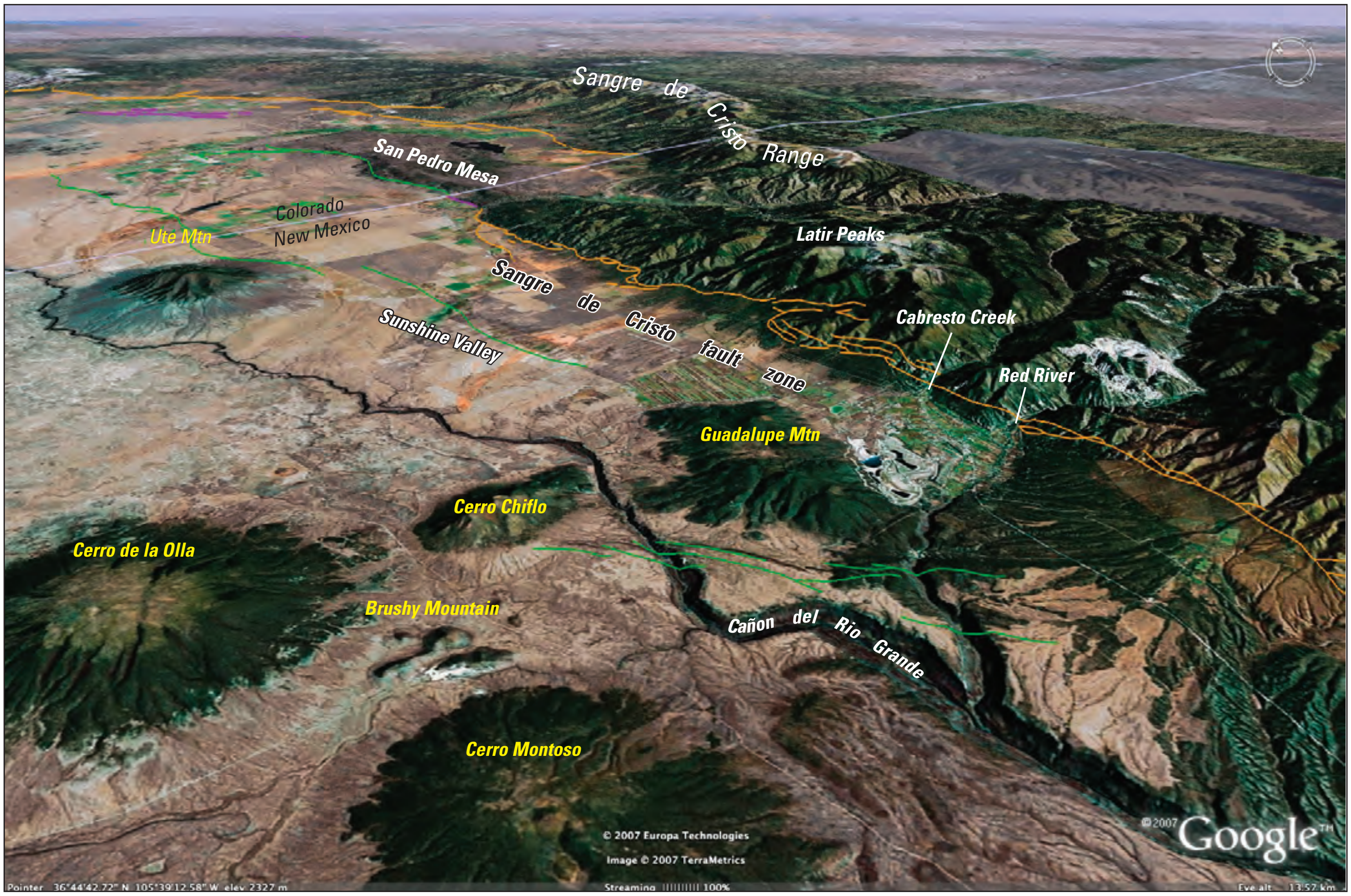

Frontispiece, Chapter C. Oblique aerial view of Sunshine Valley as imaged by Google Earth (v.4.0.1694, beta; © 2007 Europa Technologies, New Mexico; image © 2007 TerraMetrics). Faults shown as green, orange, and magenta lines from USGS Quaternary Fault and Fold Database (http://earthquake.usgs.gov/regional/qfaults/).

Chapter C — Field Trip Day 3 Quaternary Geology of Sunshine Valley and Associated Neotectonics Along the Latir Peaks Section of the Southern Sangre de Cristo Fault Zone

By Cal Ruleman, Ralph Shroba, and Ren Thompson

Overview

Day 3 focuses on our current understanding of the volcanogenic, fluvial, and tectonic development of Sunshine Valley, including the piedmont adjacent to the Latir Peaks–Taos Mountains. We begin by discussing the volcanogenic and fluvial setting of Sunshine Valley and the Rio Grande–Red River system prior to Cañon del Rio Grande incision. This sets the stage for an inspection of the geomorphic and tectonic development and associated landforms of Sunshine Valley related to headward erosion of the Rio Grande River system.

Throughout the day we will traverse multiple surfaces related to changes in the depositional, tectonic, and geomorphic system of Sunshine Valley (fig. C–1). We have interpreted these surfaces of differing age and position as representing a shift from a slowly aggrading, closed-basin system to a degradational, cut-and-fill system with base level controlled by the incision of the Rio Grande River. We will observe and discuss structural controls on the position of the Rio Grande canyon within the basin. At the northern end of Sunshine Valley we will look at scoured channels on Servilleta Basalt (3.66–4.75 Ma) and discuss evidence for basin geomorphic system changes associated with headward erosion of the Rio Grande. We will discuss initiation of canyon erosion and its probable association with Lake Alamosa. Heading east towards the Taos Mountains–Latir Peaks range front of the Sangre de Cristo Range, day 3 will conclude with a look at Quaternary faulting along the Sangre de Cristo fault zone and the probable tectonic controls on piedmont development and morphology. To assist with geologic map reading and understanding map unit correlations, we've provided

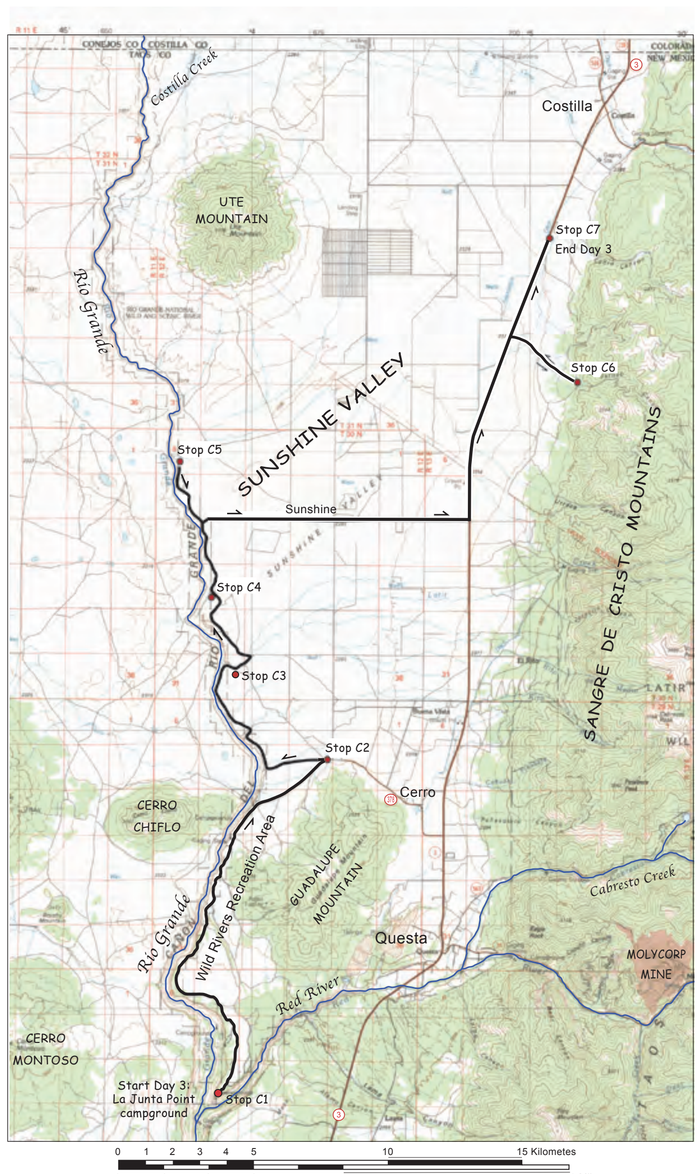

Figure C–1. Index map showing route and stops on field trip day 3.

a correlation of map unit figure to accompany all figures (fig. C–2).

Acknowledgments

We would like to give our appreciation to the staff at Wild and Scenic Rivers for providing the beautiful campsite at La Junta Point. Their assistance with our accommodations has made our last night of the field trip a delight. We also thank the Bureau of Land Management for the maintenance of roads and access across Sunshine Valley and at Urraca Ranch. In addition, we appreciate the constructive and helpful comments of Susan Olig (URS) and Daniel Koning (New Mexico Bureau of Geology and Mineral Resources), who reviewed a preliminary version of this manuscript. However, any errors that may remain are the responsibility of the authors.

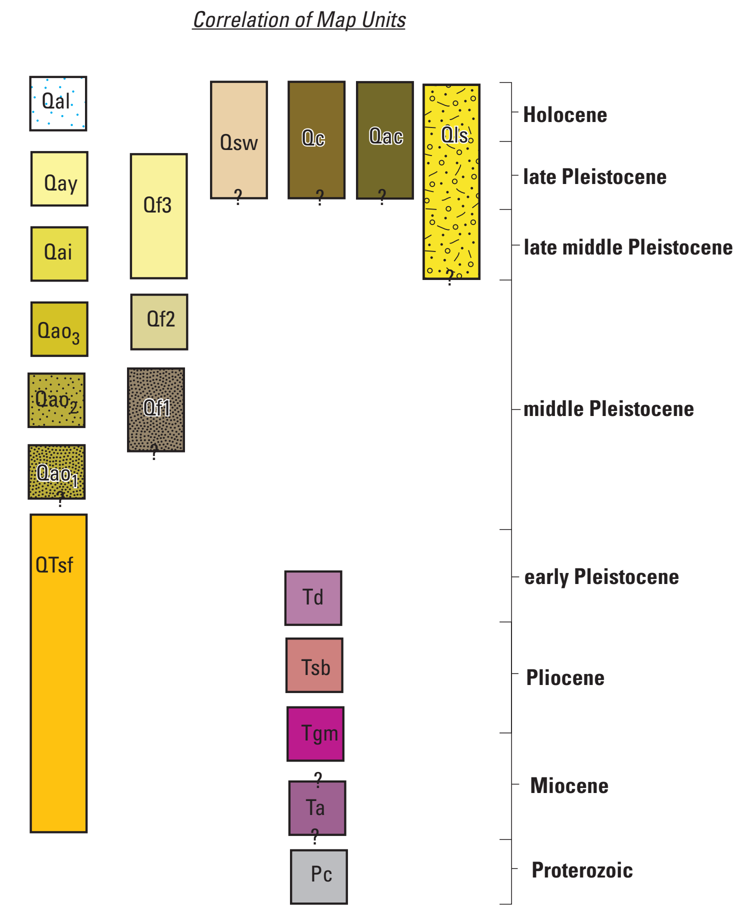

Figure C–2. Correlation of map units for Sunshine Valley.

Stop C1 — Volcanic and Geomorphic Setting of the Sunshine Valley and Taos Plateau

Speakers: Ren Thompson and Cal Ruleman
Start time: 7:30 am
Duration: 30 minutes
Location: La Junta Overlook Campground, Wild Rivers and Scenic Rivers BLM Park and Campground, about 6 mi southwest of Questa, N. Mex.
Guadalupe Mountain 7.5' quadrangle
GPS: NAD27, Zone 13, 438735 m E., 4056803 m N.
Elevation: 7,450 ft asl (approximate at campground)

Synopsis

At this location we will discuss the volcanic stratigraphy of the Servilleta Basalt (3.66–4.75 Ma) exposed in canyon walls and the geomorphic setting prior to canyon incision north of the Rio Grande–Red River confluence. Here we will discuss the Rio Grande's evolution in relation to the Red River–Cabresto Creek terrace suites and correlative units within Sunshine Valley.

Discussion

La Junta Point overlooks the confluence of the Red River and Rio Grande and provides an unparalleled view into the volcanic and sedimentary base deposits exposed in the deeply incised canyons of both drainage systems (fig. C1–1). Prior to capture of the upper Rio Grande drainage system (Wells and others, 1987; Machette and others, chapter G, this volume), the Red River drainage formed the headwaters of the ancestral Rio Grande in northern New Mexico. The thick sedimentary deposits underlying volcanic rocks of the Taos Plateau volcanic field are predominantly alluvial fan gravels of the Red River drainage system that were undercut and slumped as

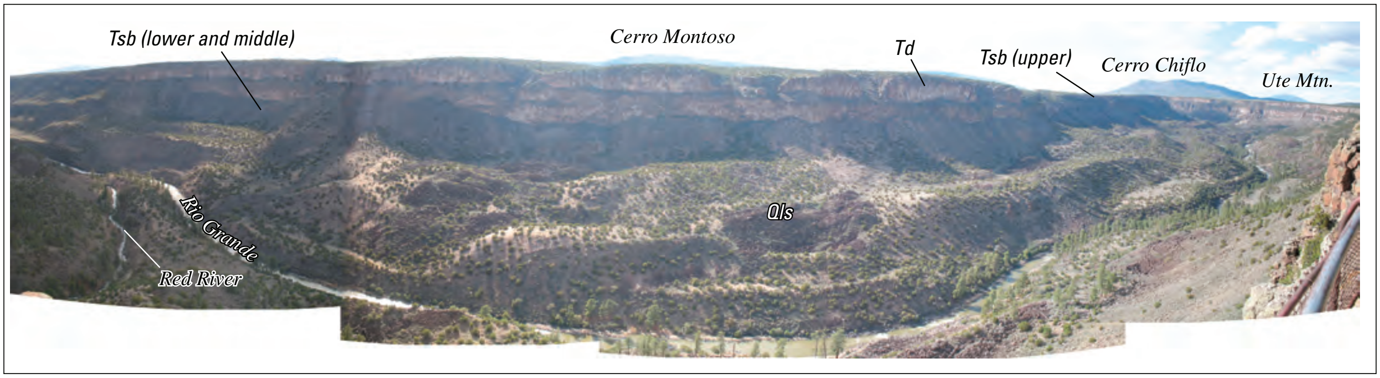

Figure C1–1. Panoramic view of the west wall of the Rio Grande gorge as seen from La Junta Point.

Toreva blocks after incision by the integrated Rio Grande–Red River fluvial system.

The westward-prograding Red River alluvial fan had a profound effect on the syndepositional and postdepositional distribution of volcanic rocks of the Taos Plateau volcanic field (Dungan and others, 1984). Lava flows exposed at the confluence of the Rio Grande and Red River erupted from vent areas to the south and west. These flows pinch out eastward against, and overlie as thin lava flow veneers, the thick sequence of west-sloping fluvial deposits. The volcanic section thickens markedly to the south, away from the topographically high fan deposits; this relation is most notably reflected in the thickening of the composite thickness of the Servilleta Basalt southward toward the "High Bridge" over the Rio Grande gorge, northwest of Taos, N. Mex. The volcanic stratigraphy exposed in the Red River drainage is dominated by lava flows erupted from volcanic centers east of the Rio Grande drainage. These basalts flowed westward and overlie older members of the Servilleta Basalt exposed on the western rim of the Rio Grande gorge rim (McMillan and Dungan, 1986). The complex interplay of volcanism and basin deposition is integral to the interpretation of stratigraphy exposed along the length of the Rio Grande drainage where it incises rocks of unit Taos Plateau volcanic field. The confluence of the Red River and the Rio Grande can be seen in the lower left corner of the photograph in figure C1–1. Alluvial-fan deposits of the ancestral Red River underlie landslide deposits (unit Qls) from river level to the base of the overlying volcanic section. Volcanic rocks of the western gorge rim include (1) a capping flow of Servilleta Basalt (unit Tsbu) visible along the gorge rim near the left and right margins of the photograph, (2) a petrologically atypical, sparsely phyric dacite lava flow (unit Td) from the "UCEM" (Unnamed Cerrito East of Montoso) volcano that forms the gorge rim in the center of the photograph, and (3) basal lava flows of Servilleta Basalt (unit Tsbl) that overlies alluvial-fan deposits.

Proximal to Questa, the Red River and Cabresto Creek emerge from the Sangre de Cristo Mountains and form two deeply incised canyons and the headwaters of the ancestral Rio Grande. This fluvial system has an associated suite of seven pre-Holocene terraces ranging in elevation from 7,660 to 7,320 ft above sea level (Pazzaglia and Wells, 1990). The oldest terrace (unit Qt1) is formed on sediment of the Santa Fe Group (>640 ka) at an elevation of 7,660 ft. It includes a capping coarse-grained gravel veneer. Pedogenic soils on this terrace tread are characterized by stage III–IV carbonate development, indicative of >250 ka deposits (Machette, 1985). Pazzaglia (1989) mapped this surface as unit Qt2 and assigned an age of 300–600 ka on the basis of soil morphology and regional correlations. The unit Qt2 surface is inset into a surface grading to the youngest of the three pre-Rio Grande Cañon incision deposits (unit Qao) mapped to the northwest in Sunshine Valley. The highest surface north of Cabresto Creek and south of Red River is correlated with the highest and oldest surface mapped in Sunshine Valley (unit Qao1), characterized by a pebble-gravel cap overlying fine-grained, silty, basin fill sediments of the Santa Fe Group (unit QTsf). This deposit overlies what has been previously called the Lama Formation (Pazzaglia, 1989), which consists of moderately to well sorted, gravelly, silty sands and sandy pebble gravels with carbonate development ranging from stages II to IV. To the north within Sunshine Valley we have differentiated three subunits of this gravel deposit capping the Santa Fe Group: units Qao1, Qao2, and Qao3.

Stop C2 — Highest Depositional Surface Within Sunshine Valley

Speaker: Cal Ruleman and Ralph Shroba
Start time: 8:30 am
Duration: 30 minutes
Location: Fork in road of Wild and Scenic Rivers Road and BLM Rim Road
Sunshine Valley, New Mexico 7.5' quadrangle
GPS: NAD 27, zone 13, 442701E, 4068963N
Elevation: 7,522 ft asl

Synopsis

This promontory on Servilleta Basalt yields a view to the north showing the highest depositional surface across Sunshine Valley (fig. C2–1). To the north, this surface is underlain by Plio-Pleistocene Santa Fe Group capped by less than 2 m of pebbly coarse sand. The gentle to flat slope of this surface grades to the southwest across the river canyon and is interpreted as reflecting the last depositional cycle (units Qao1, Qao2, and Qao3) before deep canyon incision was initiated and entrenchment of subsequent younger deposits occurred. The route we follow north across Sunshine Valley will traverse this older surface several times.

Discussion

We begin our traverse of Sunshine Valley where Servilleta Basalt is exposed on an erosional bedrock surface. To the north, intrabasin faulting has tilted and downdropped the Servilleta Basalt to induce subsequent burial by the Plio-Quaternary Santa Fe Group (>640 ka) (figs. C2–2 and C2–3). This bedrock surface is approximately 7 m (22 ft) above the oldest pebbly coarse sand deposit of unit Qao at this location, mapped as Qao2. We correlate this surface with the oldest portions of the Costilla–Cabresto Plain to the north, as well as with the highest surface proximal to Red River and Cabresto canyons. Younger middle and late Pleistocene deposits are entrenched and inset into this surface by as much as 30 m (100 ft).

A gravel pit to the northeast (UTM NAD27 443041 E, 4069217 N) (fig. C2–3) exposes younger inset deposits with two buried soils beneath late Pleistocene eolian silts and thin fan gravel deposits (unit Qay). The soil sequence exposed here contains a 45-cm-thick Stage III calcic horizon on coarse gravel deposits capped by approximately 60 cm of loess with strong Bt development, interpreted as buried late-middle Pleistocene eolian deposits (unit Qai). We interpret this exposure to indicate that post–unit Qao deposition was limited to eolian infilling of abandoned inset channels in the unit Qao surface. The lack of channel-fill alluvial deposits and the presence of eolian silts indicates that incision dominated the post-middle Pleistocene fluvial setting. The coarser pebble gravel underlying the Bk stage III soil horizon indicates that a fluvial system, probably fed from Cabresto Creek and small drainages to the north, existed at this location until unit Qao was incised. After a period of deep incision occurred, these channels became filled by units Qai- and Qay-correlative eolian and alluvial deposits, respectively.

Figure C2–1. View north across Sunshine Valley and towards Ute Mountain.

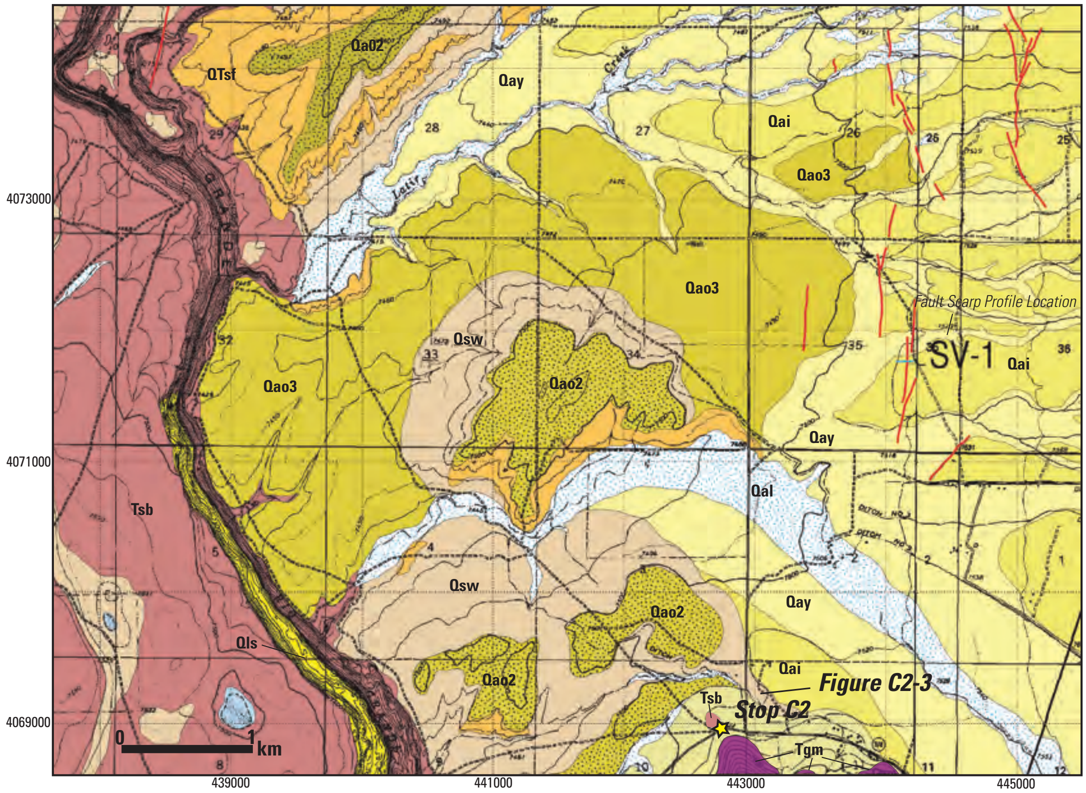

Figure C2–2. Geologic index map for stop C2. Units listed as follows: Qal, Holocene alluvium; Qsw, late Pleistocene and Holocene slopewash deposits; Qls, late Quaternary landslide deposits; Qay, late Pleistocene; Qai, late-middle Pleistocene alluvium; Qao2 and Qao3, middle Pleistocene alluvium; Tsb, Servilleta Basalt; and Tgm, Guadalupe Mountain dacite. Red lines are mapped Quaternary faults. UTM coordinates are given in NAD 27 coordinate system. SV–1 is number of fault scarp profile.

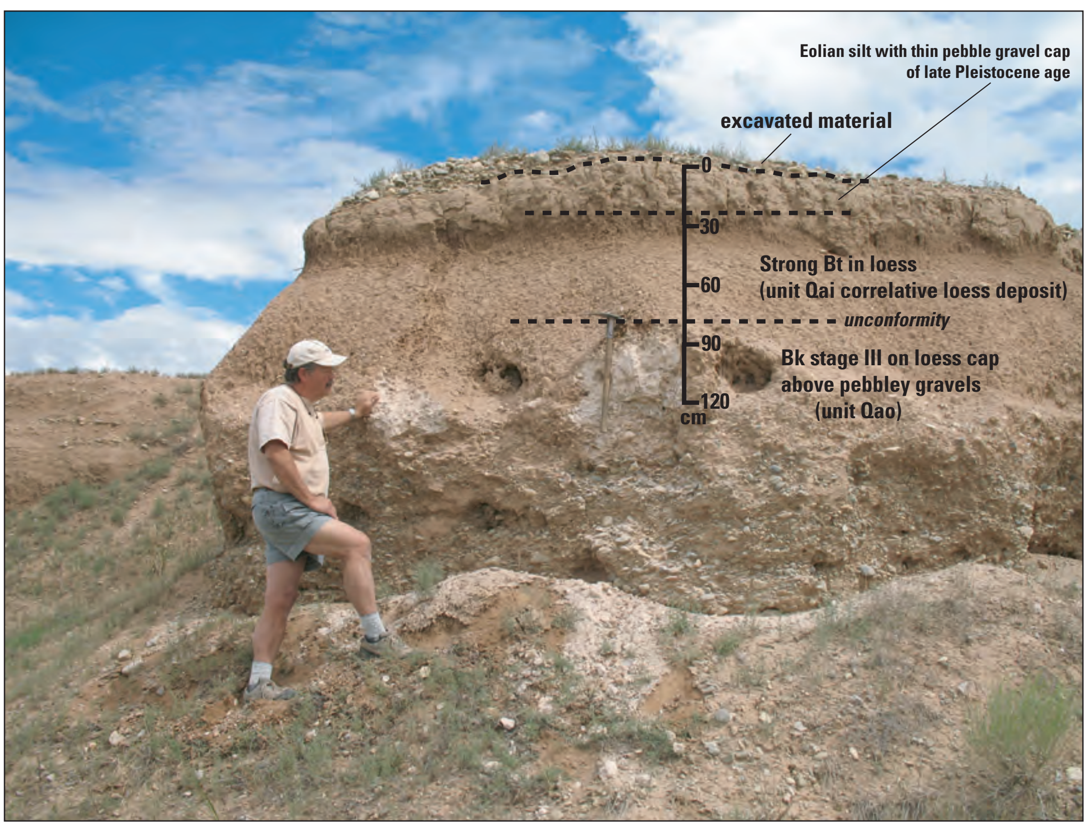

Figure C2–3. Soil sequence exposed in gravel pit northeast of stop C2.

Stop C3 — Faulted Servilleta Basalt (3.66–4.75 Ma) at Latir Creek

Speaker: Cal Ruleman
Start time: 10:00 am
Duration: 30 minutes
Location: Rio Grande Rim Road
Sunshine Valley, New Mexico 7.5' quadrangle
GPS: NAD 27, zone 13, 439447E, 4072188N
Elevation: 7,410 ft asl

Synopsis

Upper Pleistocene and younger alluvium were deposited with an unconformity against an exhumed fault line scarp cut on Servilleta Basalt. Antithetic to the west-dipping southern Sangre de Cristo fault zone along the range front to the east, these antithetic fault strands apparently bound the Sunshine Valley graben along the western basin margin and are considered to be the northern extension of the Gorge fault zone mapped to the south in proximity to Taos and Arroyo Hondo (fig. C3–1).

Discussion

The fault evident at this stop is part of a north-northwest-trending fault zone characterized by east- and west-facing scarps on individual fault strands having displacements of less than 20 m (fig. C3–2). This fault zone roughly coincides with Cañon del Rio Grande, indicating probable fault control on the river's position within the basin as first proposed by Winograd (1959). This fault zone continues to the south where it is the Gorge fault zone (Read and others, 2004) and bounds the western margin of the Taos Plateau near Cañon del Rio Grande (Cordell and Keller, 1984). Read and others (2004) noted that the expression of this fault zone is subtle, but it can be identified by fault scarps, lineaments, and springs. To the south of the confluence of the Red River with the Rio Grande, this fault zone includes the Dunn fault (Dungan and others, 1984) and fault strands splaying off of the Embudo fault (Kelson and Baur, 1998). At stop C3, upper Pleistocene to Holocene alluvium and loess have been deposited with buttress unconformity against an east-facing exhumed fault-line scarp on the Servilleta Basalt.

At stop C3 we have mapped pebbly coarse sand of unit Qao3 on the upthrown side of the fault, and to the north units Qao2 and Qao1 drape across this fault zone as well, indicating that no apparent middle to late Quaternary displacement occurred along this particular fault zone. Thus, we interpret these scarps as exhumed fault-line scarps, concealed by the Santa Fe Group–Lama Formation (>640 ka) and middle Pleistocene alluvium (units Qao1, Qao2, and Qao3) and exhumed by subsequent erosion and incision. Approximately 4 km to the east, intrabasin faults within the central part of Sunshine Valley and range-bounding faults on the east side of Sunshine Valley have late-middle to late Pleistocene displacement, indicating dominant central and eastern basin-margin tectonic activity (fig. C3–3). Mapping of subtle lineaments and escarpments within central Sunshine Valley indicates probable Holocene displacement of <1 m, possibly a product of coseismic displacement associated with large events (>M_w 7.0) along the range-bounding southern Sangre de Cristo fault zone (Ruleman and Machette, chapter J, this volume). Gravity and magnetic data support the presence of this western basin-bounding fault zone as well as a very complex intrabasin fault system (Bankey and others, 2005, 2006) (fig. C3–4).

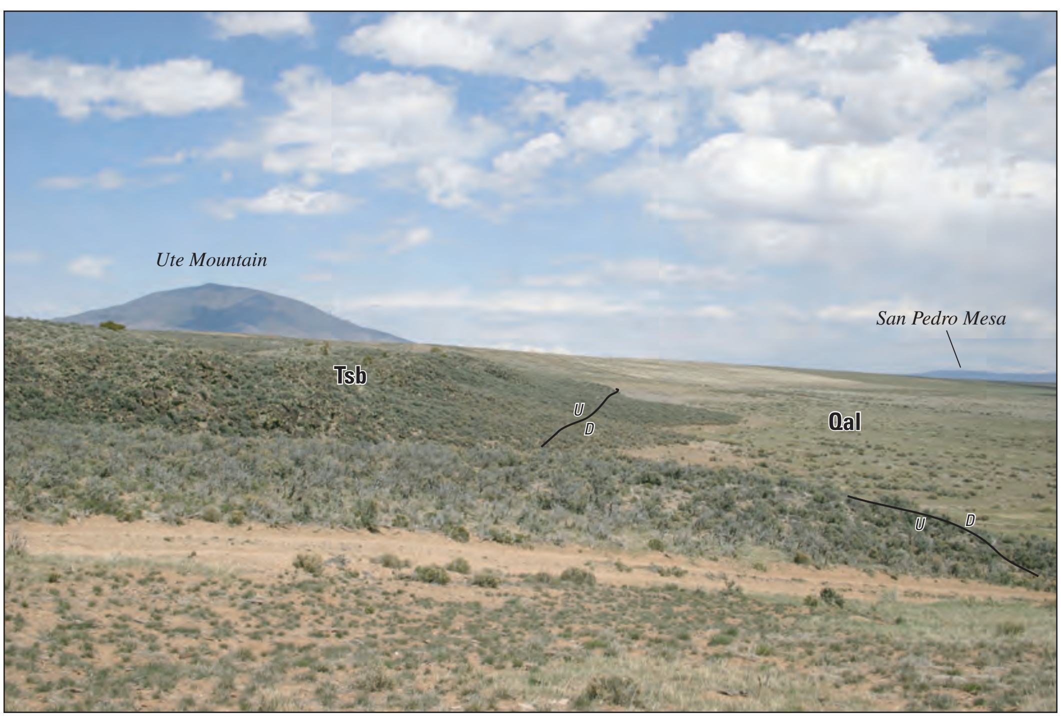

Figure C3–1. View to the north at stop C3. These escarpments on Servilleta Basalt are exhumed fault line scarps with no apparent middle to late Pleistocene displacement.

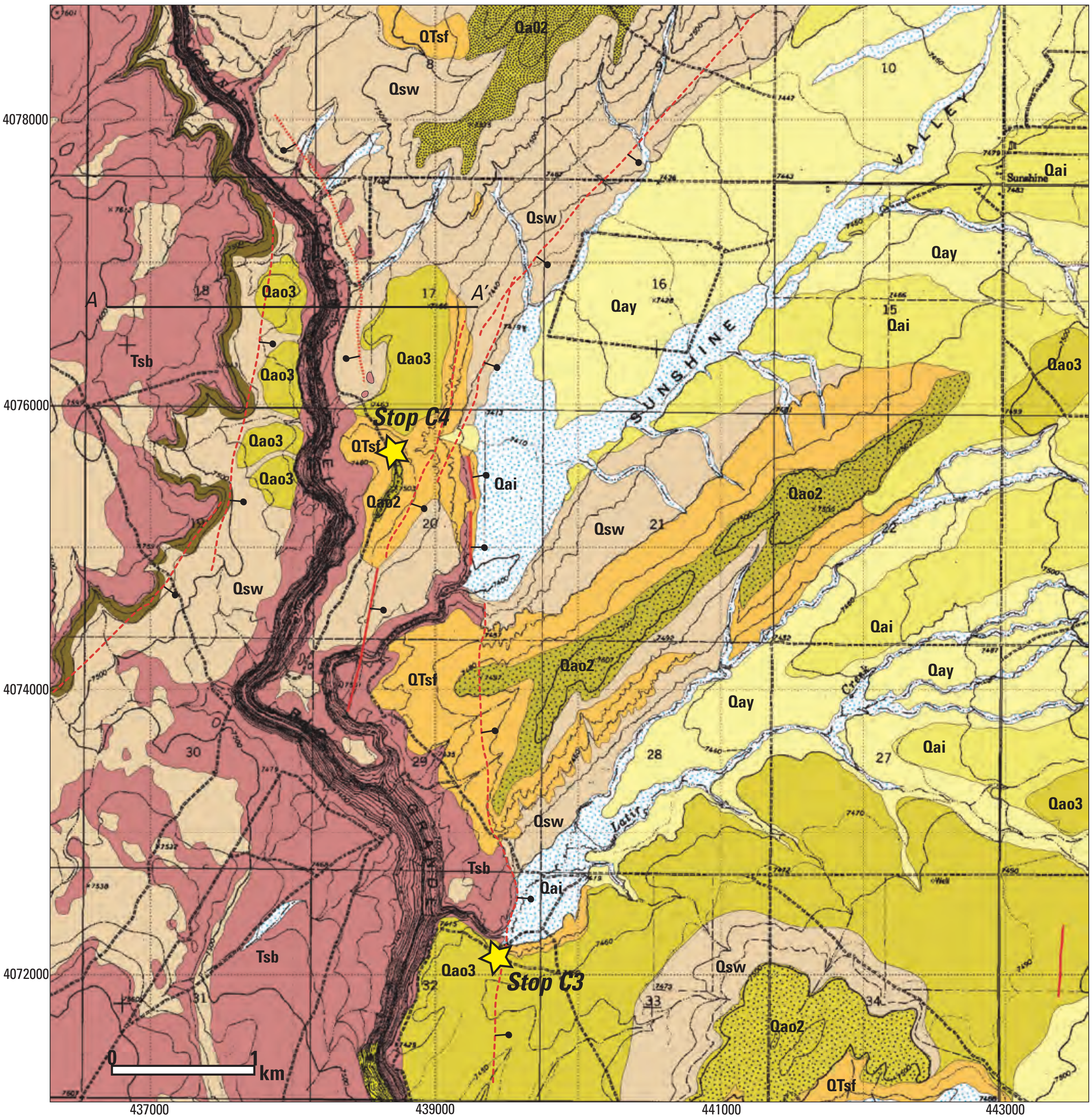

Figure C3–2. Geologic index map of stops C3 and C4. Units listed as follows: Qal, Holocene alluvium and Qsw, late Pleistocene and Holocene slopewash deposits; Qay, late Pleistocene alluvium; Qai, late-middle Pleistocene alluvium; Qao2 and Qao3, middle Pleistocene alluvium; QTsf, Santa Fe Group (>640 ka); and Tsb, Servilleta Basalt. Solid red lines are faults of probable late Pliocene to early Quaternary displacement, dashed where inferred and dotted where concealed. UTM coordinates given in NAD 27 coordinate system.

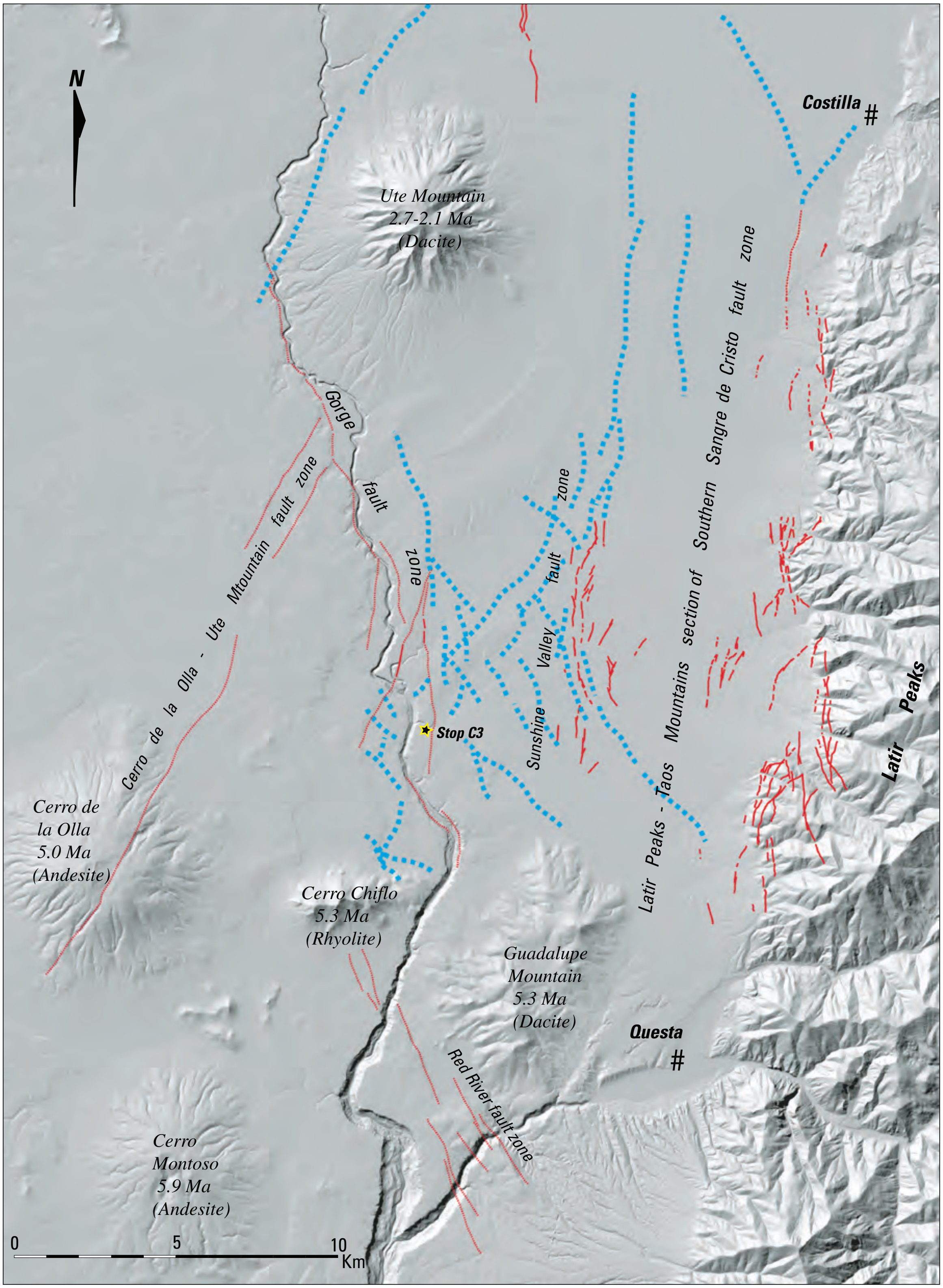

Figure C3–3. Volcanic centers and structural framework of Sunshine Valley (modified from Read and others, 2004). Solid red lines are late-middle Pleistocene to Holocene faults scarps. Dotted red lines are fault scarps and exhumed fault line scarps of middle Pleistocene and older age. Dashed blue lines are faults mapped from our preliminary interpretation of aeromagnetic data from Bankey and others (2005 and 2006). Shaded-relief base map by Ted Brandt (U.S. Geological Survey).

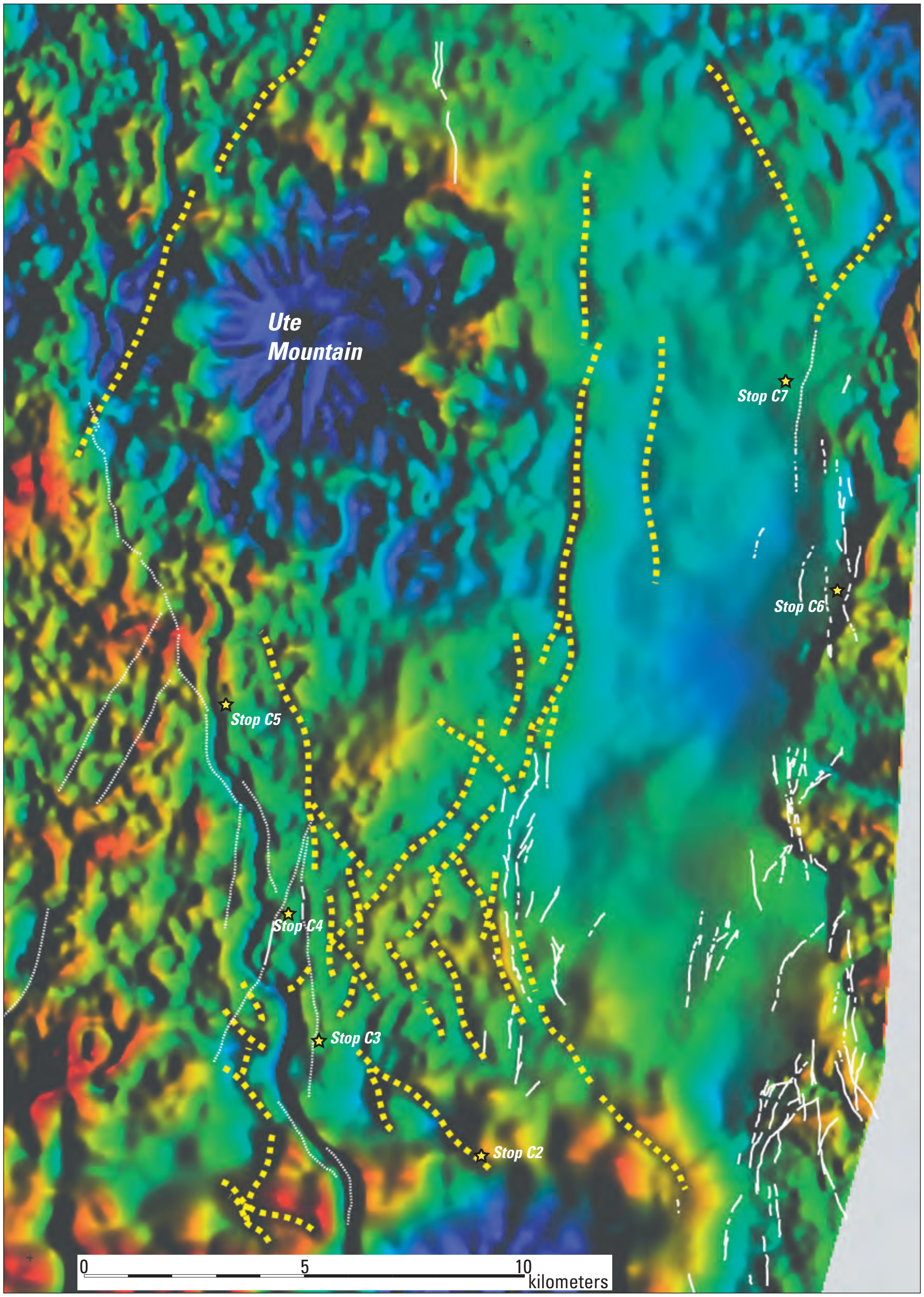

Figure C3–4. Color shaded-relief image of aeromagnetic data merged from two different surveys (Bankey and others, 2005, 2006) and structural framework of Sunshine Valley. The total data range is 2645 nT, with low to high values represented by cool to warm colors, respectively. Illumination is from the east. Data were filtered to enhance details and reduced to the pole to facilitate interpretation. Image courtesy of V.J.S. Grauch (USGS). Solid white lines are late-middle Pleistocene to Holocene fault scarps. Dotted white lines are inferred faults and exhumed fault line scarps. Dashed yellow lines are interpreted faults from aeromagnetic data.

Stop C4 — Old Alluvium (Unit Qao2) Overlying Servilleta Basalt and Santa Fe Formation

Speakers: Ralph Shroba and Cal Ruleman
Start time: 11:00 am
Duration: 30 minutes
Location: Sunshine Valley, New Mexico 7.5' quadrangle
GPS: NAD 27, zone 13, 438745E, 4075600N
Elevation: 7,480 ft asl

Synopsis

At this stop we observe pebbly coarse sand in the basal part of unit Qao2 and underlying silty sand of the Santa Fe Group (unit QTsf) exposed in a shallow gully. Unit Qao2 is the middle unit of three old alluvial units derived from the Sangre de Cristo Mountains that predated the incision of the Cañon del Rio Grande. The top of unit Qao2 is inset about 15 m (50 ft) below the top of the oldest of the three units (unit Qao1) at 7,550 ft asl and is about 13 m above the top of the youngest unit (unit Qao3) at 7,460 ft asl.

Discussion

This inset of units Qao2 and Qao3 below unit Qao1 suggests minor episodes of stream incision and backfilling after the widespread deposition of unit Qao1 but prior to deep canyon cutting by the Rio Grande (fig. C3–2). Late middle Pleistocene alluvium (unit Qai) is the next youngest deposit preserved within the valley and is inset into unit Qao as much as 30 m, suggesting a period of deep incision and extensive erosion between deposition of units Qao and Qai. At this stop, unit Qao2 is about 1.8 m thick and mainly coarse sand. However, granules are abundant and granitic and volcanic pebbles as large as 3–5 cm are common. The upper 5 m of the underlying sediment (Santa Fe Group) is similar in character to Santa Fe Group sediment exposed in other small outcrops north and south of Ute Mountain. Here and at these other outcrops, the Santa Fe commonly consists of very silty, mostly very fine to medium sand; it is consolidated, slightly sticky, and plastic to very plastic, and it has strong brown, reddish yellow, and pink colors (7.5YR 5/6, 6/6, and 7/4, dry; Munsell, 1994). The abundance of medium sand and finer material in the Santa Fe suggests deposition in a low-energy, closed-basin environment. The low point of the basin was between Cerro Chiflo and Guadalupe Mountain at an elevation between about 7,480 and 7,640 ft, about 8 mi (13 km) southeast of here.

About 0.4 km northeast of here, alluvium of unit Qao3 is about 3.4 m thick; it consists of 1.3 m of subangular pebble sandy gravel rich in volcanic and granitic pebbles (commonly as large as 3–4 cm) overlain by 2.1 m of pebbly sand. These deposits overlie slightly silty, mostly very fine to fine sand of the Santa Fe Group (unit QTsf). The top of unit Qao3 projects across the Cañon del Rio Grande (fig. C4–1), which indicates a preincision age for the entire Qao alluvial sequence.

NOTE 1: Along our drive to stop C5, follow the route on geologic index map to identify local intrabasin faults and topographic relations among Quaternary deposits. These faults form a shallow, north-trending graben system, which the Rio Grande has incised and eroded, leaving most of the grabens with very subtle expression.

NOTE 2: Lunch at stop C5: 12:00 pm

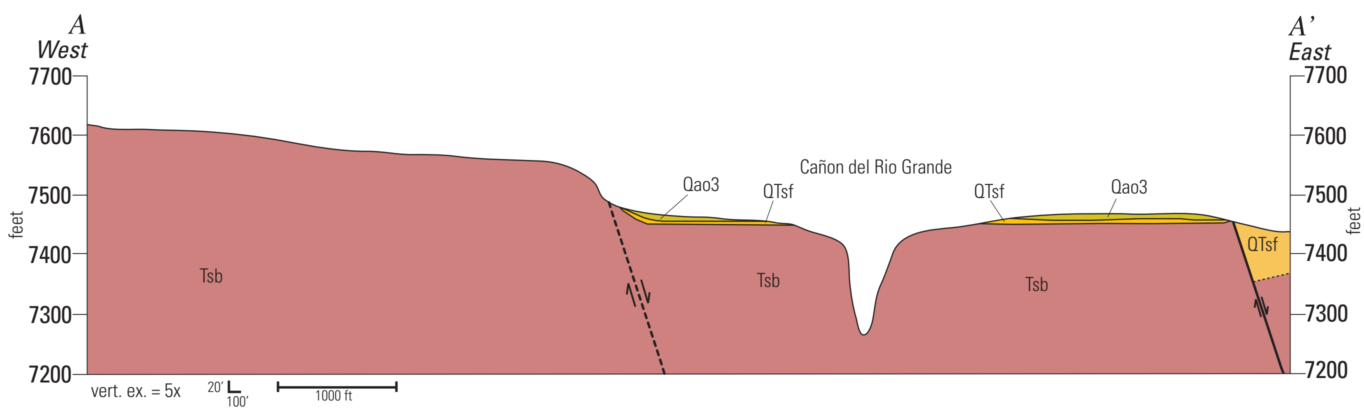

Figure C4–1. Cross section A-A' within north of stop C4 (see figure C3–2 for exact location). Units listed as follows: Qao3, middle Pleistocene alluvium; QTsf, Oligocene to middle Quaternary sediment of Santa Fe Group (25 Ma–640 ka); and Tsb, Pliocene Servilleta Basalt (4.5–3.66 Ma).

Stop C5 — Ute Mountain Volcanic Rocks and Fan Deposits and Surficial Geology of Northern Sunshine Valley

Speakers: Ren Thompson and Ralph Shroba
Start time: 12:30 pm
Duration: 30 minutes
Location: Rio Grande Rim Road north of Sunshine Valley Road junction
Ute Mountain, New Mexico 7.5' quadrangle
GPS: NAD 27, zone 13, 437402E, 4079845N
Elevation: 7,450 ft asl

Synopsis

At this stop we will discuss (1) the lithologic composition and volcanic history of Plio-Pleistocene Ute Mountain, (2) the genesis and inferred ages of the fan deposits that flank the mountain, and (3) the inferred timing of canyon incision by the Rio Grande (fig. C5–1).

Discussion

The view to the north of here is dominated by Ute Mountain, the northernmost dacite volcano in the Taos Plateau volcanic field. Rising to an elevation of nearly 10,100 ft, Ute Mountain towers above the floor of Sunshine Valley and is a prominent landform visible from much of the southern San Luis Valley. The eroded edifice of Ute Mountain consists of a series of a monolithologic dacite lava domes, spines, and flows that all are cut by radial dikes that form prominent ridges that emanate from the summit. The eruptive age of Ute Mountain is poorly constrained by $^{40}Ar/^{39}Ar$ ages of 2.7 and 2.1 Ma (Appelt, 1998), making this volcano the youngest of the large eruptive centers of the Taos Plateau volcanic field. The dacite edifice is built upon an older eroded olivine andesite volcano of unknown age that crops out low on the flanks of Ute Mountain and in the Rio Grande gorge (Cañon del Rio Grande) immediately to the west of this stop (figs. C5–2 and C5–3). This unnamed andesite volcano locally predates the eruption of Servilleta Basalt, because lava flows exposed in the Rio Grande gorge lap onto the lower flanks of this andesitic shield (unit Ta). The Tertiary andesite lava flows exposed in the Rio Grande gorge near this location have well-developed primary pahoehoe flow textures and thus are extremely unusual, and perhaps unique, in the geologic record.

Alluvial fans, composed chiefly of debris-flow deposits of three age groups, form a wide coalesced piedmont apron on the lower flanks of Ute Mountain (fig. C5–1). These deposits record the late erosional history of the dacite volcano. On the southwest flank of Ute Mountain, the oldest exposed alluvial fan deposits (unit Qf1) overlie alluvium correlated with unit Qao1 (chapter K, this volume). The top of unit Qf1 and that of intermediate-age fan deposits (unit Qf2) project above the steep-sided lower part of the Cañon del Rio Grande (fig. C5–4). Although deposits of units Qf1 and Qf2 have not been recognized west of the Rio Grande, unit Qao3 (youngest and lowest of the three alluvial units of middle Pleistocene age) is exposed on both sides of the Cañon del Rio Grande (fig. C4–1). These relationships suggest that the deposition of units Qf1 and Qf2 may predate major canyon cutting by the Rio Grande. Geomorphic position as well as stage I and II carbonate morphology on subsurface clasts (Machette, 1985) suggests that unit Qf3 is probably equivalent or partly equivalent in age to nearby alluvial units Qay (Pinedale age) and Qai (Bull Lake age) (Cal Ruleman, unpub. mapping, 2007). On the southeast side of Ute Mountain, deposits of unit Qf3 appear to be graded to deposits of unit Qay. The inferred ages and geomorphic position of unit Qf3 suggest that the deposition of this unit postdates major canyon cutting, which began about 440 ka (chapter B, this volume).

At this location, river-scoured Servilleta Basalt is overlain by a thin veneer of pebbly sand. This scoured surface is correlated with a surface about 0.75 mi (1.2 km) northwest of here (on the west side of the Rio Grande) where we have obtained five samples for ^{3}He surface-exposure dating. The ^{3}He surface-exposure ages will help to constrain the time of initial incision of the Cañon del Rio Grande along this reach of the river. Thin deposits of gravelly alluvium of unit Qao3 are exposed on both sides of the Cañon del Rio Grande and thus predate major canyon cutting by the Rio Grande. Younger alluvial deposits (units Qay of late Pleistocene age and Qai of late-middle Pleistocene age) are inset into older alluvial deposits (units Qao1, Qao2, and Qao3) as much as 30 m, suggesting a period of widespread incision and erosion postdating deposition of unit Qao and predating deposition of unit Qai, as seen at stop C4. This period of rapid incision corresponds with base-level changes driven by the incision of the Rio Grande.

At this location, Cañon del Rio Grande is roughly 40 m (130 ft) deep. Assuming a long-term fluvial erosion rate of 0.15 mm/yr (15 cm/ka) (Dethier, 2001), the initial timing of canyon incision would be on the order of <600 ka. This roughly estimated age is in accord with the time of the draining of Lake Alamosa, located about 40 km (25 mi) north of here, at about 440 ka (chapter G, this report), assuming that an initial outburst of Lake Alamosa would have created more rapid incision rates before flow stabilized.

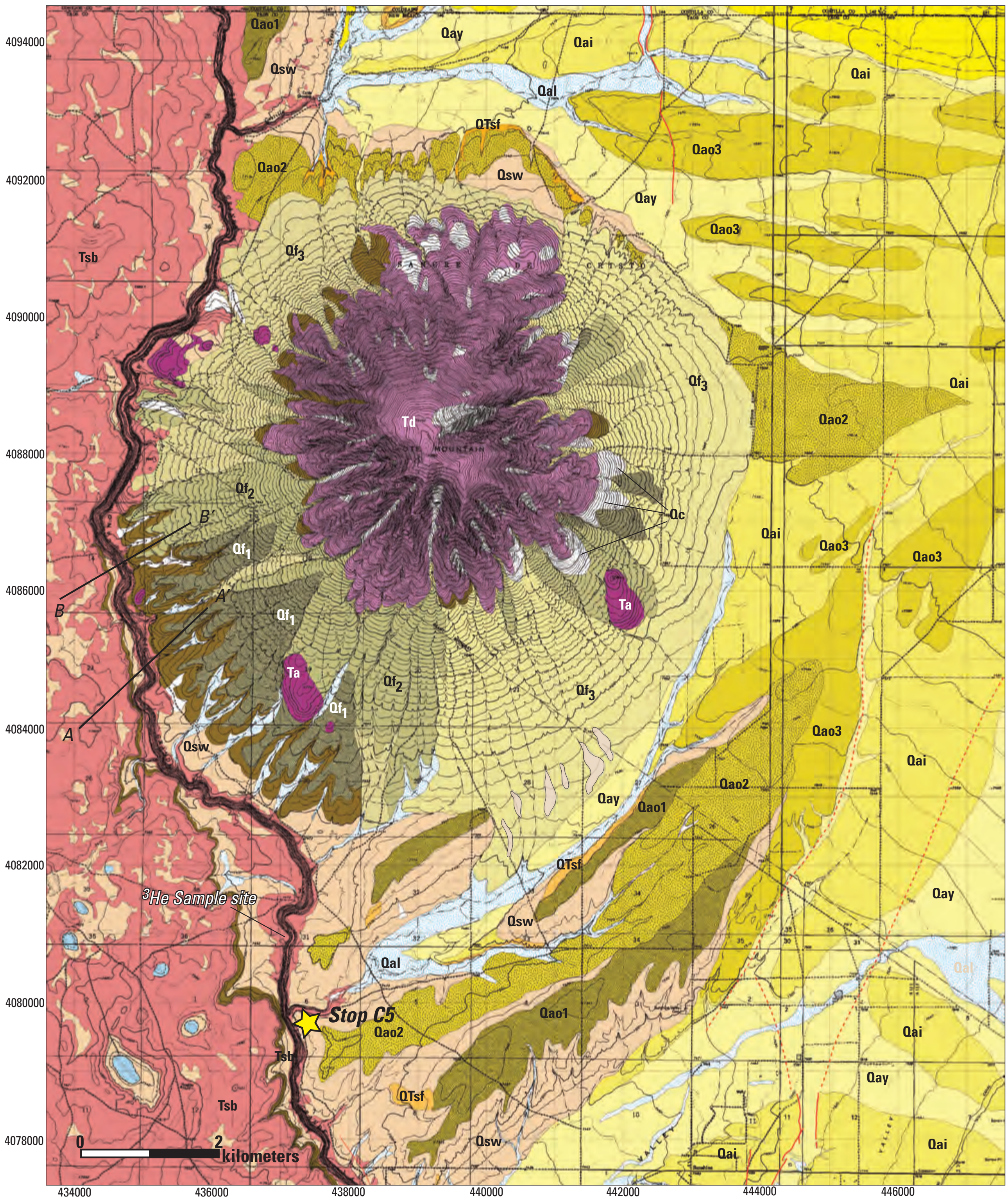

Figure C5–1. Geologic index map of stop C5 showing volcanic flows and alluvial fans associated with Ute Mountain. Units listed as follows: Qf3, late-middle and late Pleistocene fan alluvium; Qf2, upper middle Pleistocene fan alluvium; Qf1, lower middle Pleistocene fan alluvium; Qal, Holocene alluvium; Qay, late Pleistocene alluvium; Qai, late-middle Pleistocene alluvium; Qao1, Qao2, and Qao3, middle Pleistocene alluvium; Qc, Pleistocene colluvium; Qsw, late Pleistocene and Holocene slopewash deposits; Tsb, Servilleta Basalt; and Ta, andesite (early? Pliocene).

Figure C5–2. View east toward Ute Mountain from west side of Rio Grande gorge. The topographic high on the right-hand shoulder of Ute Mountain is an erosional remnant of an olivine andesite volcano that underlies the dacite volcano of Ute Mountain (unit Ta). In the foreground are terraces developed on Servilleta Basalt (unit Tsb), remnants of paleochannels incised in the basalt surface prior to entrenchment in the present-day gorge.

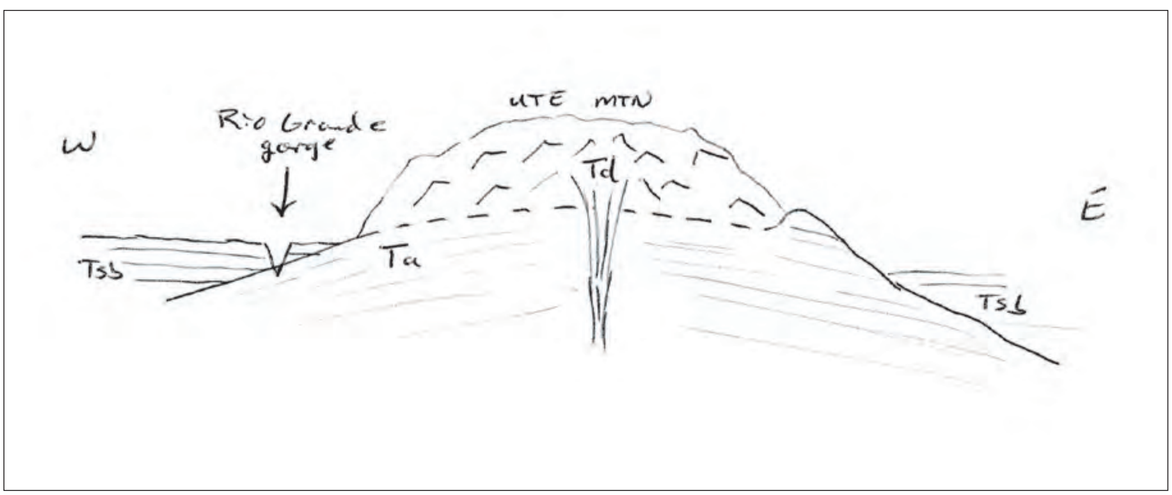

Figure C5–3. Sketch of west-east cross section through Ute Mountain showing generalized stratigraphic relations of Servilleta Basalt (unit Tsb), Ute Mountain dacite (unit Td), and buried andesite volcano (unit Ta) of unknown age.

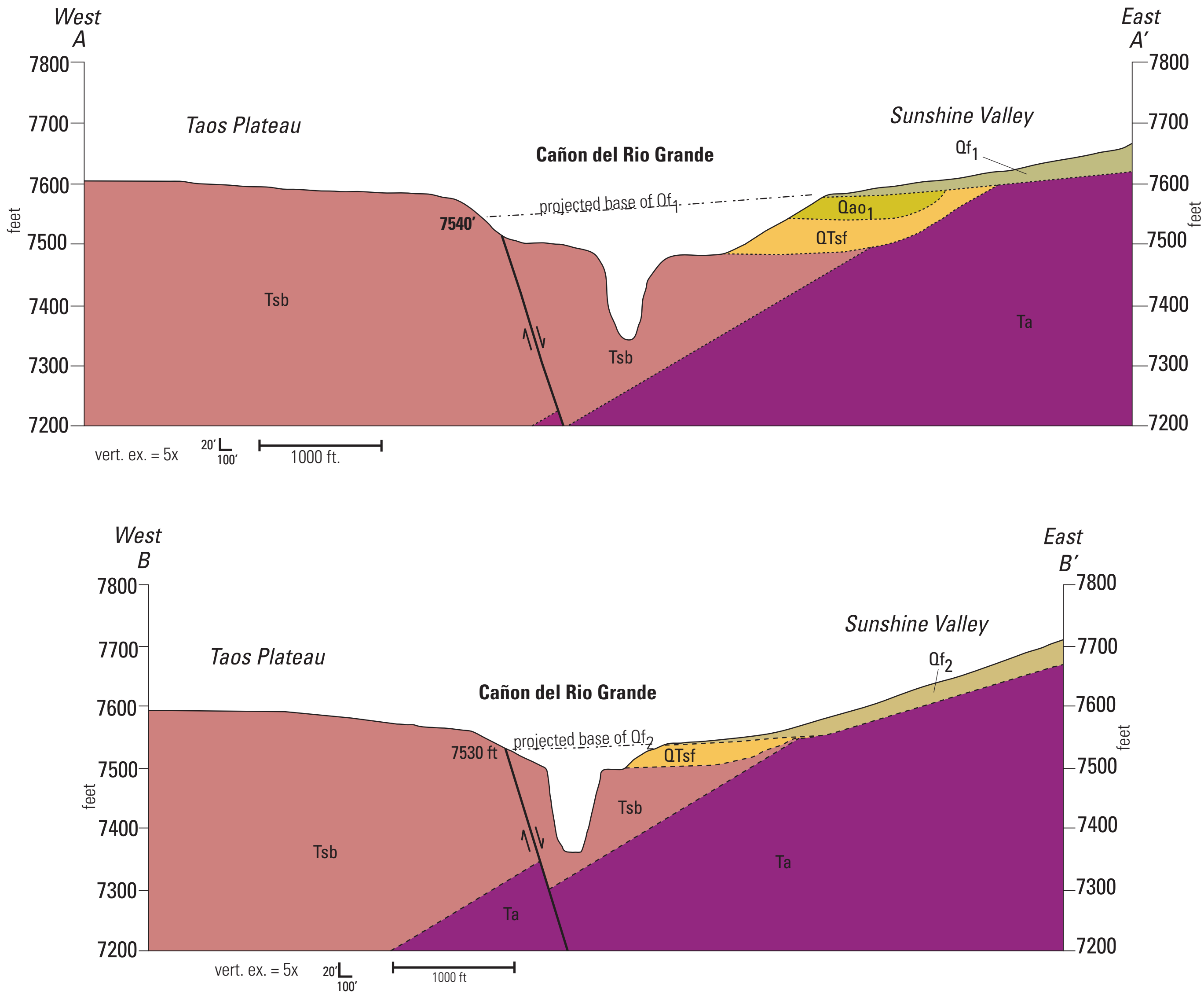

Figure C5–4. Cross sections A-A' and B-B' across Cañon del Rio Grande. Locations of cross sections shown on figure C5–1. Units listed as follows: Qf2 and Qf1, middle Pleistocene fan alluvium; QTsf, upper Oligocene to middle Quaternary Santa Fe Group (25 Ma–640 ka); Tsb, Pliocene Servilleta Basalt (3.66–4.5 Ma); and Ta, xenocrystic basaltic andesite of unknown age (>4.5 Ma).

Stop C6 — Faulted Alluvium at Jaroso Canyon, Latir Peaks Section of the Southern Sangre de Cristo Fault Zone

Speaker: Cal Ruleman
Start time: 1:15 pm
Duration: 1 hour
Location: Urraca Ranch Wildlife Management Area (BLM)
Costilla, New Mexico 7.5' quadrangle
GPS: NAD 27, zone 13, 451684 m E, 4082445 m N
Elevation: 8,080 ft asl

Synopsis

Along this section of the Sangre de Cristo fault zone between El Rito and Jaroso Canyon, we have mapped fault scarps on late-middle Pleistocene to Holocene deposits. This section of the fault zone is characterized by range-front and piedmont scarps that have 0.4–8.2 m of surface offset on units Qay and Qai deposits. As you enter the Wildlife Management Area you will see subtle, north-trending piedmont scarps of probable coseismic origin which are synthetic to the main range-bounding fault.

At the fan head, a large range-front fault scarp on late-middle Pleistocene alluvium has 5.3 m of surface offset. South of Jaroso Canyon, range-front fault scarps are at the bedrock-colluvium contact, where locally Holocene debris flows and colluvial deposits are offset 1–2 m. North of Jaroso Canyon, remnants of late-middle Pleistocene alluvium (unit Qai) are mapped proximal to the range front on the hanging wall of the southern Sangre de Cristo fault zone (fig. C6–1).

Discussion

At this location, soils on the upper surface of the fault scarp are correlative with those mapped on late-middle Pleistocene deposits (unit Qai) estimated to be 125–150 ka (Machette, 1985; Thompson and Machette, 1989) in the region. The composite soil is characterized by a 40-cm-thick Bt horizon formed in a pebble gravel (unit Qai) overlying a 30–50-cm-thick stage III Bk horizon with perhaps >200 k.y. of soil development (unit Qao) conformably beneath (fig. C6–2). Owing to leaching of carbonate at these elevations and moisture regimes, the maturity of these buried calcic soils further supports the antiquity of this surface. Buried stage III calcic horizons are found within the scarp slope, further indicating a probable >200 ka age for the faulted deposit (fig. C6–3). The fault scarp here has a surface offset of 5.3 m (fig. C6–4) and is probably the result of two or three surface rupturing events.

To the north of this stop, across Jaroso Creek, stage III calcic soils are found buried by about 1 m of late-middle and late Pleistocene alluvium on the downthrown side of the range-front fault (fig. C6–5). The fault scarp at this location has a surface offset of 7.8 m (fig. C6–6). As exposed along the arroyo shown in fig. C6–5, unit Qao is buried beneath unit Qai on the downthrown side, but unit Qao underlies the surface on the upthrown side. We correlate the surface on the upthrown

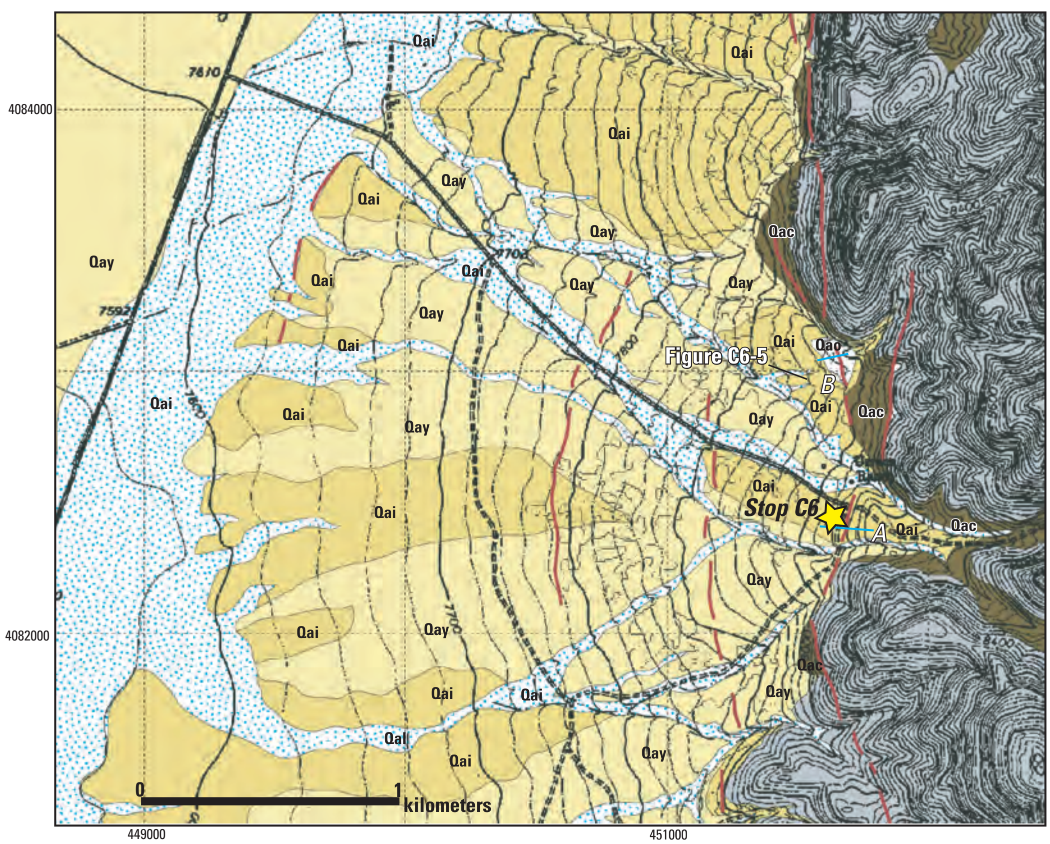

Figure C6–1. Geologic index map to stop C6. Units listed as follows: Qal, Holocene alluvium; Qay, late Pleistocene alluvium; Qai, late-middle Pleistocene alluvium; Qao, middle Pleistocene alluvium; and Qac, late Pleistocene and Holocene range-front alluvium-colluvium undivided. Fault scarps shown with red lines and fault scarp profiles shown as blue lines.

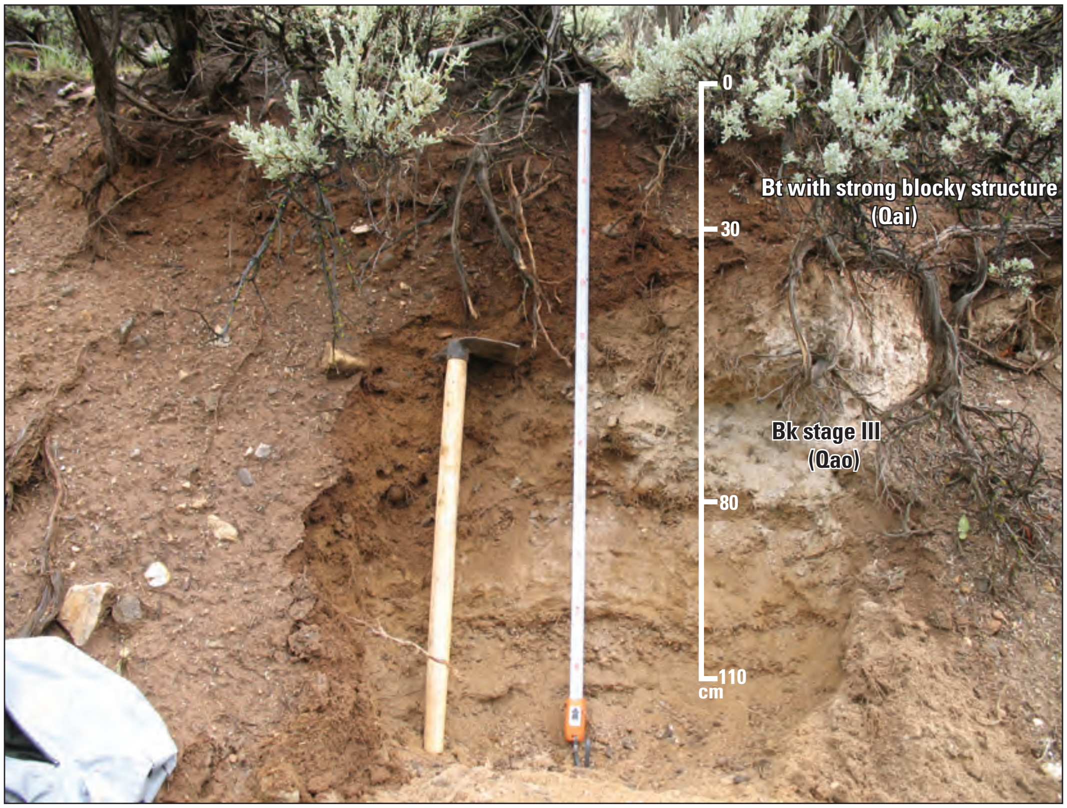

Figure C6–2. Soil on unit Qai-correlative loess overlying Bk stage III soil formed on unit Qai sandy pebble alluvium on upthrown side of fault at Jaroso Canyon.

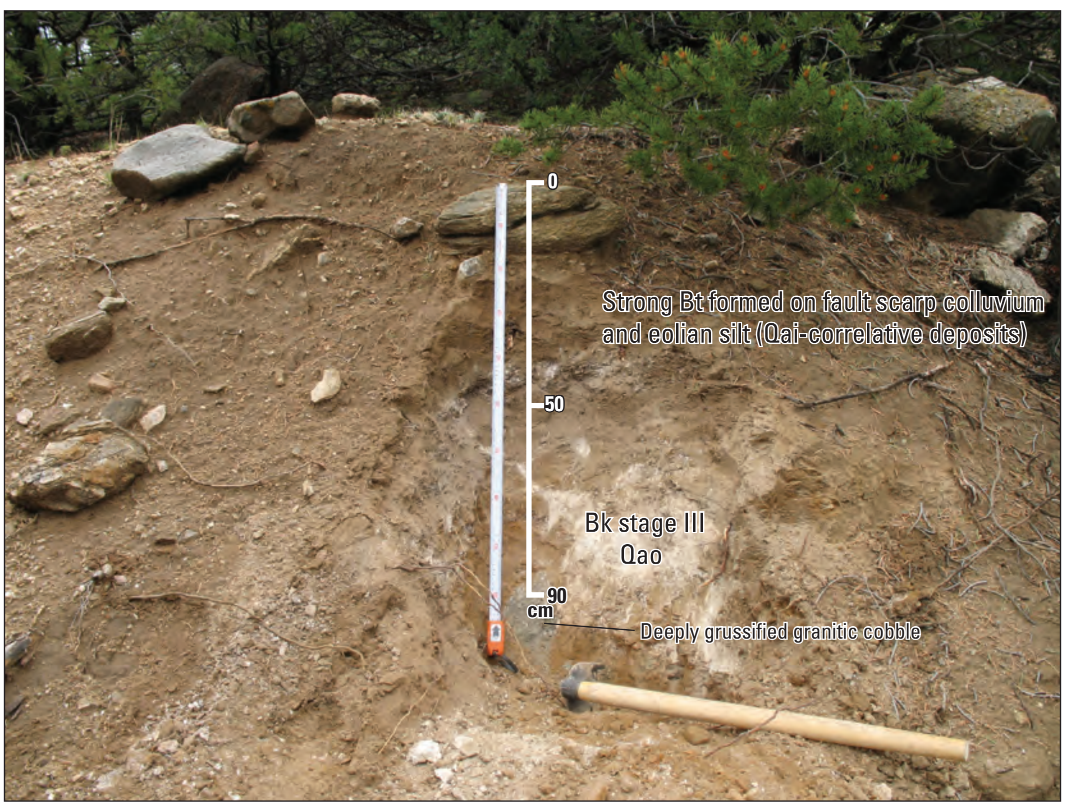

Figure C6–3. Buried soil on downthrown side of fault exposed in road cut at Jaroso Canyon. Similar soil sequence as seen in figure C6–2 with thicker deposition of unit Qai-correlative fault scarp colluvium and eolian silt.

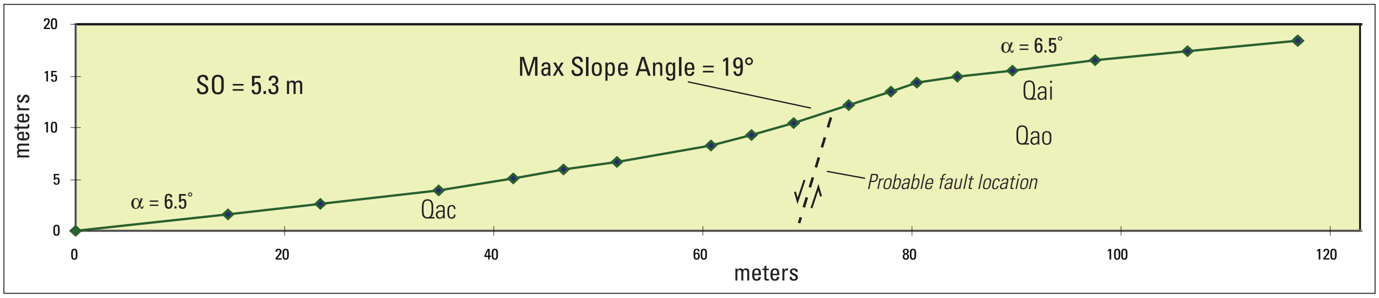

Figure C6–4. Fault scarp profile A at Jaroso Canyon. The profile was measured across late-middle Pleistocene deposits (unit Qai), Bull Lake equivalent (130,000 ka) on the footwall and late Pleistocene to Holocene fault-derived alluvium-colluvium (unit Qac). Far-field slope of offset geomorphic surface shown as the symbol α.

side with the deposit buried by late-middle Pleistocene alluvium shown in figure C6–5, resulting in an estimated surface offset of 10–12 m on >200 ka deposits.

The presence of these older surfaces proximal to the range front is an indication that during late Pleistocene time, alluvial processes at Jaroso Canyon were dominated by fan head incision and alluvial progradation, rather than by range-front aggradation. Less than 2 m of deposits correlative with units Qai and Qay have been deposited on the downthrown side of the fault, and they are mostly localized fault scarp colluvium and slopewash.

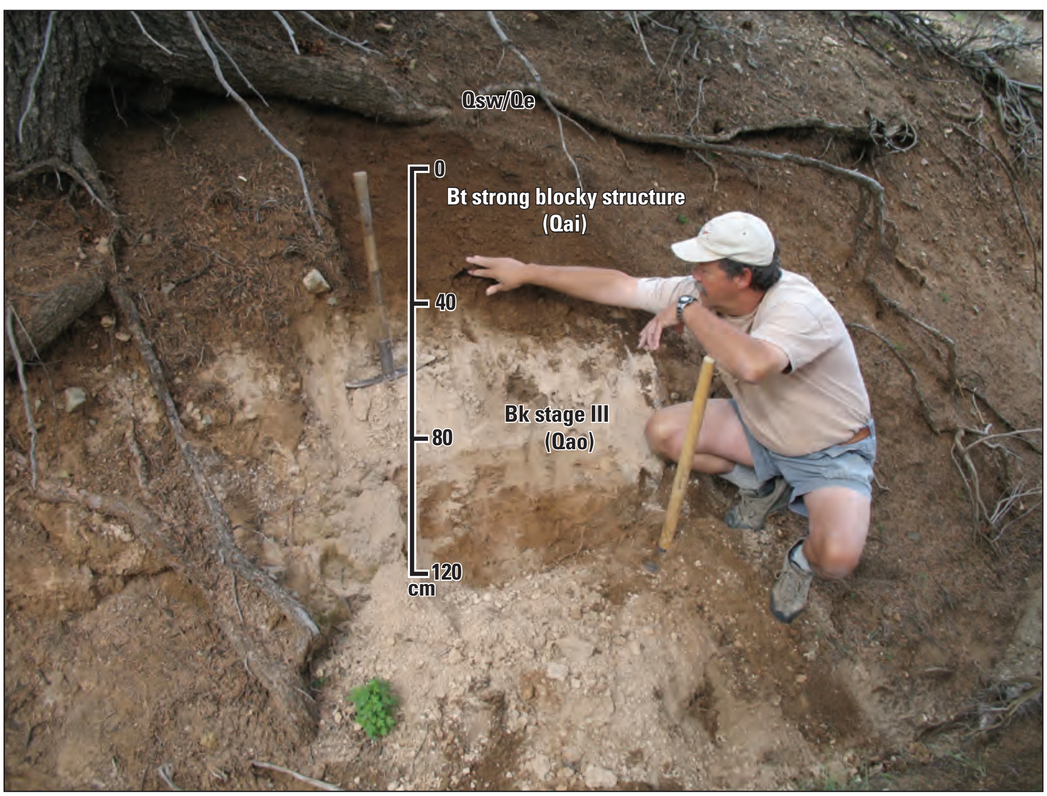

Figure C6–5. Soil profile north of Jaroso Canyon. This soil sequence is buried by about 20–30 cm of late Pleistocene slopewash deposits and eolian silt (unit Qsw/Qe).

The observed 5.3–7.8 m of surface offset on unit Qai (130 ka) yields an average late-middle Pleistocene to Holocene slip rate of 0.04–0.06 mm/yr. Range-bounding normal faults with these slow slip rates are typically characterized by highly sinuous, embayed range fronts with skeletal basal faceted spurs, whereas faults scarps are rare or discontinuous (Bull, 1977, 1984; McCalpin, 1996). Since the faulting occurs at the range front and has slow slip rates and long recurrence intervals (>30 k.y.), accommodation space is not developed proximal to the mountain-piedmont junction, leading to the dissection of older fanhead surfaces and basinward progradation of younger alluvium (Bull, 1977). Thus, the piedmont fan morphology along this section of the Sangre de Cristo fault zone seems to support a late-middle Pleistocene (<150 ka) slip rate of 0.01–0.1 mm/yr.

Contrary to this conclusion about late-middle Pleistocene slip rates along the Latir Peaks section of the southern Sangre de Cristo fault zone, the range-front morphology along this section of the Sangre de Cristo fault zone is characterized by a precipitous, linear range front with well-defined, basal faceted spurs. These features indicate relative slip rates an order of magnitude greater (> 0.1 mm/yr; dePolo, 1998) than those quantified from late-middle Pleistocene to Holocene datums. Menges (1990) determined a post-Pliocene slip rate of 0.12 to 0.26 mm/yr on the basis of a correlation between bench heights above faceted spurs along the range front and displaced Servilleta Basalt on top of San Pedro Mesa. The shorter term slip rates (<150 ka) suggest a decrease from the average long-term slip rate. The disparity in slip rates derived from offset late Quaternary deposits and range-front morphology suggests that the steep, faceted range-front morphology is a relict of greater pre–late-middle Pleistocene slip rates along the range-bounding fault (see Ruleman and Machette, chapter J, this volume).

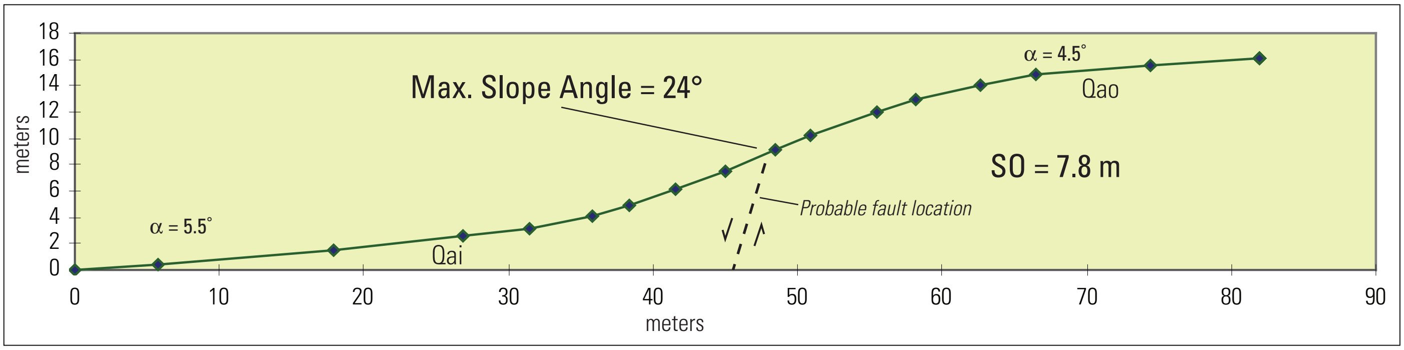

Figure C6–6. Fault scarp profile B at Jaroso Canyon on vertically offset middle Pleistocene deposits (unit Qao). Less than 1 m of Bull Lake-equivalent deposits (unit Qai) and younger late Pleistocene deposits have been deposited above unit Qao on the downthrown side. The far-field slope of the displaced geomorphic surface is indicated by the symbol α.

Stop C7 — Piedmont fault scarp on Cedro Canyon fan

Speaker: Cal Ruleman
Start time: 2:45 pm
Duration: 15 minutes
Location: Highway 522, south of Costilla, N. Mex.
Costilla, New Mexico 7.5' quadrangle
GPS: NAD 27, zone 13, 450667E, 4087722N
Elevation: 7,720 ft asl

Synopsis

Looking east from this stop, we see faulted alluvium of the Cedro Canyon fan complex. Faults that transect this complex have scarps as much as 10 m high on units Qao and Qai (Machette and Personius, 1989) (figs. C7–1 and C7–2*)*. Scarp heights decrease to the north to 2 m, where the fault is buried by latest Pleistocene and Holocene alluvium. No apparent late Pleistocene or Holocene displacement has occurred along this strand of the Latir Peaks section of the southern Sangre de Cristo fault zone. Soils on the upper surface of the Cedro Canyon fan have Bk stage II–III development, whereas deposits in the hanging wall are humic, fine-grained silts, sands, and pebbly gravels of late Pleistocene to Holocene age. At the Cedro Canyon fan head, we found a Bk stage III soil horizon (unit Qao) buried by 2.6 m of late-middle Pleistocene alluvium (unit Qai) and late Pleistocene alluvium (unit Qay), indicating that localized fanhead aggradation has occurred at the range front. No scarps have been identified along the main range-bounding fault. However, the fault could be at the bedrock-colluvium junction. On the skyline, Servilleta Basalt (3.66–4.75 Ma) caps San Pedro Mesa providing a datum to quantify long-term slip rates through well log correlation.

Discussion

At the mouth of Cedro Canyon, a coarse-grained, cobble-boulder gravel with a 60-cm-thick Bt/Bk stage I soil horizon (unit Qai) unconformably overlies a Bk stage III horizon formed on a pebbly sand (unit Qao). This deposit is overlain by approximately 2 m of finer grained sandy-cobble alluvium (unit Qay) (fig. C7–3). We interpret the Bk stage II–III soils exposed along the crest of the intrabasin fault scarp to be characteristic of middle Pleistocene deposits mapped within the region (unit Qao) and correlative with the Bk stage III soil buried at the canyon mouth (fig. C7–4). These features indicate that range front faulting of the original Qao surface has backtilted the deposit 1°–2° and induced aggradation of younger deposits (units Qai and Qay) at the fanhead.

The strong Bt horizon formed in the overlying pebbly gravel and loess is characteristic of soils on late-middle Pleistocene deposits (unit Qai). This exposure is similar to

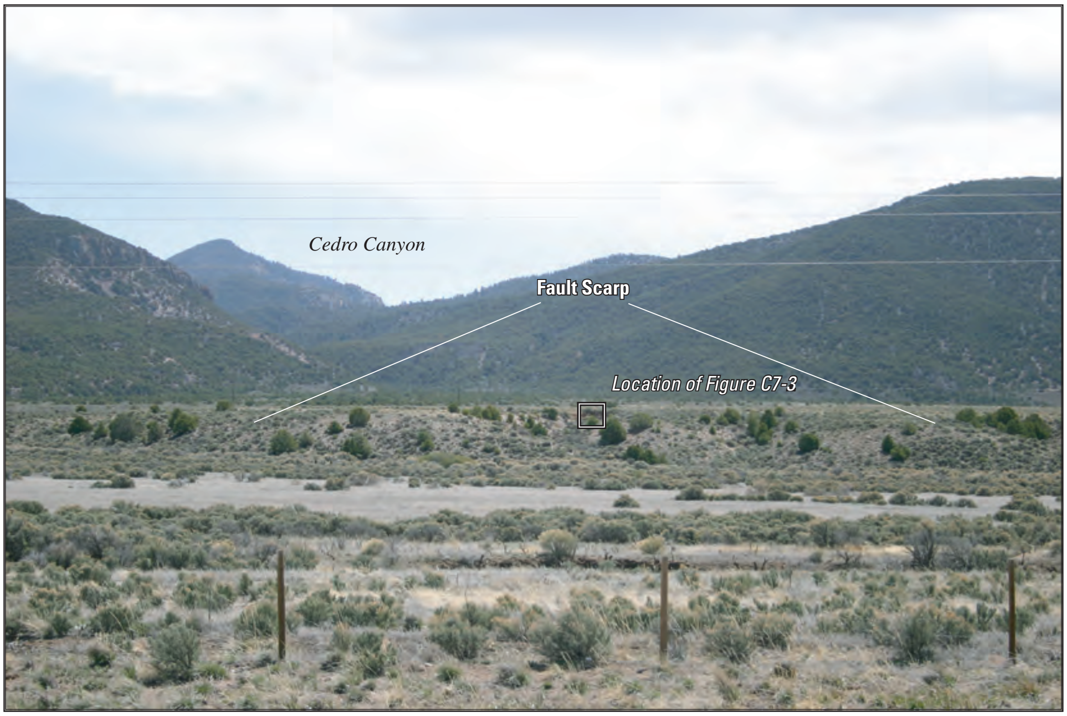

Figure C7–1. View east from stop C7 toward Cedro Canyon.

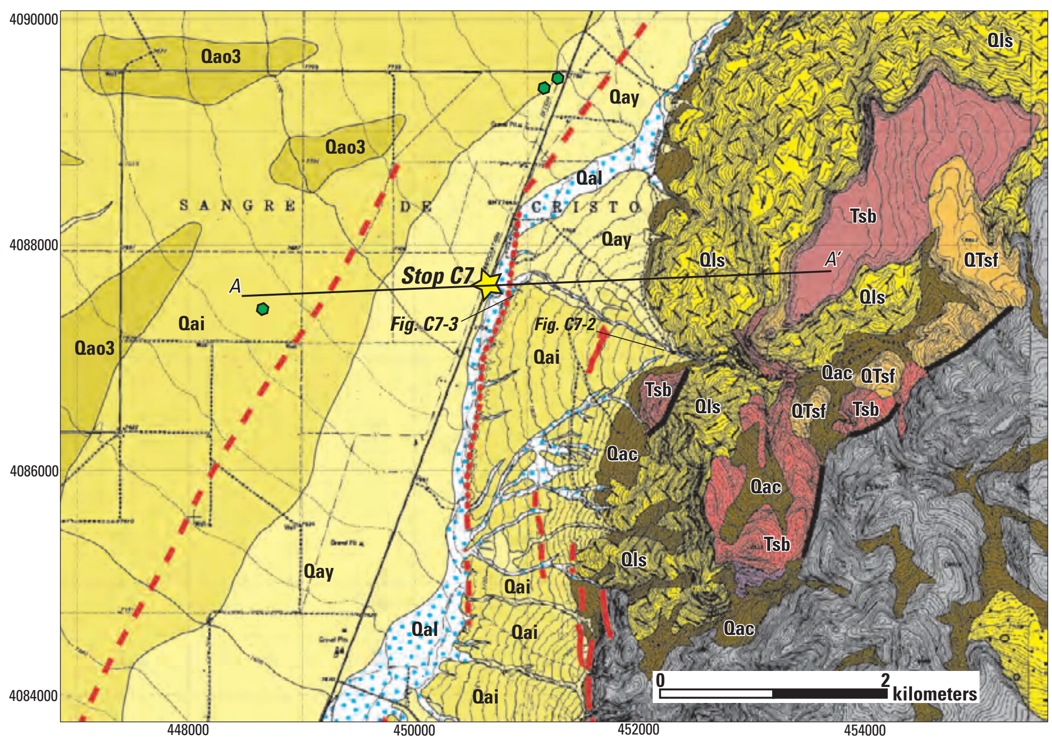

Figure C7–2. Geologic index map for stop 7. Units mapped listed as follows: Qal, Holocene alluvium; Qay, late Pleistocene alluvium; Qai, late-middle Pleistocene alluvium (130,000 ka); Qao3, middle Pleistocene alluvium; Qls, middle and late Pleistocene landslide debris undifferentiated; Qac, late Pleistocene to Holocene alluvium-colluvium undivided; QTsf, Pio-Quaternary Santa Fe Formation; and Tsb, Servilleta Basalt. Faults shown in red, dashed where inferred and dotted where concealed. Green polygons are locations of wells used to constrain cross section A-A'.

that found at Urraca Ranch, where unit Qai overlies unit Qao. Subsequent fluvial trimming of the scarp and deposition of late Pleistocene and Holocene sediments on the hanging wall leaves the amount of offset on Qai uncertain. On the basis of fault scarp profiles from Machette and Personius (1984) and soil development on unit Qao on the upper surface, we can infer that a minimum of 8–10 m of surface offset has occurred on a datum older than 200 ka, yielding a minimum slip rate of 0.05–0.1 mm/yr. This estimated slip rate is consistent with slip rates estimated at Jaroso Canyon.

Wells drilled to the north and west of stop C7 show Servilleta Basalt (unit Tsb) (3.66–4.75 Ma) at depth (fig. C7–2). This unit is correlated with the basalt flows capping the uplifted block of San Pedro Mesa. Lipman and Reed (1989) mapped Servilleta Basalt capping the southern end of San Pedro Mesa as the Cerro flow and dated it at (4.3 Ma). Well data logged in 1959, 1997, and 1998 show two flows of the Servilleta Basalt in the subsurface; either might correlate with the 4.3 Ma flow and allow us to estimate a minimum slip rate for the past 4.3 Ma. By inferring that flows in the hanging wall within the subsurface are either correlative withor younger than the Cerro flow cappin; San Pedro Mesa, two minimum throw calculations can be estimated across the fault, a minimum of 2,000 ft and preferred minimum of 2,200 ft (fig. C7–5). The offset has been rounded owing to uncertainties in flow thickness and precise tilt calculations on the Servilleta Basalt. For comparison, refer to figure B8–4 from Machette (this volume) for cross sections approximately 17 km to the north showing displacement and slip rates estimated by offset on the Servilleta Basalt.

For the minimum throw, we use the base of the Cerro flow on San Pedro Mesa as the footwall datum. The surface elevation of San Pedro Mesa is 8,943 ft at this location. We subtract an approximate average flow thickness of 50 ft to get an elevation of 8,900 ft for the base of the flow on the footwall. A tilt of 5° on the basalt projected to the west approximately 6,500 ft contributes an additional 500 ft to the base of the flow, yielding an elevation of 9,400 ft. Using well log B (fig. C7–5) to determine the hanging wall datum, we start with a surface elevation of 7,782 ft. The top of the upper flow was reached at 398 ft in the subsurface, an elevation of 7,384 ft, rounded to 7,400 ft for our estimations. This elevation (7,400 ft) is subtracted from the projected base of the Cerro flow (9,400 ft), yielding a net throw of 2,000 ft, or 610 m. Six hundred and ten meters of throw during 4.3 m.y. yields a long-term slip rate (since 4.3 Ma) of 0.14 mm/yr.

The preferred minimum amount of throw across the fault is based on the projected footwall base of the Cerro flow (9,400 ft) and subtracting the elevation of the base of the second flow recorded in log B (588 ft) (fig. C7–5). This base depth subtracted from the surface elevation (7,782 ft) yields an elevation of 7,194 ft, which is rounded to 7,200 ft for our purposes. This elevation (7,200 ft) is subtracted from the projected footwall base of the Cerro flow (9,400 ft) to quantify a net throw of 2,200 ft, or 670 m, for the last 4.3 m.y. A long-term slip rate determined from the preferred minimum throw is estimated to be 670 m/4.3 m.y. or 0.16 mm/yr. These long-term slip rates are correlative with those quantified by Menges (1990a,b), for this section of the Sangre de Cristo fault zone, of 0.12–0.26 mm/yr.

By comparing our estimated long-term slip rates with slip rates estimated for the past <200 k.y., we see that the Latir Peaks section of the southern Sangre de Cristo fault zone has dramatic changes in slip rates over shorter periods of time. On the basis of the fault scarp morphology, surface offset on relative-age deposits, and late-middle Pleistocene to Holocene piedmont morphology, long-term slip rates are potentially two times as great as slip rates quantified for the late-middle Pleistocene to present along this section. We propose that the Sangre de Cristo fault system, consisting of northern, central and southern zones, has similar long-term slip rates (>1 Ma) that may be double the short-term rates (<200 ka) for an individual zone. During these shorter periods of time (<200 ka), stress is transferred from one zone to another, reducing the seismic hazard along one and increasing it along another (see Ruleman and Machette, chapter J, this volume).

Figure C7–3. Cedro Canyon fanhead exposure in stream cutbank. Stratigraphy is interpreted as late Pleistocene alluvium (unit Qay) over late-middle Pleistocene (unit Qai) alluvium overlying a Bk stage III horizon in middle Pleistocene alluvium (unit Qao).

Figure C7–4. Soil exposure at crest of piedmont fault scarp on Cedro Canyon fan complex.

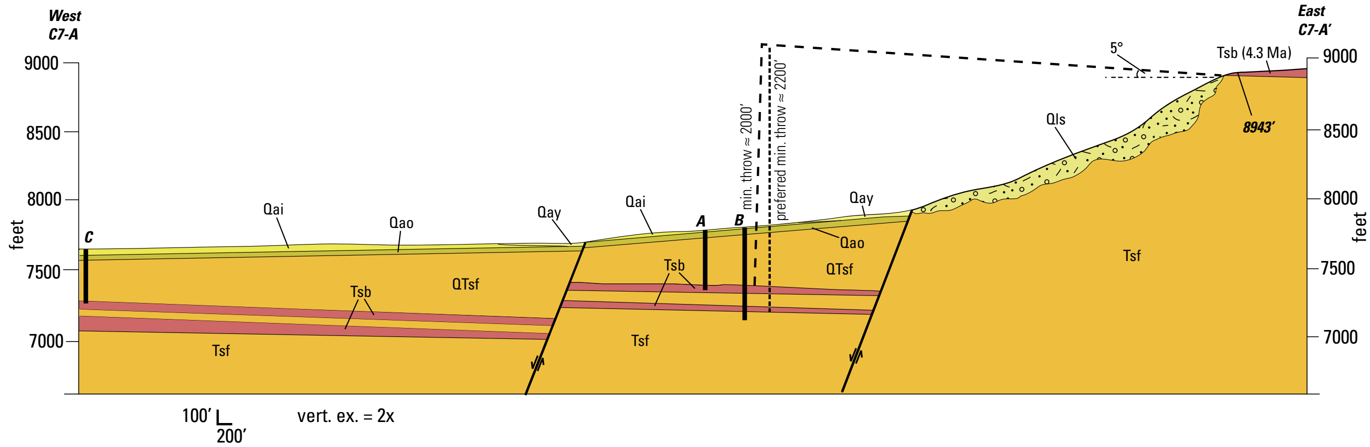

Figure C7–5. Cross section A-A' showing offset Servilleta Basalt (unit Tsb, 3.66–4.75 Ma). Units shown as follows: Qay, late Pleistocene alluvium; Qai, late-middle Pleistocene alluvium; Qao, middle Pleistocene alluvium; Qls, middle to late Pleistocene landslide debris; QTsf/Tsf, Santa Fe Group (>640 ka); and Tsb, Servilleta Basalt. Age of Servilleta Basalt (unit Tsb) on San Pedro Mesa from Lipman and Reed (1989). Well logs A, B, and C record Servilleta Basalt at 415–460 ft, at 398–456 ft/539–588 ft, and at 387–405 feet, respectively.

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