1.45 Ga suggests a 31-mi-thick (50 km) orogenic plateau behind an outboard plate collision (located in Texas), like the Tibetan plateau behind the Himalayas (Hillenbrand et al., 2023a) and the modern-day elevated orogenic plateau of the western United States (Karlstrom et al., 2022).

FIGURE 3.9. Stop in the vicinity of the tunnels to "jump timescales" and examine impressive incision of the hard-to-erode Proterozoic basement by the Guadalupe River. This small stream has the stream power during flash flood events, using boulders as tools, and over time carving the Guadalupe Box.

Stop in the vicinity of the tunnels to examine the impressive young incision of the Guadalupe Box by the Guadalupe River. As a thought experiment, the tops of the cliffs are ~330 ft (~100 m) above the river. If we consider the incision rate of 490 ft/Ma (150 m/Ma) given by the 630-ka Lava Creek B terrace of the Guadalupe River just downstream near the Jemez River confluence, we might infer that this basement gorge has been cut during this same time frame, over the past ~660,000 years. But neotectonic uplift of the footwall block relative to the confluence terraces across the Sierrita segment of the San Ysidro-Jemez fault system (see Karlstrom et al., 2024) is documented by east-down offset of the Bandelier Tuff of about 52 ft (16 m) just to the north (Formento-Trigilio and Pazzaglia, 1998). Faulting can enhance the river incision rate of the upthrown side and 52 ft (16 m) over 1.23 Ma would be a slip rate of 50 ft/Ma (13 m/Ma) on average, such that we would expect footwall incision rates to be ~535 ft/Ma (~163 m/Ma). If so, Guadalupe Box would have been cut in 613,000 years (100 m / 163 m/Ma = 613 ka). The complexities of mapping the fault strands and determining fault slip rates (through time) is a work in progress (Reed et al., 2024). The methodology of merging structural and geomorphic datasets is needed to understand landscape evolution in neotectonically extending regions. This is fault-enhanced river incision, in which the equation is: footwall (uplifting block) incision rates = hanging wall (down-dropped block) incision rates + fault slip rate (Reed et al., 2024). The basement block of Guadalupe Canyon is on the north side of a curving segment of the San Ysidro-Jemez fault zone that previous workers called the Sierrita fault (Kelley, 1977; Woodward, 1977). Similar basement granite crops out at Soda Dam along the Jemez fault segment farther northeast, suggesting a Laramide ancestry for these sections of the fault system.

Walk back down (or catch a ride) to the snack truck. Load up and head to Soda Dam.

FIGURE 3.10. The basal contact in this view back down canyon from Soda Dam shows that the 1.62-Ma Bandelier ash-flow tuff (Otowi Member) filled irregular paleotopography in a paleo San Diego Canyon.

Waypoint 3 [35.667832°, -106.743196°]

0.0 **RE-ZERO ODOMETER** at the junction with State Road 4. Turn left (north). *0.2*

0.2 La Junta Fishing Site. Each of the pullouts over the next few miles along the Jemez River are sampling locations for Crossey et al.'s (2013b) water quality study. *1.5*

1.7 Las Casitas Fishing Site. Note numerous landslides in San Diego Canyon. The cliff of Bandelier Tuff is undermined by erosion of softer Paleozoic units; blocks break off on steeply dipping joints, then back-rotate as the blocks slip (and creep) down the softer strata. This geometry of back-rotated bedrock landsliding has been named Toreva blocks for Toreva, Arizona by Reiche (1937). *1.3*

3.0 San Diego Fishing Site. *0.4*

3.4 Landslide "alley" (one of many). *0.3*

3.7 Vista Linda Campground. *0.1*

3.8 View at 1:00 of sub-Bandelier Tuff paleotopography. *0.6*

4.4 Spanish Queen Picnic Site. *1.4*

5.8 Village limits of Jemez Springs. *1.8*

7.6 Jemez Springs Community Park. *0.4*

8.0 "Downtown" Jemez Springs. *0.1*

8.1 Jemez Springs Bath House. *0.7*

8.8 National Park Service office for Vallez Caldera National Preserve. *0.1*

8.9–9.0 View of high travertines named Deposit A by Goff and Shevenell (1987). The top of this travertine deposit slopes gently toward the river. Travertine on this side overlies paleo–Jemez River gravels, which overlie a bedrock strath cut on Mississippian/Pennsylvanian strata. The right side shows a travertine drape (Deposit Ai, Fig. 3.12) deposited on basement rocks (see Stop 2). At 9:00 are mini-tent rocks near the base of the Bandelier Tuff cliff. *0.3*

9.3 Cross the Jemez River. *0.4*

Waypoint 6 [35.792642°, -106.686984°]

STOP 2. Soda Dam.

9.7 Drive past Soda Dam and park on the left for Stop 2. Across the highway and up the steep hill to the west is a section of Mississippian and Pennsylvanian strata (Fig. 3.14). The Mississippian Arroyo Peñasco Formation rests on the basement and is about 6 ft (2 m) of sandstone of likely fluvial origin (Del Padre Member) overlain by about 16 ft (5 m) of marine

FIGURE 3.11. Jemez springs have natural outlets along the river. Water from drill holes produces the main water for the bath house. Spring water temperature is 156°F (69°C; McGibbon et al., 2018), and flows from leaks and overflow of the wells precipitate travertines. These rocks are forming today! Waters here are hotter and fresher than Soda Dam hot springs, a conundrum if one envisions a simple geothermal plume cooling and picking up solutes as it travels down the Jemez fault system. This is resolved, at least conceptually, by considering multiple semiconfined fault and aquifer pathways (Goff et al., 1981; McGibbon et al., 2018).

FIGURE 3.12. Crossing the Jemez River approaching Soda Dam, there is an excellent view of the high travertines called Deposit A (Goff and Shevenell, 1987) and Ai (inset drape of Jean et al., 2024) that were deposited as the river carved down to its present position. Jemez River gravels at the base of the travertine are resting on shallowly dipping Paleozoic strata. Cliffs of Bandelier Tuff are in the shadow in the background.

limestone (Espiritu Santo Member). The overlying Mississippian Log Springs Formation is about 56 ft (17 m) of purple and green shale and sandstone, likely of nonmarine origin. The Middle Pennsylvanian Sandia Formation rests disconformably on the Log Springs Formation, and it is considered to be the first synorogenic sediments of the Ancestral Rocky Mountain orogeny. Sandia strata are quartz-dominated sandstones and conglomerates of fluvial origin interbedded with marine and nonmarine shales and marine limestones. The lowermost part of the Middle Pennsylvanian Gray Mesa Formation caps the section and represents a marine carbonate platform setting. The remainder of the Pennsylvanian section can be found west of the highway north of this Soda Dam section (see Lucas and Krainer, 2024).

Soda Dam is an iconic place for visitors and a sacred site for Jemez Pueblo. Please respect it, leave no trace, and appreciate it. Soda Dam blocked the valley until the road was blasted across the travertine dam in the 1960s. Soda Dam came under the jurisdiction of the U.S. Forest Service in 1976, when a joint project was initiated between the U.S. Forest Service and Jemez Pueblo to try to minimize damage to this location by heavy visitation. Newer efforts are also underway.

Given the relatively small area of Soda Dam and the many

FIGURE 3.13. The first glimpse of Soda Dam shows why it is a famous New Mexico destination and of cultural significance for Jemez Pueblo. Like the Twin Mounds, this place is a nexus of different waters. The Jemez River is cold and fresh, and most of its volume is derived from snowmelt and rain in the Valles Caldera and surrounding areas. Soda Dam has CO_2-rich hot springs that bubble up along faults right here, including into the pool at the base of the waterfall. These waters have been depositing travertine (freshwater limestone) over the past >600,000 years (Goff and Shevenell, 1987; Jean et al., 2024).

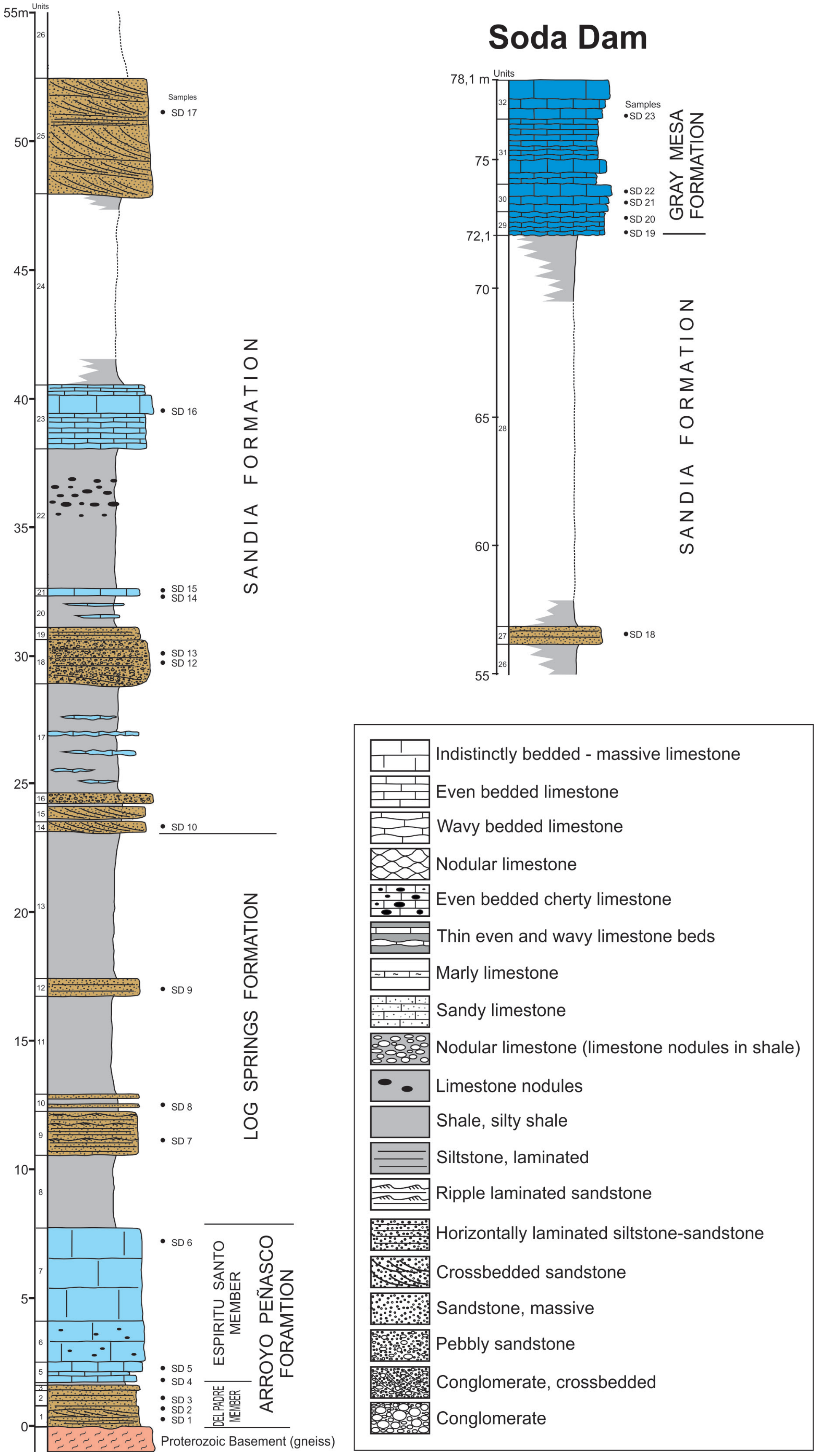

FIGURE 3.14. Basal Paleozoic stratigraphic section just west of Soda Dam.

things to see and discuss, we plan to divide into smaller groups and migrate around to different stations, as shown in Figure 3.15. Plan to spend about 20 min at each station, and reassemble near the vehicles for lunch by 12:30 PM.

Maps of Soda Dam show slightly different versions of how many fault strands are present and/or their dip direction (Woodward et al., 1977; Goff and Shevenell, 1987; Kelley et al., 2003; Moats, 2004; Tafoya, 2012). This reflects the complex geology along the Jemez segment of the San Ysidro-Jemez fault zone here. The interpretation in Figure 3.16 shows the Precambrian granites here to be part of a Laramide horst, bound on the northwest and southeast by reverse/transpressional faults, with southeast-side up on the Soda Dam fault needed to explain the monocline at the cave where the Great Unconformity is subvertical. The southeast contact of the basement block dips 50° northwest and is the conjugate reverse fault of basement over limestones ("Madera Group" or Gray Mesa Formation). The Jemez fault segment is drawn beneath the north side of the high travertine deposit (Deposit A). The Soda Dam fault segment passes through the hot springs and the central vein of the fissure ridge of Deposit B. All of these strands have travertine along them and are being reactivated by Quaternary extensional displacement that provides conduits for ascent of waters and deposition of travertine. Note the orthogonal fissure ridges on top of Soda Dam formed by faults that provide pathways for mounds that form above their intersection.

FIELD TRIP STATIONS AND TOPICS: A TRAVERTINE LEXICON

(A) The hydrothermal system, hot springs, and "xenowhiffs." Xenowhiffs (Crossey et al., 2009) are analogous to xenoliths (foreign rocks caught up in ascending magma), but in this case they are foreign (mantle-derived) gases entrained in the ascending hydrothermal waters. Examine the bubbling vents; the bubbles are mostly CO_2 but also contain trace gases of helium with a $^3He/^4He$ value of 0.84 R_A, which indicates that about 10% of the helium is derived from a morb-like mantle (Goff and Janik, 2002; Crossey et al., 2016). Directly across the road from the hot spring vents is the central vein of the Soda Dam fissure ridge (Fig. 3.23).

FIGURE 3.15. This view from Deposit Ai shows the interaction of travertine deposition and the Jemez River. The fissure ridge at Soda Dam spans across the Jemez River Canyon. It was described as a box canyon or barrier by early travelers before the road was cut at the near side. Locations and main topics for the field trip discussion stations: (1) Hydrothermal system, hot springs and "xenowhiffs," (2) a view of the cave area monocline, upturned Great Unconformity overlain by 200-ka gravels, (3) Soda Dam and "travitonics," (4) Grotto Springs, active travertine deposition, and "chemical volcano" in the river.

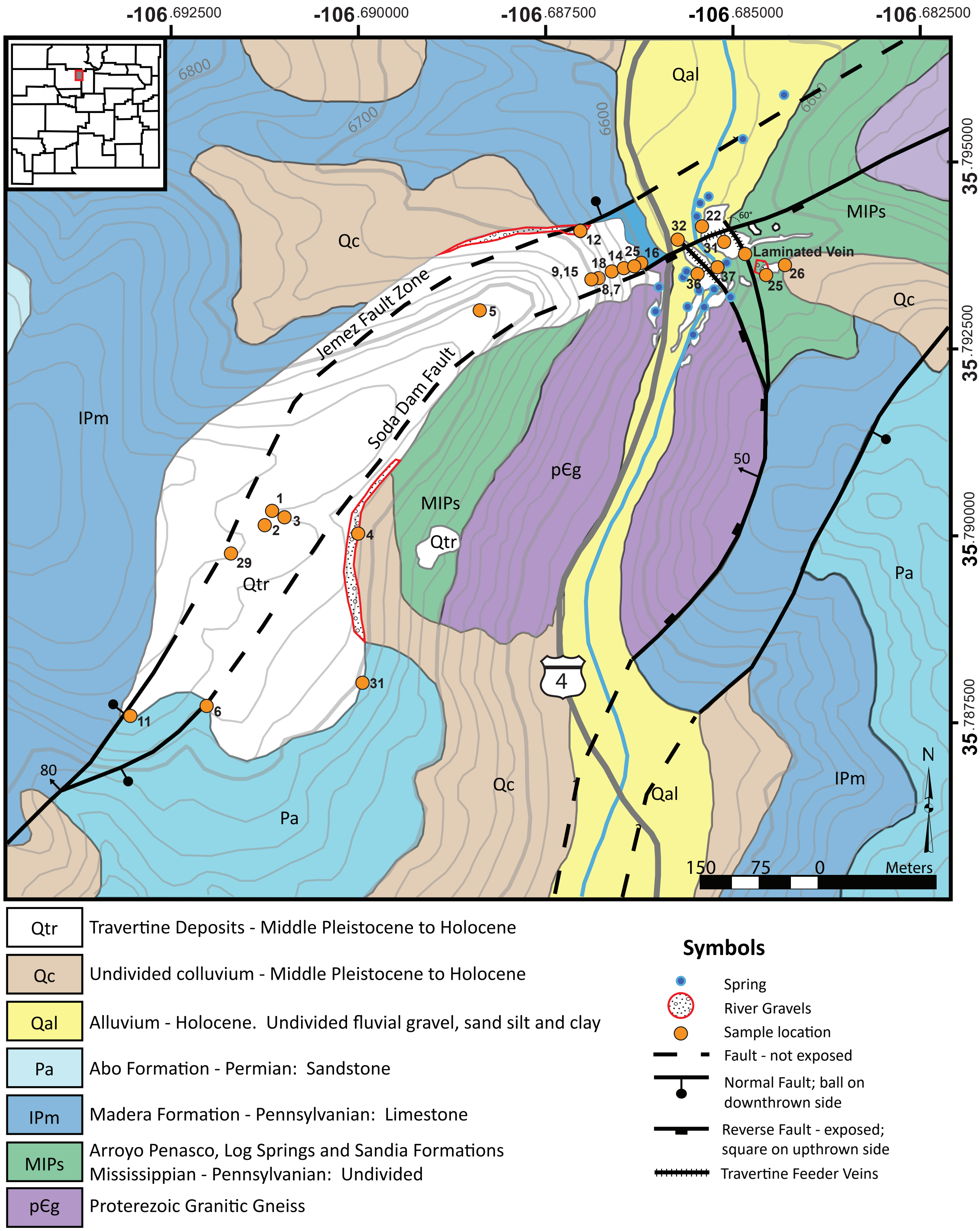

FIGURE 3.16. Geologic map of the Soda Dam area (modified from Goff et al., 1981; Goff and Shevenell, 1987; Kelley, et al. 2003; Moats, 2004; Tafoya, 2012) showing travertine deposits A, Ai, B, C, and D (Soda Dam) as along faults. The Jemez fault zone here has numerous strands including the Laramide reverse fault/monocline structure seen at the cave. The basement block is interpreted as a horst block within a Laramide reverse/right-slip fault zone.

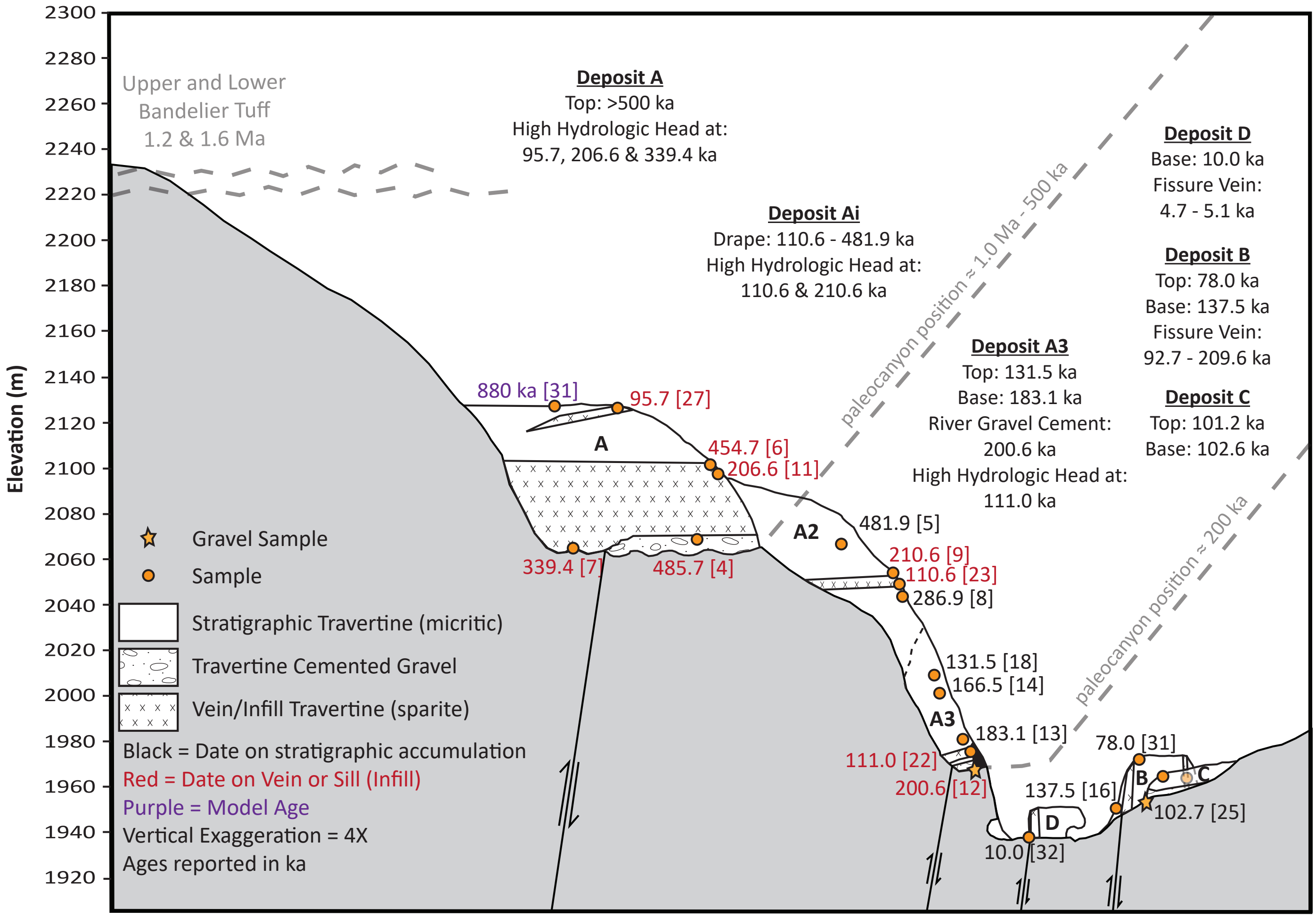

FIGURE 3.17. Schematic west-east profile across San Diego Canyon depicting elevations and U-series ages of travertine samples as well as paleocanyon positions indicated by dated gravels (Tafoya, 2012). Facies dated include stratigraphic travertine (micrite; black) intruded by sills, veins, and infillings (red) that represent continued artesian fluids that moved up faults into existing deposits. Travertine ages and inferred times of high head are listed for each deposit. Dates are in Table 1 of Jean et al. (2024).

FIGURE 3.18. High gravels at the base of Deposit A are up to 33 ft (10 m) thick and contain giant boulders of Bandelier Tuff. The underlying strath is >500–600 ka and possibly records an outburst flood deposit from the demise of a caldera lake. These gravels are crosscut by a 486-ka calcite spar sill. Reed et al. (2024) correlate this gravel with the 630-ka Lava Creek B terrace.

FIGURE 3.19. The base of Deposit A is crosscut by sills of coarse calcite spar with crystal fibers perpendicular to the sill. This sill (U-series date of 486 ka) and other infillings into older travertine deposit range from 491 to 96 ka. This indicates continued artesian head up the faults. The top of Deposit A, and hence the initial depositional age of the gravel and the micrite, is outside U-series range (>500–600 ka) and gives model ages of 491–786 ka with large uncertainty (Jean et al., 2024).

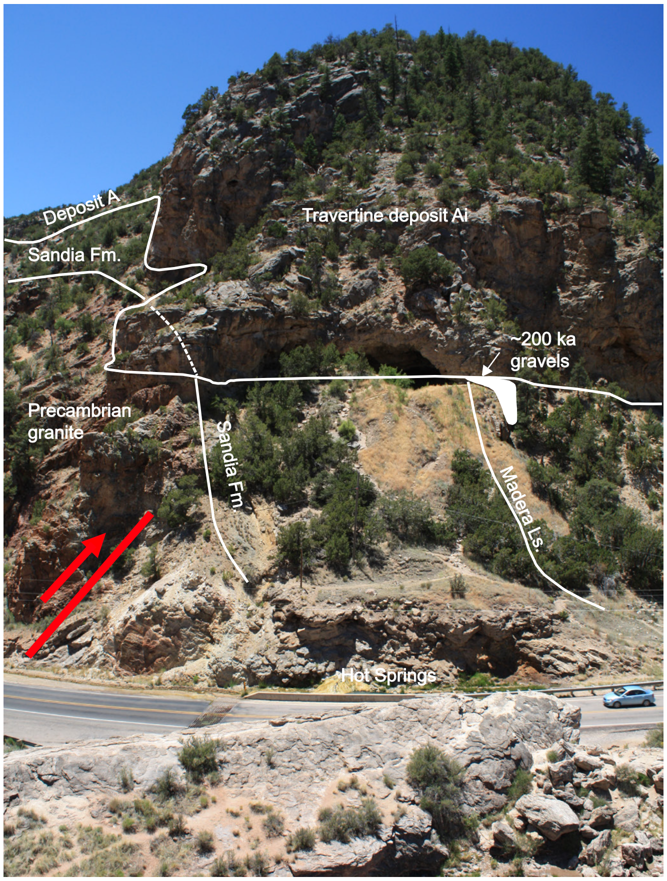

FIGURE 3.20. Deposit Ai is a drape of travertine that was deposited on the sloping edge of Deposit A as the Jemez River was incising deeper into San Diego Canyon. A 482-ka age near the top of the deposit may be close to its initial depositional age. The 287–111-ka ages within the drape are infillings that indicate continued high head and artesian waters seeping up faults into Deposit A and Ai. At the base of the inset, at the cave, are gravels cemented by 201-ka travertine that may be close to the age of this gravel (see incision discussion below).

(B) Soda Dam and "travitonics." The term "travitonics" was used by Hancock et al. (1999) to argue that travertine-depositing springs and resulting travertine deposits are generally aligned along faults that are under extension or transtension. The top of Soda Dam is a place where two fissure ridges intersect at right angles—a northwest fault for the main dam, and a small northeast fault that is parallel to the Jemez fault zone (Fig. 3.15). Deposit B also has two fissure vein segments. Fault intersections under extension provide linear pathways for upward fluid ascent.

(C) Fault-influenced incision. The cave area has 200-ka gravels atop a beveled surface on the upturned Great Unconformity and steeply dipping basal lower Paleozoic strata. Figures 3.17 and 3.20 show the interpretation that this is a Laramide monocline cored by southeast-side-up reverse faults that brings up the basement block.

(D) External CO_2. Hot water still ascends part way up the central Soda Dam fissure and forms a pool in a small cave called the Grotto. The large travertine volumes require that the waters

FIGURE 3.21. Deposit B has a central vein and is a fissure ridge with similar geometry to Soda Dam. It gives ages from as old as 210 ka in the feeder vein to 78 ka in the micrite at the top of the fissure ridge. These ages are interpreted to reflect a ~132-ka depositional longevity of Deposit B. Deposit C (102 ka) was also deposited within this time interval. The position of the river at about 200 ka (at the cave) suggests that river incision may have interacted with growth of deposits B and C, and there are gravels below Deposit C indicating a 100-ka river position. The artesian head pushing waters up the Soda Dam fault from 200 to 100 ka near the river was much less than existed up the Jemez fault to develop infillings in Deposit A over the same interval.

FIGURE 3.22. Soda Dam (Deposit D) is a fissure ridge deposit where hot waters ascended up the central fault, deposited travertine within a central calcite vein, and also seeped up and out on both sides. This view is looking back toward the hot springs by the road from just above the waterfall where the Jemez River undercuts Soda Dam. After the road was smoothed out across Soda Dam in 1976, the head of the hot water supply was diminished such that flow on top of Soda Dam was cut off, but hot waters still come up the fault to a level a few meters directly beneath this picture at the grotto, and you can also see CO_2 bubbles ascending into the pool at the base of the waterfall. Dates from Soda Dam range from 10 ka near its base to 2 ka at its top.

FIGURE 3.23. The lowest layers in the stratigraphic accumulation at this location near road level gave a U-series date of 5000 years, which was likely near the time Soda Dam started building. The central fissure vein has ages of 4700 to 5100 years.

be supersaturated with “external” CO_2 of magmatic origin.

(E) “Chemical volcano” building in the river. The “battle” between lower world (hot springs) and upper world (river) waters is evident in a travertine mound vent that is building right in the river. Over short time periods, the lower world waters and travertines can “win,” but over long time periods, the river has no difficulty breaking through the deposit and leaving older deposits (like A, B, and C) stranded on the sides of the deepening canyon. Using Deposit B as an analog, Soda Dam could remain active for tens to hundreds of thousands of years as the Jemez River incises deeper.

FIGURE 3.24. A small travertine mound or “chemical volcano” is building in the Jemez River.

(F) Tectonic salinization. The water quality impact of Soda Dam spring on the Jemez River is described by numerous workers (Goff et al., 1981; Reid et al., 2003; Jochems et al., 2010; Goff and Goff, 2017; Szynkiewicz et al., 2019). Crossey et al. (2013b) conducted a 10-year campaign sampling of nine stations along the Jemez River from the East Fork confluence to San Ysidro. The results show that numerous geochemical tracers and the overall total dissolved solid load of the river increase in abundance where the hot springs mix with the river at Soda Dam. Arsenic, chloride, strontium, and other elements degrade water quality but when the river is flowing strongly, for example during spring runoff, these effects are diluted, and the geothermal inputs are not enough to be harmful. However, at low flow, the downstream analyses show Jemez waters to exceed EPA drinking water standards. This study is a caution for future climate change scenarios, as reduced snowpack is predicted to result in a higher percentage of low flow times and hence more time of impaired surface water quality in the Jemez River.

(G) Travertine as a climate record. Travertine deposition requires both groundwater and external CO_2, and either or both may control how much travertine gets deposited. If deposition is water-limited, we might see a correlation between wet climate intervals and travertine volume. If it is CO_2- limited, we might see a correlation with volcanic eruptions. As proposed by Goff and Gardner (1994) and Jean et al. (2024), travertine deposition at Soda Dam may also provide a record of the history of caldera lakes where groundwater head would have been increased at high lake levels, promoting higher flow in downstream springs. Also, the gravel at the base of Deposit A is not a usual Jemez river gravel (Fig. 3.18) and may reflect an outburst flood event from the demise of a volcanic dam in the headwaters of the Jemez River about 600 ka.

END OF THIRD-DAY ROAD LOG

Combined references for the First-Day, Second-Day, and Third-Day Road Logs are available on p. 95 and on the NMGS website at: https://nmgs.nmt.edu/publications/guidebooks/downloads/74