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River incision histories of the Black Canyon of the Gunnison and Unaweep Canyon: Interplay between late Cenozoic tectonism, climate change, and drainage integration in the western Rocky Mountains

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ABSTRACT

The Black Canyon of the Gunnison and Unaweep Canyon in western Colorado have long been viewed as classic examples of post-Laramide Plio-Pleistocene uplift, which in the case of Unaweep, is thought to have forced the Gunnison River to abandon the canyon. Ongoing field studies of the incision histories of these canyons and their surrounding regions, however, suggest that post-Laramide rock uplift has been regional, rather than local in nature. River incision rates calculated using ca. 10 Ma basaltic lava flows as a late Miocene datum suggest that long-term incision rates range from 61 to 142 m/m.y. with rates decreasing eastward towards the central Rocky Mountains. Incision rates calculated using the ca. 640 ka Lava Creek B ash range from 95 to 162 m/m.y., decrease eastward towards the mountains, and are broadly similar in magnitude to the longer-term incision rates. Locally, incision rates are as high as 500–600 m/m.y. along the lower reaches of the Black Canyon of the Gunnison, and these anomalously high values reflect transient knickpoint migration upvalley. Knickpoint migration was controlled, in part, by downvalley base-level changes related to stream piracy. For example, abandonment of Unaweep Canyon by the Gunnison River could have led to rapid incision through erodible Mancos Shale as the Gunnison River joined the Colorado River on its course around the northern end of the Uncompahgre Plateau.

Geophysical data show that abandonment of Unaweep Canyon was not caused by differential uplift of the crest of Unaweep Canyon relative to the surrounding basins. Instead, the ancestral (Plio-Pleistocene?) Gunnison River flowed through Cactus Park, a major paleovalley that feeds into Unaweep Canyon, and continued downvalley to its juncture with the Dolores River near present-day Gateway, Colorado. The average gradient of the ancestral Gunnison River through the canyon prior to abandonment was ~7.5–7.6 m/km. Lithological and mineralogical considerations suggest that the Colorado River also flowed through and helped to carve Unaweep Canyon, although the Colorado River probably exited Unaweep Canyon prior to abandonment by the Gunnison River. The ancestral Gunnison River remained in its course and incised through bedrock for a long enough period of time to produce terrace remnants in the Cactus Park region that range in elevation from 2000 to 1880 m. Abandonment of the canyon by the Gunnison River was followed by formation of a natural dam that probably led to deposition upvalley of ~50 m of lacustrine sediments in Cactus Park. Recent mapping in the lower reaches of Unaweep Canyon indicate that a landslide could have led to damming of Unaweep Canyon, perhaps while it was occupied by underfit streams.

INTRODUCTION

Late Cenozoic uplift of mountain ranges in the western U.S. and elsewhere has been the subject of much debate (Molnar and England, 1990). Deeply incised river valleys in the western United States are commonly attributed to rock uplift driven by an as yet unresolved combination of tectonic, climatic, and geomorphic factors (Epis and Chapin, 1975; McMillan et al., 2002, 2006; Pederson et al., 2002). Age estimates for the timing of incision in the Rocky Mountains range from early Cenozoic (Laramide) to late Cenozoic (Hunt, 1956; Gregory and Chase, 1992, 1994; Wolfe et al., 1998). Tectonic influences on incision in this region are poorly understood and are typically attributed to crustal thickening (McQuarrie and Chase, 2000), mantle heterogeneity (Humphreys and Duecker, 1994), or Rio Grande Rift propagation (Leonard, 2002). Different scales of tectonic forcings have been proposed and include both regional epeirogenic uplift (Karlstrom et al., 2005) and more localized block uplifts (Hansen, 1965, 1987; Steven, 2002). Geomorphic factors such as stream piracy and river integration also strongly influence river incision (Zaprowski et al., 2001; Pederson et al. 2002). Climatic forcings have been proposed both at long and shorter time scales; for example, a change to more erosive climate in the past 2–4 m.y. (Peizhen et al., 2001) and alternating glacial-interglacial oscillations in the Rockies (Dethier, 2001).

This field trip guide discusses magnitudes, rates, and patterns of late Cenozoic river incision in the region and describes the interplay among tectonics, climate change, and drainage reorganization in the western slope of the Rocky Mountains. We focus on Black Canyon of the Gunnison (Day 1) and Unaweep Canyon (Day 2), both of which are considered classic examples of late Cenozoic localized "block" uplifts that controlled river incision (Hansen, 1965; Hunt, 1969; Lohman, 1981) (Fig. 1). Topics and questions that we will discuss include the following.

- Tectonic processes: Is uplift regional or local in nature? For example, does it involve both Laramide blocks and

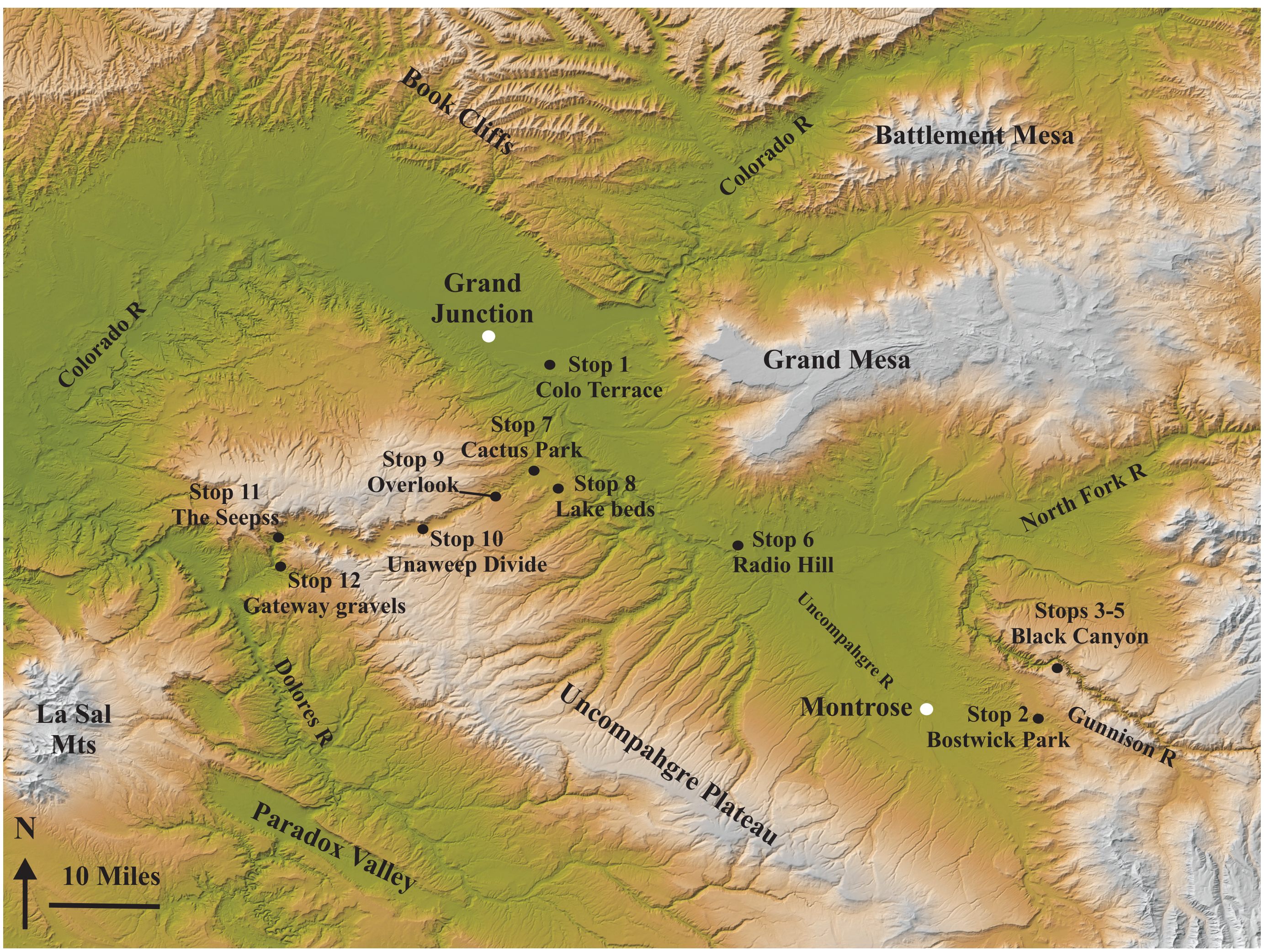

Figure 1. Locations of field trip stops.

adjacent sedimentary basins? Does it involve both the Rockies and the Colorado Plateau?

- Climatic processes: How have glacial and interglacial oscillations affected river incision histories?
- Geomorphic processes: How have processes such as stream piracy and drainage integration affected base level change and incision?

DAY 1: BLACK CANYON OF THE GUNNISON

Stop 1—100 m Colorado River Terrace, Mesa County Landfill

Grand Mesa and Long-Term Incision Rates

This stop affords excellent views of Grand Mesa and late Quaternary Colorado and Gunnison River terraces in the Grand Junction area. Grand Mesa and the basaltic lava flows that cap it are the starting point for discussions of long-term evolution of river systems in western Colorado. The western edge of Grand Mesa is capped by 200 ft of basaltic lava flows that range in age from 9.22 to 10.76 Ma (Kunk et al., 2002). The flows thicken eastward (> 600 ft thick) and show evidence of paleoflow directions to the west. Based on the geometry of the lava flows on Grand Mesa, it seems likely that basalt flowed onto a low-relief area, probably representing a west-sloping paleovalley, possibly associated with streams draining northwest from the West Elk Mountains (Betton et al., 2005). The resistant nature of the basalt, coupled with the less resistant nature of the shale and mudstone that formed the walls of the paleovalley, caused a reversal in the topography as erosion began to dominate this region post–9.22 Ma. In other words, what was once the lowest point in the landscape is today the highest. As down-cutting by the ancestral Colorado River system occurred, ~1 mile (1.6 km) of sediment has been removed over the past ~9.2 m.y., giving a long-term average bedrock incision rate of ~142 m/m.y. Incision left behind a sequence of main-stem terraces, tributary terraces, and fan complexes, several of which are readily observed at this location. Grand Mesa and other ca. 10 Ma basaltic lava flows in western Colorado provide an important datum for calculating long-term incision rates across the region. As discussed in the following, long-term incision rates vary regionally from 61 m/m.y. to 142 m/m.y., with slower rates of incision upstream, toward the Rocky Mountains (Fig. 2).

Late Quaternary Colorado and Gunnison River Terraces

There are about eight Colorado River strath terraces and a similar number of Gunnison River strath terraces in the region. The terraces range from 15 to 170 m in height above their respective modern river. Colorado and Gunnison River terraces are easily differentiated based on differences in gravel composition. The Colorado River drains a wide variety of geologic provinces, and its gravels consist of significant amounts of sedimentary rock, including distinctive Eocene oil shale and Paleozoic red siltstones and sandstones. In contrast, the Gunnison River gravels chiefly contain Oligocene volcanic clasts of the San Juan and West Elk Mountains and distinctive Precambrian granite, gneiss, and quartzite clasts from the Gunnison Uplift and Ouray area.

Stop 2—Bostwick Park Paleovalley and Gravel Pit

This stop provides an outstanding example of a partially exhumed valley fill of an ancient Gunnison River tributary referred to here as the ancestral Bostwick River. The river gravels exposed in the gravel pit are the basal unit of a paleovalley fill (up to 48 m thick) underlain by Mancos Shale that can be mapped south from Red Canyon to Ridgway, Colorado, a distance of ~22 miles (35 km) (Hudson et al., 2006; Kelley et al., 2007) (Fig. 3). The paleovalley was first recognized by Dickinson (1965), who identified the presence of Lava Creek B ash throughout the Bostwick Park area, and additional mapping was completed by Hansen (1971). The most prominent remnants of the Bostwick River valley fill are preserved in Bostwick Park and Shinn Park. The abundance and distribution of volcanic clasts shows that this ancestral river system flowed north from the San Juan Mountains and joined the Gunnison River via Red Canyon, a tributary canyon to the Black Canyon of the Gunnison. The volcanic-rich clast composition of the basal Bostwick Park gravels might indicate that the ancestral Bostwick River flowed north via present-day Cow Creek, a tributary of the Uncompahgre River that drains Cimmaron Ridge (R. Dickinson, U.S. Geological Survey, 2008, personal commun.).

River gravels in the pit (up to 12 m thick) are overlain by the 640 ka Lava Creek B ash. The absence of any significant pedogenic features separating the Lava Creek B ash from the underlying river gravels and a preliminary cosmogenic burial age (D. Granger, Purdue University, 2007, personal commun.; R. Dickinson, U.S. Geological Survey, 2008, personal commun.), it seems likely that the Bostwick Park paleovalley was abandoned some time shortly prior to 640 ka, perhaps due to stream capture by the ancestral Uncompahgre River in the vicinity of Colona, Colorado. Abandonment of the valley by the ancestral Bostwick River set the stage for the accumulation and preservation of the thick valley fill. Subsequent deposition and reworking of the Lava Creek B ash, along with yellow sandy mud reworked from nearby hills of Mancos Shale, filled much of the valley (Hudson et al., 2006). Red gravelly sand, probably derived from Mesozoic strata of the Gunnison Uplift, forms a southward thinning wedge that veneers the yellow sandy mud unit. In this scenario, most of the valley filling appears to have occurred following abandonment, a point that we will come back to later in the field trip when we visit Unaweep Canyon.

Stop 3—Black Canyon of the Gunnison National Park Visitor Center and Canyon Overlooks

At this stop, we will begin discussing the geology and origins of the Black Canyon of the Gunnison (Fig. 4). The river here has deeply incised resistant Precambrian rocks that are part of the Laramide-age Gunnison Uplift to form one of the narrowest (350 m) and deepest (700 m) bedrock canyons in North America.

Along the south and west flank of the uplift is a thick sequence of Mancos Shale. Many observers have questioned why the Gunnison River incised resistant Precambrian rocks rather than eroding into Mancos Shale. One possible answer to this question lies in the paleogeography of the region. Just upstream of the Black Canyon, the Gunnison River is straddled to the north and south by thick wedges of volcanic debris that thin toward the river. These are volcanic rocks associated with the West Elk Mountains to the north and the San Juan Mountains to the south. The Gunnison River is located within a saddle separating the two opposing wedges of volcanic debris and thus its location was probably constrained by the original distribution of these deposits (Hansen, 1987). One inference from these relationships is that the Gunnison River and its ancestral courses have probably existed at roughly the same location (in the vicinity of the Black Canyon) since the Oligocene. As the river incised through the Oligocene, then Mesozoic, deposits of the Gunnison uplift, the ancestral Gunnison River became superimposed onto and hence cut a deepening channel within Precambrian rocks. Someday it is likely that Cedar Creek will erode headward through Mancos Shale and capture the Cimarron River near Cerro Summit. If this were to happen, increased flow to the west via Cedar Creek could cause diversion of the Gunnison out of the Black Canyon to form an abandoned gorge, similar to Unaweep Canyon (see below).

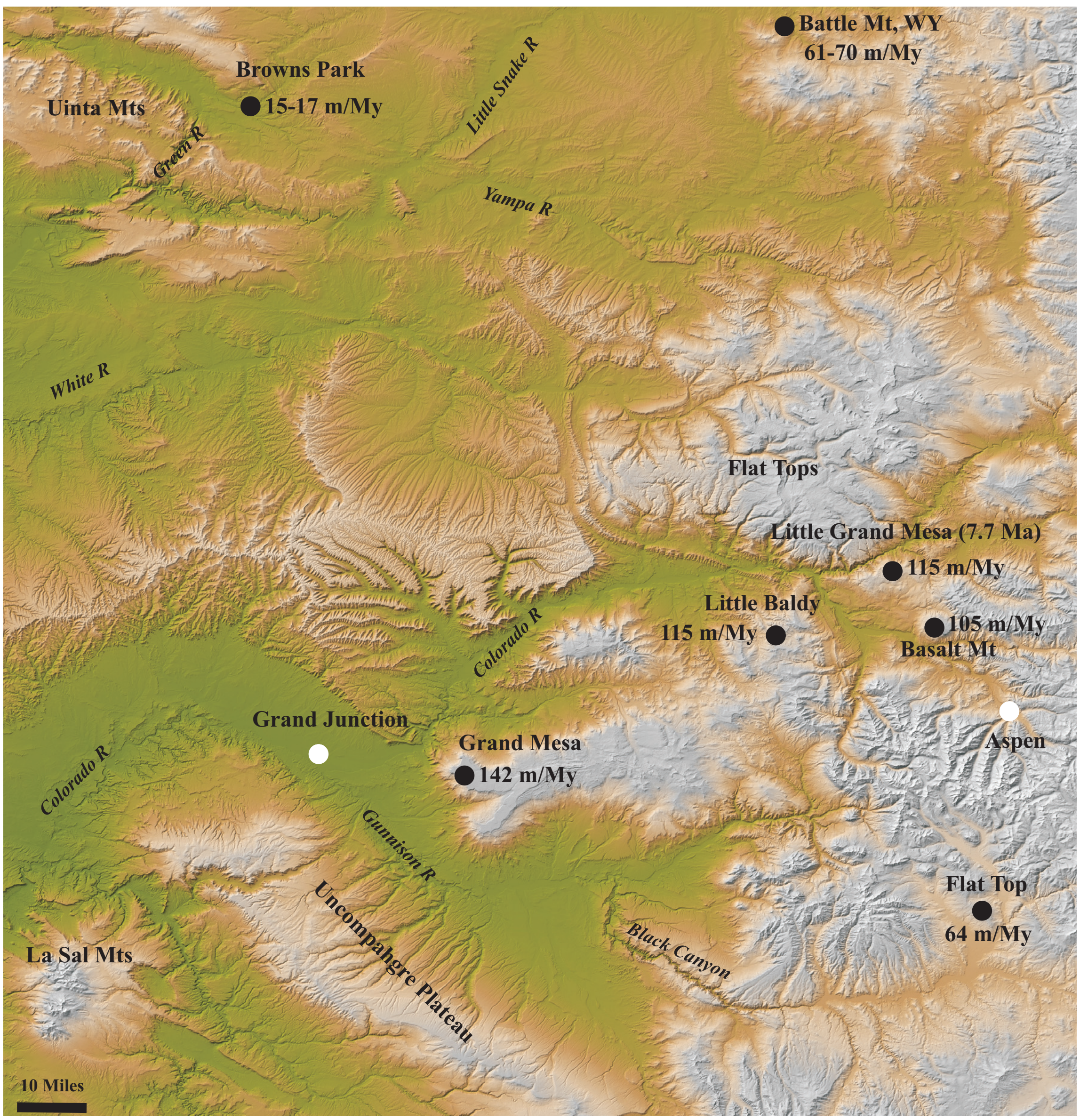

Figure 2. Map of river incision rates in western Colorado over the past 10 m.y. Rates calculated using ca. 10 Ma basaltic lava flows, except Little Grand Mesa, which is dated to ca. 7.7 Ma. Data from Izett (1975), Greene et al. (2001), and Kunk et al. (2002).

Hansen (1965) suggested that the Gunnison River incised to form the Black Canyon in response to recent uplift and tilting of the Precambrian rocks of the Black Canyon. He interpreted the river gravels that are found along the north rim of the canyon (e.g., Grizzly Creek gravels, Fig. 4) as deposits of an ancient river tributary (now abandoned) whose profile has been tilted to the north due to recent uplift. Recent study by Schneeflock et al. (2002), however, suggests that the gravel terraces described by Hansen may or may not be time correlative; hence, the observed geometries of terraces might also be explained in terms of stream piracy of Grizzly Creek by Iron Creek, and hence evidence for tilting from these data remain equivocal. Ake et al. (2002) summarized evidence for post-Miocene (Hansen, 1965, 1971) and historical (1983: M 3.4; Wong and Humphrey, 1989) seismic activity along the Cimarron–Red Rock fault zone on the southwest flank of the Gunnison Uplift (Fig. 4). Although poorly constrained, normal slip rates were estimated as 0.01 mm/yr, with a speculative right lateral strike-slip component of 0.02 mm/yr. It remains unclear if Cenozoic strain magnitude has been large enough to significantly affect incision rates and patterns.

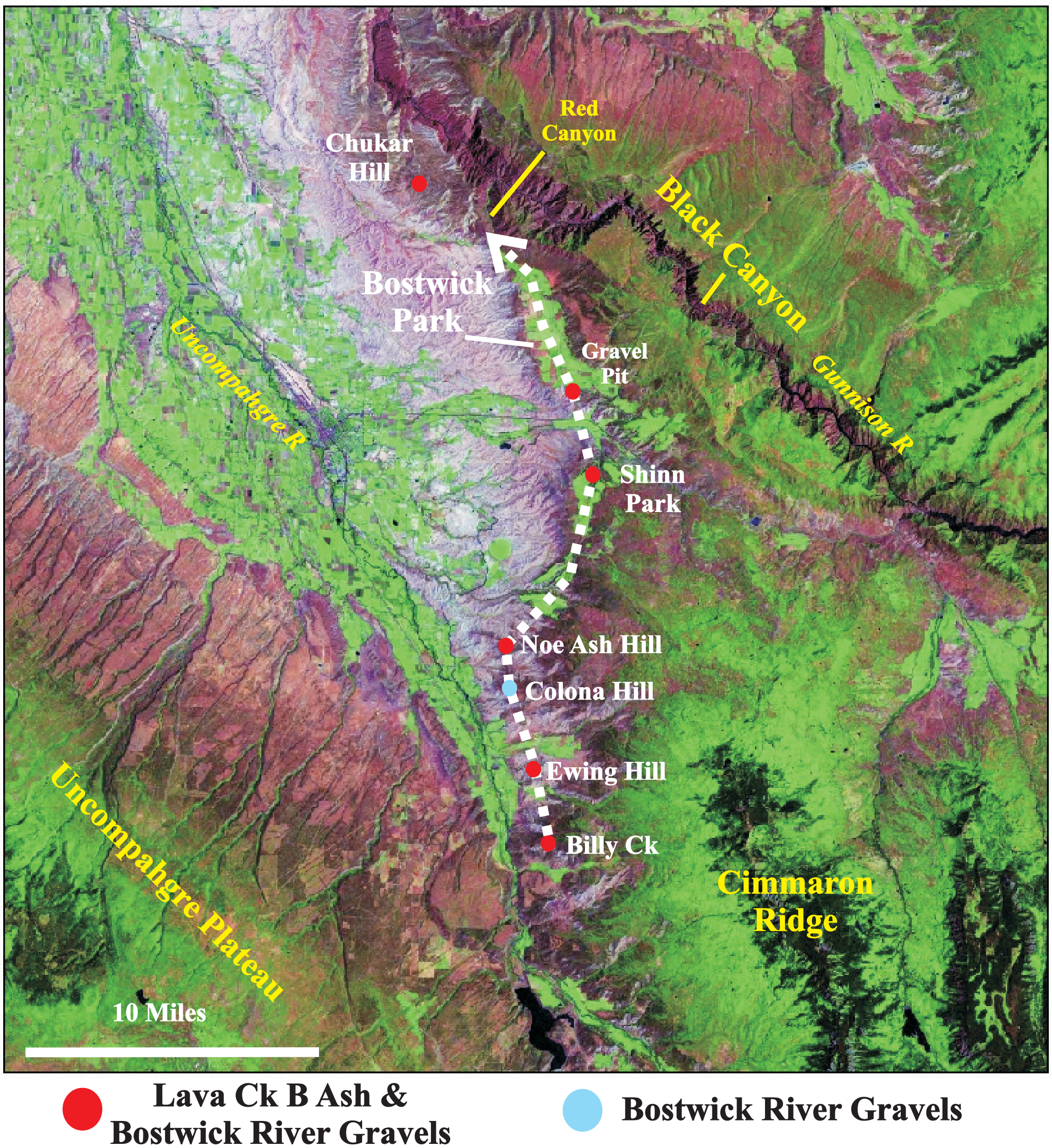

Figure 3. Satellite image showing the location of the ca. 640 ka Bostwick Park paleovalley and significant valley-fill remnants. Dashed line indicates the approximate axis of the paleovalley.

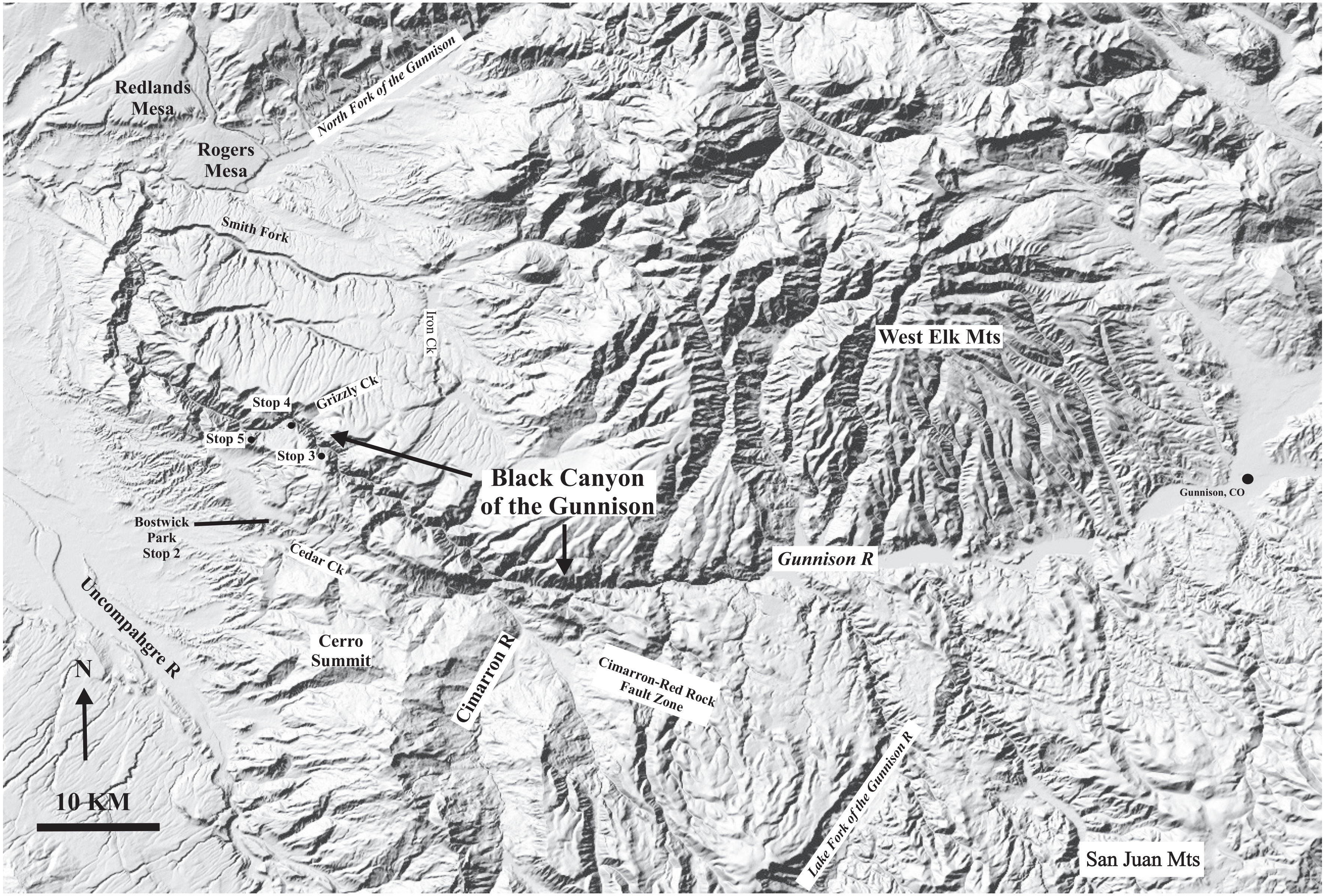

Figure 4. Shaded relief map showing the Black Canyon of the Gunnison.

Stop 4—Chasm View and Painted Wall Overlooks

Between Chasm View and the Painted Wall, we see the maximum depth (2300 ft; 701 m) and steepest gradient (up to 68 m/km) of the Black Canyon. The longitudinal profile of the Gunnison River (Fig. 5) shows that this steepest reach is within a larger knickzone that extends from the confluence with the North Fork to Blue Mesa dam (Fig. 5) at an average gradient of 8.1 m/km. The knickzone is developed in Precambrian rocks, which undoubtedly have a strong effect in localizing the position of the knickzone, but the steepest parts of the knickpoint do not begin where Precambrian rocks first outcrop. Gradients are shallower upstream of the knickpoint where the river is also in Precambrian rock, and similar bedrock canyons in Precambrian rocks (e.g., Westwater Canyon) of the Colorado-Gunnison system do not show similar steep gradients. This, plus the differential incision rates documented across the knickzone (see below) argue that the knickzone represents a transient feature of the river profile whose exact origins are not fully understood.

The height of the upper ancestral Gunnison River (approximately in its present course) at ca. 35 Ma is indicated by the base of the Oligocene West Elk Breccia ash flow units within the low part of the landscape as discussed above and shown in Figure 5. Bedrock "straths" for the Oligocene Gunnison River were ~500 m lower than at 10 Ma; hence, bedrock incision rates were small (or negative due to surface uplift) and gradients were low from 30 Ma to 10 Ma. By ca. 10 Ma, the paleo-Gunnison drainage network was established at ~3200 m (9500 ft) as defined by basalts at Grand Mesa and Flat Top Mountain near Gunnison (Fig. 5). Well-defined long-term average bedrock incision rates since 10 Ma on the Gunnison River vary across the knickzone from ~150 m/m.y. below the knickzone to ~55 m/m.y. above the knickzone.

Similar to the 10 Ma incision rates, average bedrock incision rates measured over the past 640 k.y. in areas upstream and downstream of the knickzone are variable. Rates vary from 130–150 m/m.y. (location C in Fig. 5; Darling et al., 2007), to 500–640 m/m.y. within the Black Canyon proper (Sandoval, 2007), to 90–95 m/m.y. upstream (Hansen, 1965). The 640 ka profile, reconstructed from terraces containing Lava Creek B ash, indicates ~25 km upstream migration of the profile (Fig. 5). The best age constraint and incision rate of Black Canyon comes from projecting the ca. 640 ka Bostwick tributary to its intersection with the Gunnison River, suggesting 507 m of incision over the past 640 k.y. (location G in Fig. 5). The similarity of downstream 10 Ma (150 m/m.y.) and 640 ka (130–150 m/m.y.) incision rates suggests the possibility of steady average rates. If so, data from Red Rock Canyon (location G) indicate that Black Canyon has been carved in the past 1.4 m.y.

Ten strath terraces ascend from the North Fork–Gunnison River to 670 m above the modern river (location E in Fig. 5). A cosmogenic burial date of ca. 1 Ma on the seventh terrace anchors the 640 ka profile (at Qt 5/6) giving an average incision rate of 220 m/m.y. (D. Granger, Purdue University, 2007, personal commun.). These strath terraces and associated pediments are inferred to record glacial-interglacial stages superimposed on an overall steady bedrock incision in the Black Canyon.

Although driving forces remain poorly constrained, we presently favor a hybrid model including near-steady bedrock incision during the past 10 m.y. due to upstream migration of a transient wave of incision. This transient possibly reflects downstream base-level fall due to drainage reorganization (see below), minor block tilting and local neotectonics (Hansen, 1965; Ake et al., 2002), and regional mantle-driven epeirogenic surface uplift (Karlstrom et al., 2005). Effects of increased climate erosivity in the past 3.5 m.y. are possible, but not yet documented in terms of increased incision rates (Peizhen et al., 2001).

Stop 5—Warner Point

This stop provides an overlook onto the Bostwick–Shinn Park paleovalley from the flank of the Gunnison Uplift. This trail provides spectacular views of the ~300-m-high, southwest facing, Red Rocks–Cimarron fault topographic scarp and the ancestral Bostwick River course. The Red Rocks–Cimarron fault zone forms the southwest edge of the Gunnison uplift. This system has several segments that separate uplifted Precambrian rocks and overlying Mesozoic strata in the core of the uplift from Cretaceous Mancos Shale and the overlying late Quaternary Boswick River paleovalley (Dickinson, 1965; Hansen, 1971). The fault dips 50°–70° northeast and originated and accumulated most of its slip during Laramide faulting (Hansen, 1971). Although outcrop exposure of the fault itself is poor as it crosses Red Rock Canyon, it does not appear to offset late Pleistocene to Holocene alluvial fans at this location. Variable topographic relief along the scarp is interpreted to be the result of differential erosion of soft Mancos Shale outcrops on the southwest side relative to harder Precambrian rocks on the northeast (Ake et al., 2002).

The presence of the Lava Creek B ash and underlying river gravels permits the reconstruction of the gradient of the ca. 640 ka Bostwick River. Comparisons between gradients of the modern Gunnison and Uncompahgre Rivers and ca. 640 ka rivers show that ancestral Bostwick River had a much lower gradient than its modern counterparts (Fig. 6). This difference in gradient geometry could be explained by post–640 ka base-level lowering downvalley that caused a transient knickpoint to migrate upvalley, which led to a wave of incision. It is tempting to speculate that the transient knickpoint and wave of incision were triggered by base-level changes associated with abandonment of Unaweep Canyon. In this scenario, transient knickpoints migrated up both the Gunnison and Uncompahgre Rivers, leading to substantial incision of the lower reaches of the Black Canyon and a significant portion of the Uncompahgre Valley between Ouray and Delta, Colorado. Similar to the situation with the Black Canyon, an Uncompahgre River knickpoint exists in the Precambrian rocks located immediately upstream of Ouray, and the valley downstream of this point is largely floored by erodible sedimentary rocks such as the Mancos Shale. The presence of Mancos Shale would have facilitated rapid migration of the knickpoint and could help account for the

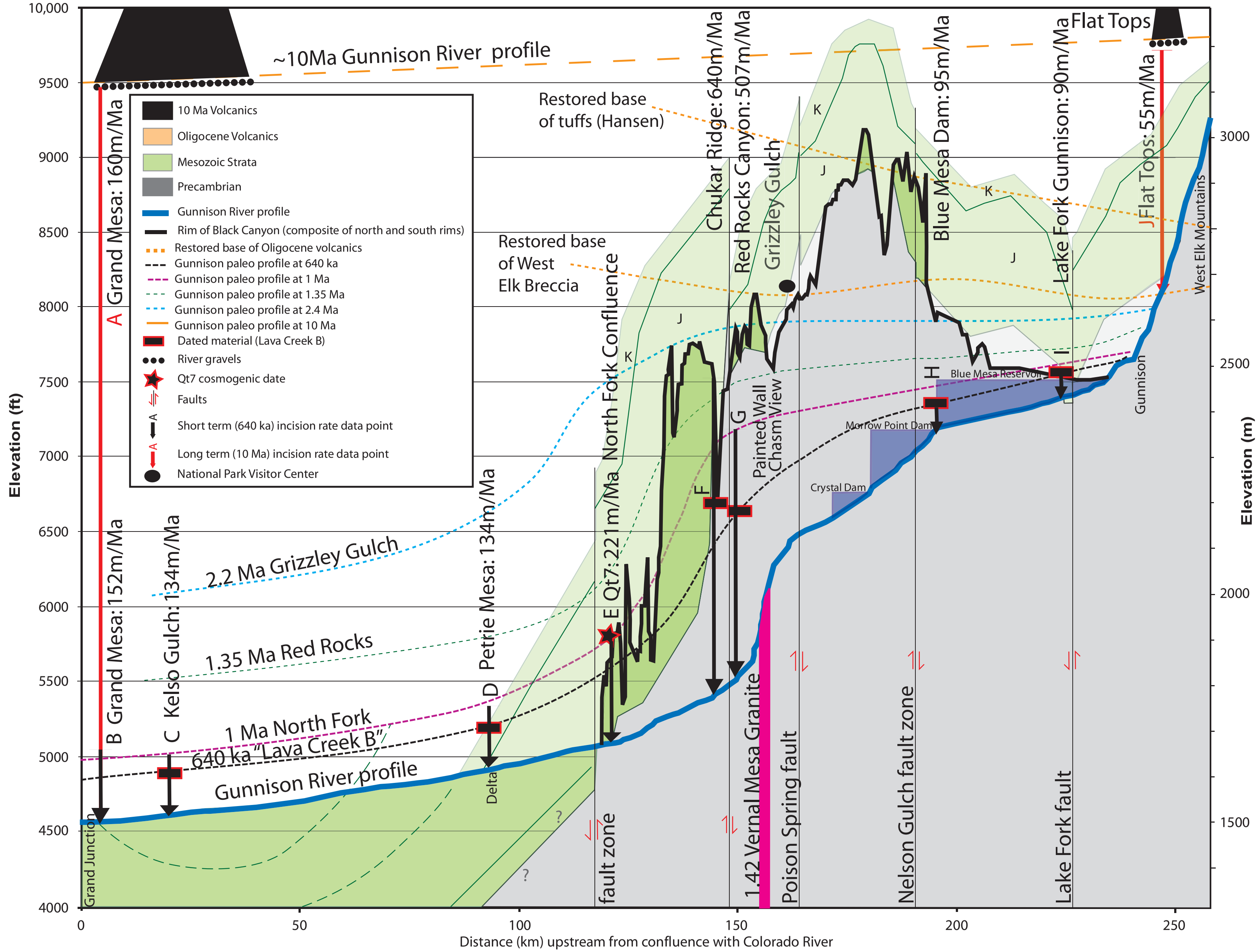

Figure 5. Longitudinal profile of the Gunnison River and reconstructed gradients over the past 10 Ma. Bedrock geology (Hansen, 1971) and the topography of the canyon walls in the vicinity of the Black Canyon of the Gunnison are also shown.

anomalously rapid incision rates in the Uncompahgre Valley measured over the past 640 k.y. near Red Canyon (>600 m/m.y.) and upvalley toward Ridgway, Colorado (>300 m/m.y.) (Kelley et al., 2007) (Fig. 7).

Hansen (1965) argued that the localized incision of the Black Canyon of the Gunnison reflects local tilting and uplift of this Precambrian block. In the absence of definitive evidence of the extent of Quaternary faulting, an alternative explanation is that there has been regional uplift of the Black Canyon area, including western Colorado in general. Regional data show that river incision began after 10 Ma and was certainly under way along rivers such as the Colorado by 7.7 Ma (Kunk et al., 2002), which suggests that Pleistocene glacial cycles had little to do with the onset of canyon cutting in the Colorado Rocky Mountains. Whether or not Pleistocene glacial cycles may have accelerated incision is debatable, but comparisons between the long-term (10 m.y.) and shorter-term (640 k.y.) incision rates are quite similar (Figs. 2 and 7). This similarity raises questions regarding previous interpretations of accelerated incision over the past 2–3 m.y. due to increased Pleistocene river discharge (Dethier, 2001; Kunk et al., 2002). If incision rates have been fairly constant over the past 10 m.y., then the mechanism(s) driving river incision must operate over time scales longer than the ice age cycles. Perhaps the similar long- and shorter-term incision rates provide indirect evidence of broad regional uplift of western Colorado since the late Miocene, as suggested by McMillan et al. (2006).

Stop 6—Radio Hill

Long-Term Uncompahgre and Gunnison River Evolution

High-elevation volcanic-clast–dominated river gravels are present along the crest and northeastern flanks of the Uncompahgre Plateau (Sinnock, 1978; Betton et al., 2005) (Fig. 8). Scattered gravels occur at elevations as high as 10,000 ft, and significant gravel deposits are present at elevations of 9000 ft and less. Elevations of the gravels generally decrease to the northeast down the dipslope of the Uncompahgre Plateau. These observations suggest that the ancestral Uncompahgre River has been simultaneously incising and migrating downslope along the contact between resistant Cretaceous Dakota Sandstone and less-resistant Mancos Shale. The net result of this dipslope migration and incision has been to carve a very deep (4000–5000 ft) but very broad river valley. The 640 ka Uncompahgre River gravels at Kelso Gulch record the late stages of this long-term river incision and dipslope migration.

Beginning as far southeast as Escalante Canyon, ancient Gunnison River gravels begin to appear along the flanks of the Uncompahgre Plateau. These gravels represent Gunnison River courses that were located downstream of the paleo-confluence of

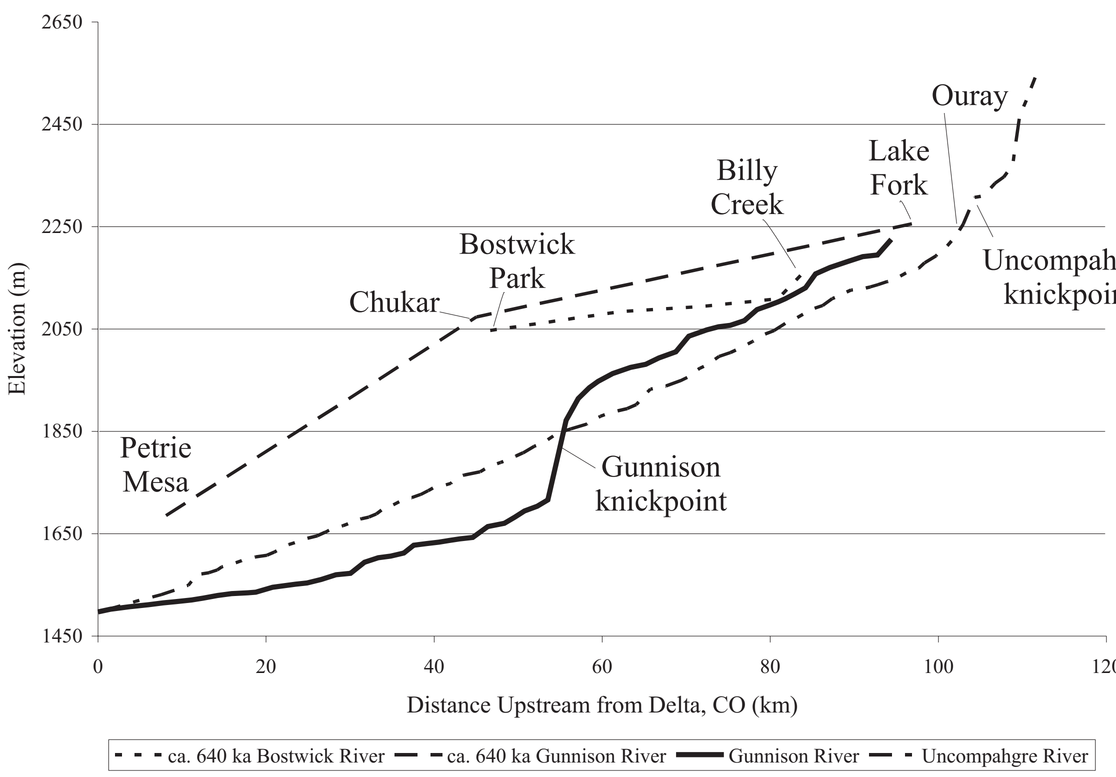

Figure 6. Long profiles of the modern Gunnison and Uncompahgre Rivers and ca. 640 ka Bostwick and Gunnison Rivers. Both of the modern river knickpoints are associated with Precambrian rocks uplifted during the Laramide orogeny. The locations listed along the profiles are shown in Figures 3 and 4. From Hudson et al. (2006).

the Uncompahgre and Gunnison Rivers. The presence of these gravels at elevations of up to ~6600 ft shows that the ancestral Gunnison River must have turned southward as it exited the Black Canyon of the Gunnison, or turned westward and exited the canyon at a point south of the modern canyon mouth, in order to explain the ancient Gunnison River gravels present downstream of Escalante Canyon (Fig. 8).

Grand Mesa Terraces

From "Radio Hill" numerous gravel-capped terraces can be seen on the south flank of Grand Mesa, extending from Paradox Mesa on the west to Oak Mesa on the east (Fig. 9). These surfaces provide a detailed record of the late Cenozoic erosional history of Grand Mesa and surrounding areas. Two types of terraces exist. Those east of Surface Creek represent fluvial outwash and alluvial-fan deposits, whereas those west of Surface Creek are mainly pediments. Bedrock under all but the highest surfaces is the Late Cretaceous Mancos Shale. Previous discussions of the terraces can be found in Cole and Sexton (1981), Cole and Aslan (2001), Aslan and Cole (2002), Baker et al. (2002), Betton et al. (2005), and Rider et al. (2006).

The gravel capping the terraces is strongly dominated by basalt clasts from Grand Mesa, with small amounts (1%–2%) of sandstone, quartzite, chert, diorite, andesite, granite, hornfels,

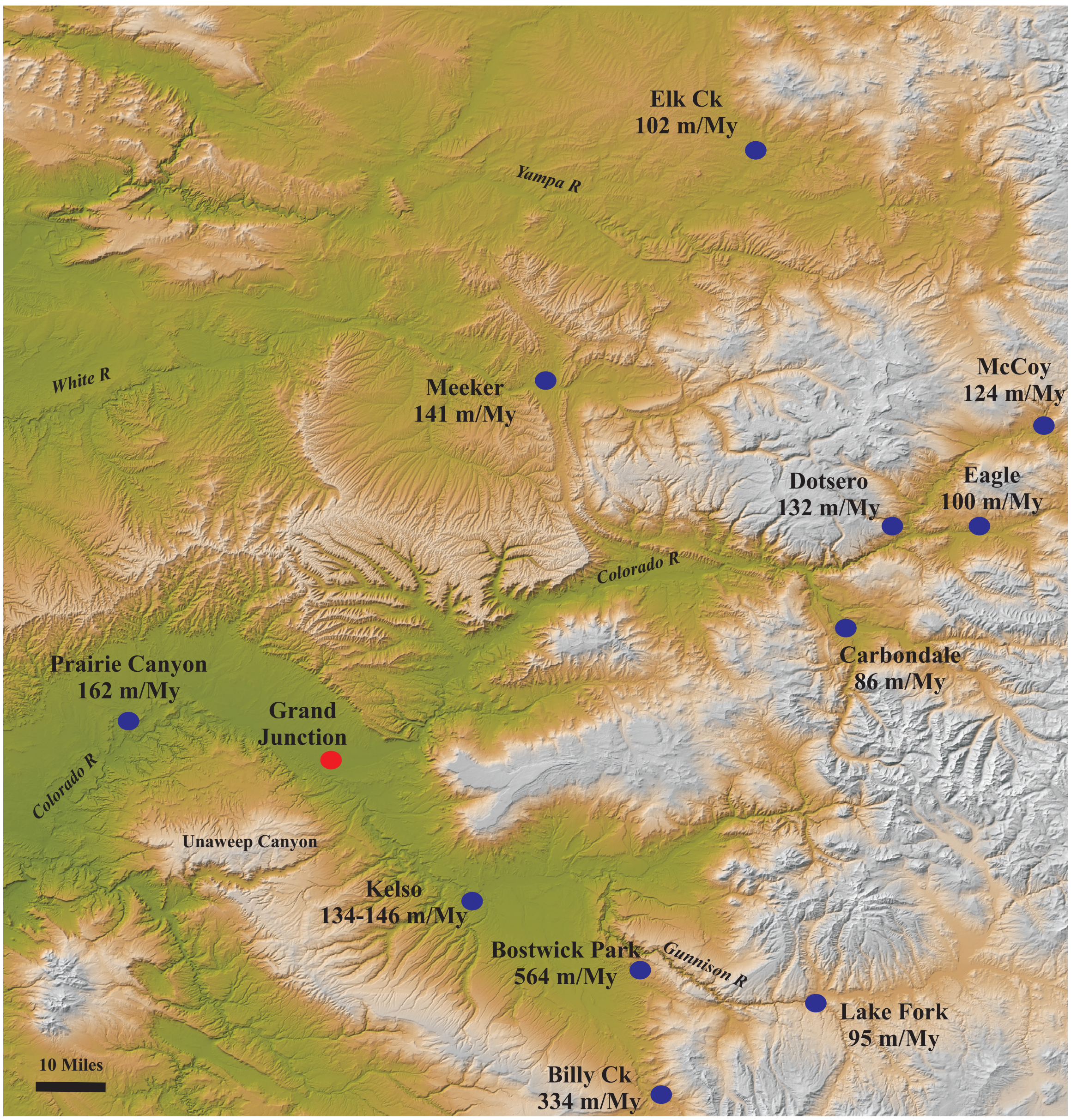

Figure 7. Map of river incision rates over the past 640 ka in western Colorado. Data are from Larson et al. (1975), Izett and Wilcox (1985), Willis and Biek (2000), Hudson et al. (2006), and Darling et al. (2007).

schist, and gneiss. These "exotic" clasts probably represent the eroded remnants of ancient river (North Fork of Gunnison?) gravels high on the south flanks of Grand Mesa, or gravels contained in an unnamed Miocene (?) unit that underlies the basalt. The western pediment gravels are poorly stratified, range from 3 to 80 ft thick, and have basalt clasts up to 10 ft in diameter. The eastern outwash gravels are up to 250 ft thick, have clasts (sandstone and basalt) up to 20 ft in diameter, and are generally well stratified.

The ages of the terraces are poorly constrained. The only control point is the Lava Creek B ash (ca. 640 ka), which is found within the gravel sequences at Petrie Mesa and Paradox Mesa. The ash is also present at Kelso Gulch and at various locations in the upper Uncompahgre Valley. A reworked and transported unnamed Miocene ash is present in Redlands Mesa. The relative age relationships of the Grand Mesa terraces are documented in Figure 10, which shows longitudinal profiles from two control (pivot) points on Grand Mesa. The control point for the western terraces is on the tip of the Flowing Park lobe, whereas the eastern control point is near Green Mountain (Fig. 9).

Five terrace levels are illustrated on Figures 9 and 10. Level 1 is the paleotopographic surface beneath the basalt cap on Grand Mesa, which ranges in elevation from 9632 ft (west) to 11,277 ft

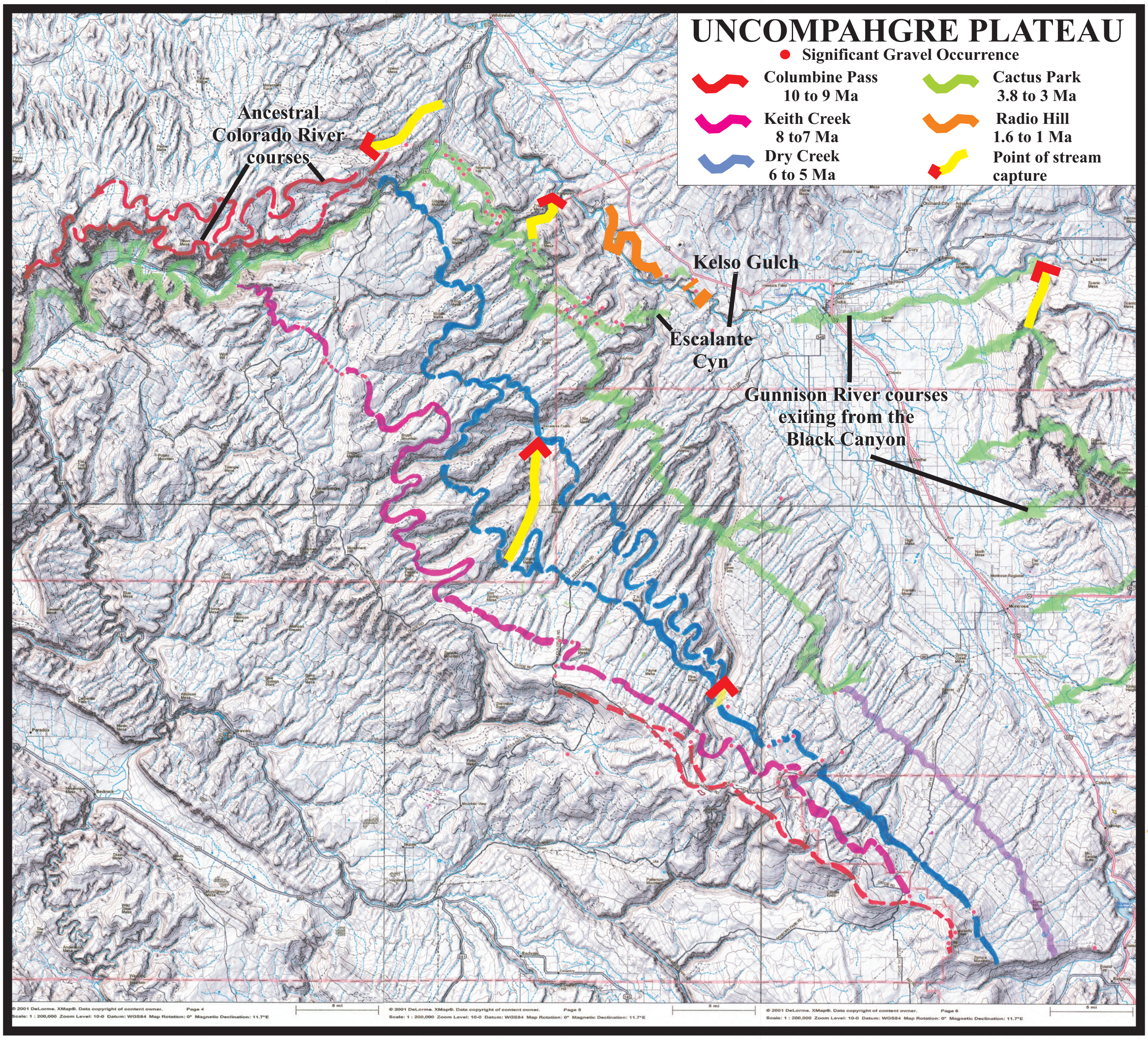

Figure 8. Map showing ancestral river courses based on the occurrence of ancient river gravels on the Uncompahgre Plateau. From Betton et al. (2005).

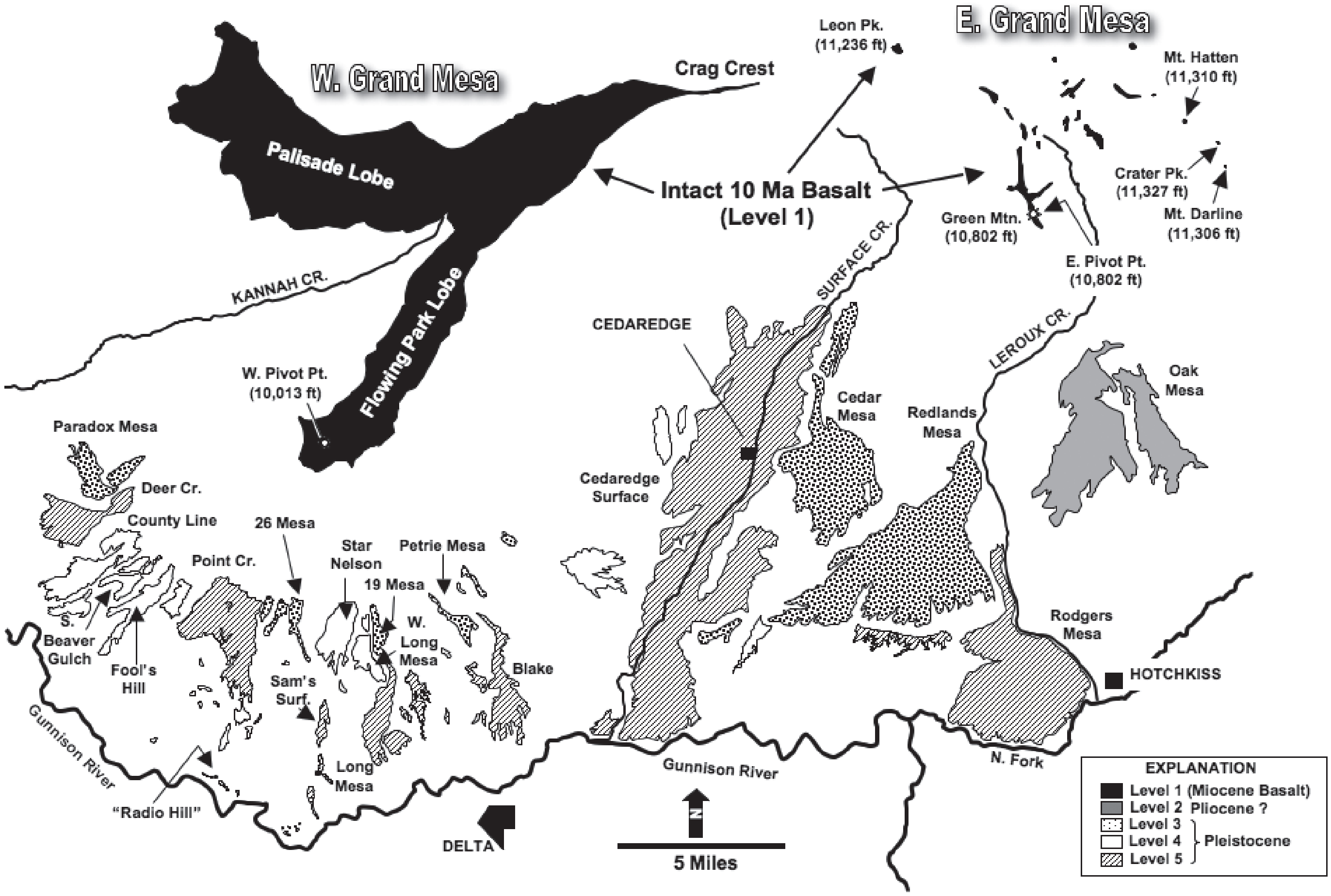

Figure 9. Reconnaissance-scale map of gravel-capped terraces on the south flank of Grand Mesa. Data from Cole and Sexton (1981), Baker et al. (2002), and Rider et al. (2006).

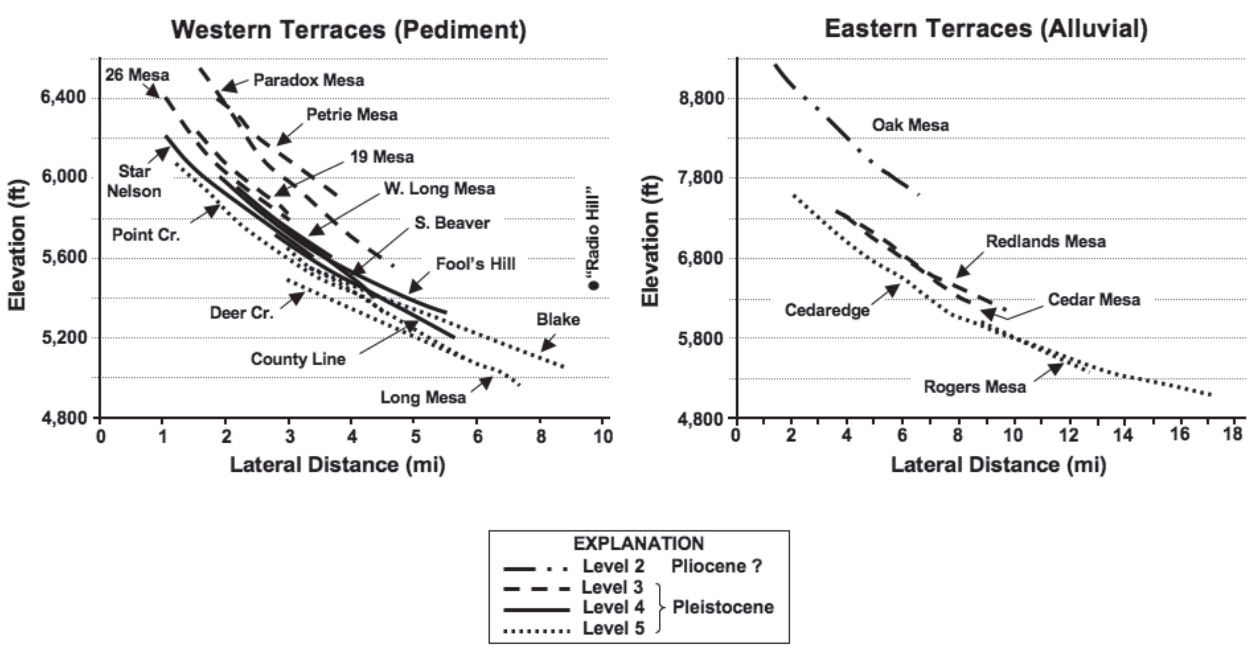

Figure 10. Longitudinal profiles of selected surfaces on the south flank of Grand Mesa; see Figure 9. Profiles for the western terraces are tied to a pivot point on the tip of the Flowing Park Lobe of Grand Mesa and are interpreted mainly as gravel-capped pediment surfaces. Profiles for eastern Grand Mesa terraces, which are capped mainly by fluvial outwash (fan) gravels, are tied to a pivot point north of Green Mountain (see Fig. 9).

(east). The age of the basalt, which has a maximum preserved thickness of 613 ft, ranges between 9.22 and 10.76 Ma (Kunk et al., 2002). Level 2 is recorded only by Oak Mesa, which ranges from 9200–7600 ft in elevation and is probably Pliocene or possibly Miocene in age based on the gross incision rate (~0.54 ft/k.y.) for western Colorado. Level 3 surfaces occur in both the west and east areas and range in elevation from ~5500 to 7400 ft. Petrie and Paradox Mesas, which contain the Lava Creek B ash, are Level 3, thus suggesting an age near 640 ka. Level 4 terraces occur only in the western area and range in elevation between ~5120 and 6200 ft; their ages possibly range between 250 and 500 ka. Level 5 surfaces occur in both areas, range in elevation between ~5000 and 7600 ft, and have possible ages between 300 and 70 ka.

DAY 2: UNAWEEP CANYON

Introduction

One of the most interesting and enigmatic incised canyons in the western United States is Unaweep Canyon, which cuts southwest across the Uncompahgre Plateau of western Colorado (Fig. 11). The central interior of the canyon is carved in resistant Precambrian gneiss and granite, which are overlain by gently dipping Mesozoic sandstone and shale (Lohman, 1981).

It has long been recognized that this canyon was carved by one or more large rivers during the late Cenozoic and that the canyon was subsequently abandoned. Abandonment has been commonly attributed to local Plio-Pleistocene uplift of the Uncompahgre Plateau relative to adjacent sedimentary basins (Cater, 1966; Lohman, 1961, 1981; Sinnock, 1981; Scott et al., 2002).

Unaweep Canyon is drained by two small underfit streams that flow in opposite directions. East Creek flows northeast to the Gunnison River and West Creek flows southwest to the Dolores River. A low divide (Unaweep divide, elevation is ~7000 ft [2130 m]) separates the two streams. Early explorers noted that Unaweep Canyon was much too large to have been cut by the existing streams, given their small size (Peale, 1877; Gannett, 1882). This observation, coupled with the fact that Unaweep Canyon cuts across the structural axis of the Uncompahgre Plateau, suggested that the canyon had formerly been occupied by the Colorado River, the Gunnison River, or both rivers (Peale, 1877; Gannett, 1882; Shoemaker, 1954; Hunt, 1956, 1969; Lohman, 1961, 1965, 1981; Cater, 1966, 1970; Sinnock, 1981). Since then, several new hypotheses have been proposed for Unaweep Canyon (Steven, 2002; Aslan et al., 2005; Soreghan et al., 2005, 2006, 2007; Noble et al., 2006; Schoepfer et al., 2007). In particular, we will discuss whether or not localized late Cenozoic uplift of the Uncompahgre Plateau caused the abandonment of Unaweep Canyon.

Stop 7—Cactus Park Gravel Pit and Gunnison River Gravels

Cactus Park is a northwest-southeast–trending paleovalley of the Gunnison River (Fig. 12). The gravel pit exposes rounded Gunnison River gravels inset against Jurassic Wingate sandstone and overlain by angular and poorly sorted local gravels derived from nearby outcrops of Jurassic and Cretaceous strata. Gunnison River gravels are distinguished from Colorado River gravels and local stream gravels by their high percentages (up to 70%) of intermediate volcanic clasts (Fig. 13A), whereas Colorado River deposits have a significantly greater proportion of sedimentary rocks, including distinctive clasts of oil shale and red sandstone and siltstone. The volcanic clasts in the Gunnison River gravels are derived from the Tertiary volcanics that blanket the San Juan Mountains and the Gunnison region located southeast of Cactus Park (Tweto, 1979). Steven (2002) suggests that the gravels in Cactus Park were deposited by the Uncompahgre River, but the presence of Precambrian granitic rocks supports a Gunnison River origin.

Southeast of the gravel pit, the valley floor of Cactus Park is dotted by scattered grass-covered hills that represent Gunnison River terrace remnants. The river gravels range in thickness from 3 to 5 m and are commonly mixed with more angular clasts of somewhat younger local gravels (Fig. 13B). In several instances, well-expressed straths separate the gravels from Jurassic bedrock. Terrace remnants range in elevation from as low as ~6140 ft to ~6400 ft, and are 460–540 m above the present-day Gunnison River. Long-term incision rates calculated based on the age of Grand Mesa basalts (ca. 10 Ma) suggest the Cactus Park gravels may be as old as 3 Ma.

The river gravels of Cactus Park accumulated as the Gunnison River simultaneously incised and migrated laterally along the dipslope of the sandstone-rich Salt Wash Member of the Morrison Formation. The dipslope migration of the river produced an asymmetric valley floored by a down-stepping flight of terraces. Based on reconstructions of the gradient of the ancestral Gunnison River in Cactus Park as well as comparisons using the modern valley gradient of the Gunnison River between Delta and Grand Junction, Colorado (8.6 ft/mi; 4.2 m/km), we suggest that the Gunnison River gravels in Cactus Park represent as many as 5 terrace levels.

Stop 8—Cactus Park Lake Beds

Pale yellow horizontal planar-bedded to laminated clayey silt and silt crop out within minor drainages in the southeast portion of Cactus Park and along the low divide that separates the northwest and southeast parts of Cactus Park (Figs. 13C and 13D). Unweathered deposits are gray (reduced) in color. The thickness of these deposits is up to 175 ft (53 m), and they stratigraphically overlie Gunnison River gravels and/or Jurassic bedrock. These bedded silts and clays are interpreted as lacustrine sediments that mark the abandonment of Cactus Park and Unaweep Canyon. Dip magnitudes and directions are commonly 2°–3° to the northeast or to the west, although beds dip as much as 10° locally.

In 2006, the Grand Junction Geological Society sponsored a drilling program of the Cactus Park lake beds and underlying river gravels (Fig. 14). Three holes were drilled near Cactus Park divide ranging in depth from 150 ft to 178 ft. Gunnison River gravels overlying Jurassic bedrock were encountered at a depth

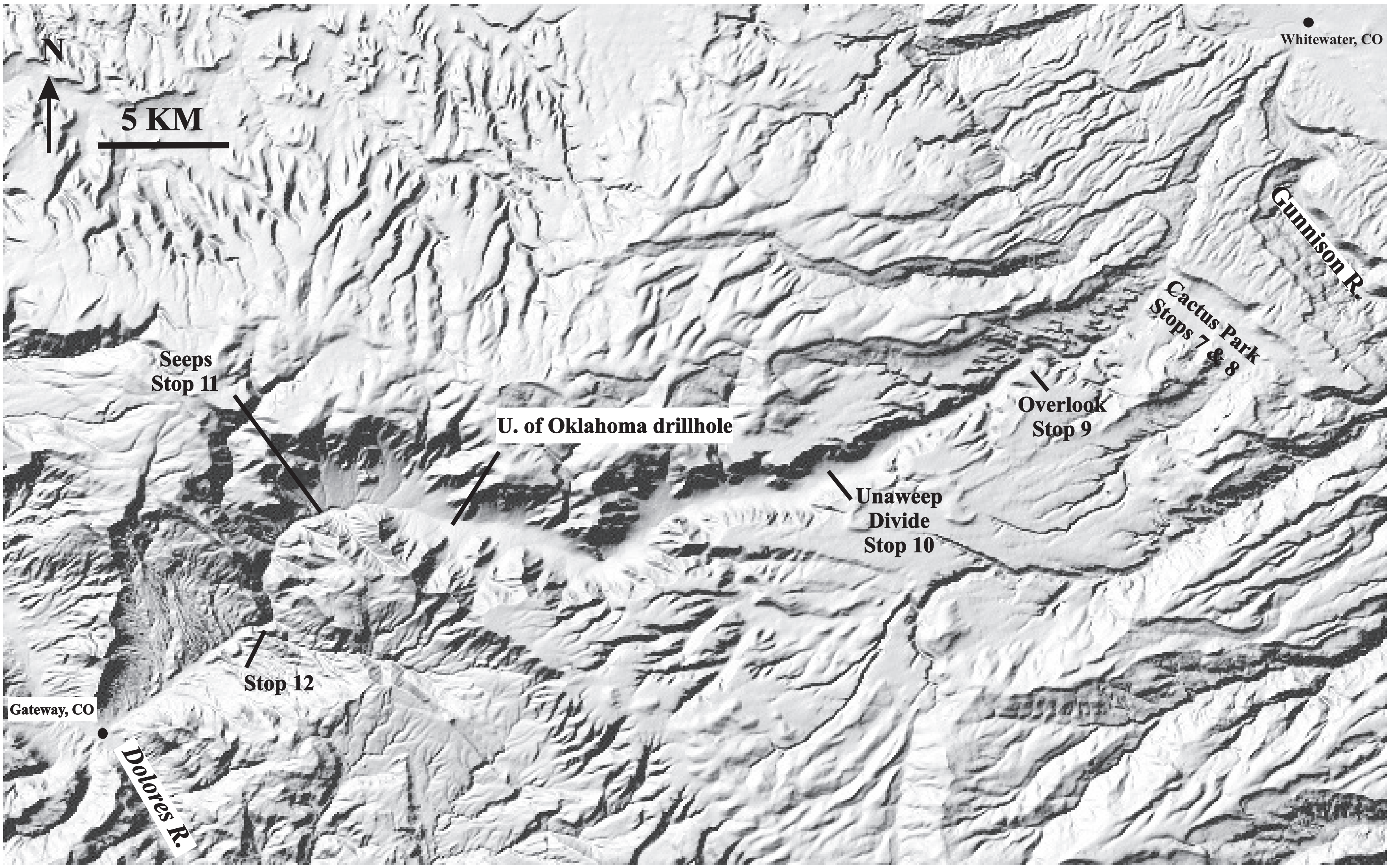

Figure 11. Shaded relief map of Unaweep Canyon. Location of University of Oklahoma drill hole from Soreghan et al. (2006).

of 164 ft. Samples were taken from the drilling program, including several 5-ft-long cores. Preliminary analysis of the cores for microfossils shows reworked Cretaceous foraminifera, possible ostracod and *Inoceramus* shell fragments, and probable Quaternary pollen (B. Hood, Grand Junction Geological Society, 2007, personal commun.; P. Bradbury and B. Thompson, U.S. Geological Survey, 2007, (personal commun.). X-ray diffraction of the clay-size fraction shows that the clay mineralogy is dominated by a mixed layer of illite-smectite clay (composed primarily of illite) and lesser amounts of discrete smectite and kaolinite. This clay mineral suite is similar to that of the Cretaceous Mancos Shale plus some admixed Morrison Formation smectite, and the deposits themselves strongly resemble weathered Mancos Shale. Trace-element geochemistry shows that Cactus Park lake beds

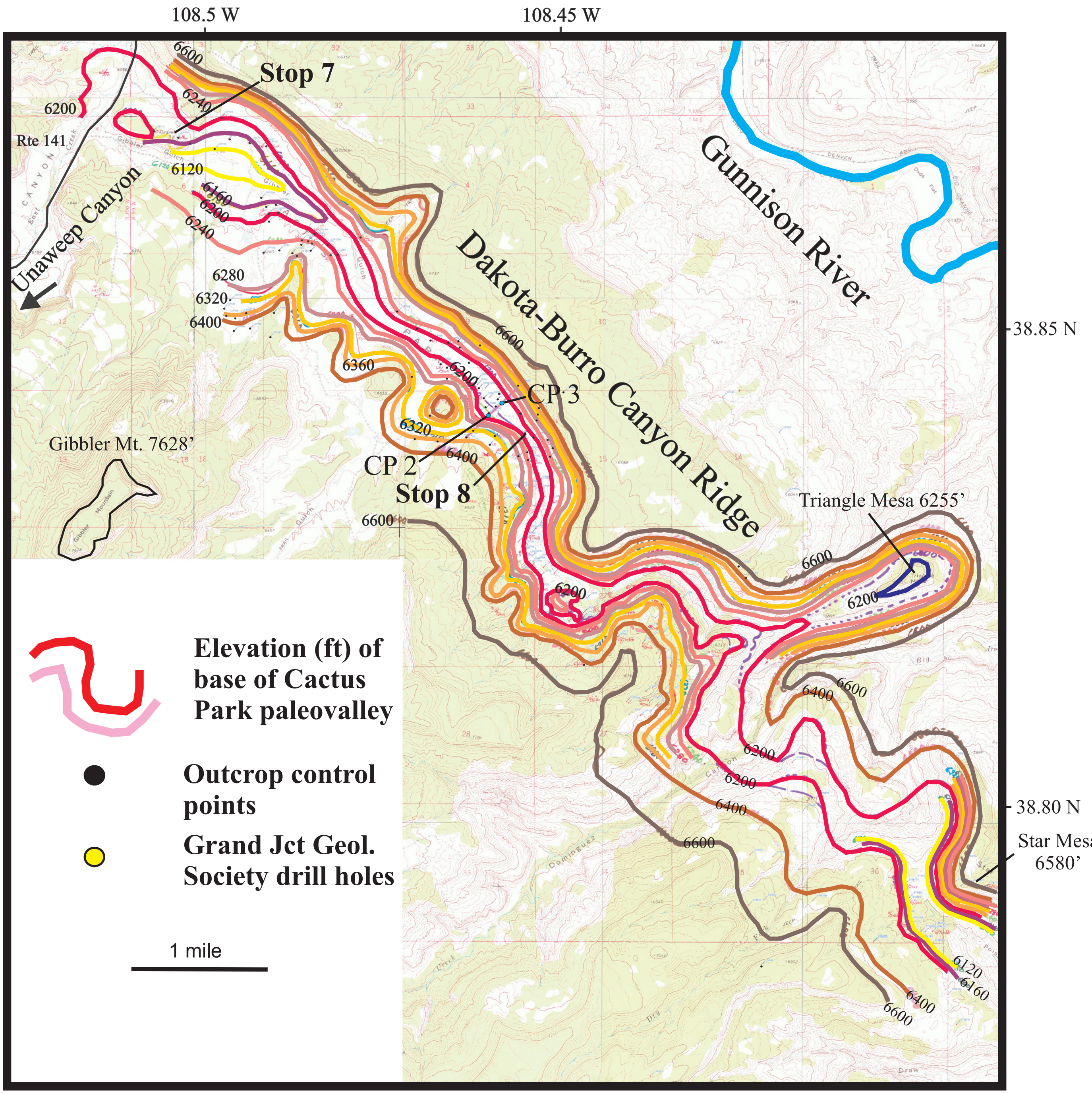

Figure 12. Map showing the geometry of the Cactus Park paleovalley. Contours are drawn on the contact between bedrock and overlying valley-fill remnants, which consist of ancient river gravels and lake beds.

are broadly similar to modern Gunnison River mud and unweathered Mancos Shale (Schoepfer et al., 2007). In general, these similarities indicate that the lacustrine sediments were at least partly derived from Mancos Shale.

Origin of Cactus Park Lake

The results of the drilling and geologic mapping suggest that Cactus Park lake beds at one time filled the Cactus Park paleovalley and buried the terraces of the Gunnison River. Prior to the deposition of the lake beds, the Gunnison River flowed northwest through Cactus Park toward Unaweep Canyon (Fig. 15A). While the Gunnison River flowed through Cactus Park, it incised episodically (as much as 400 ft) and produced the observed suite of down-stepping terrace remnants. Similar down-stepping flights of terraces are common along the modern Gunnison River (Scott et al., 2001).

Occupation of Cactus Park began soon after or while the Gunnison River deposited the oldest (or highest) gravels at Star Mesa (elevations of up to 6580 ft; Figs. 12 and 15B). The youngest (or lowest) Gunnison River gravels near Star Mesa are at elevations (~6120 ft) slightly lower than those of the lowest Cactus Park gravels (~6160 ft), which, given the location of Star Mesa upvalley from Cactus Park, indicates that the lowest Gunnison River gravels at Star Mesa are younger than the lowest Gunnison River gravels in Cactus Park. We suggest that the Star Mesa Gunnison River gravels were deposited as the Gunnison River abandoned Cactus Park and Unaweep Canyon and shifted its course to the northeast (Fig. 15B).

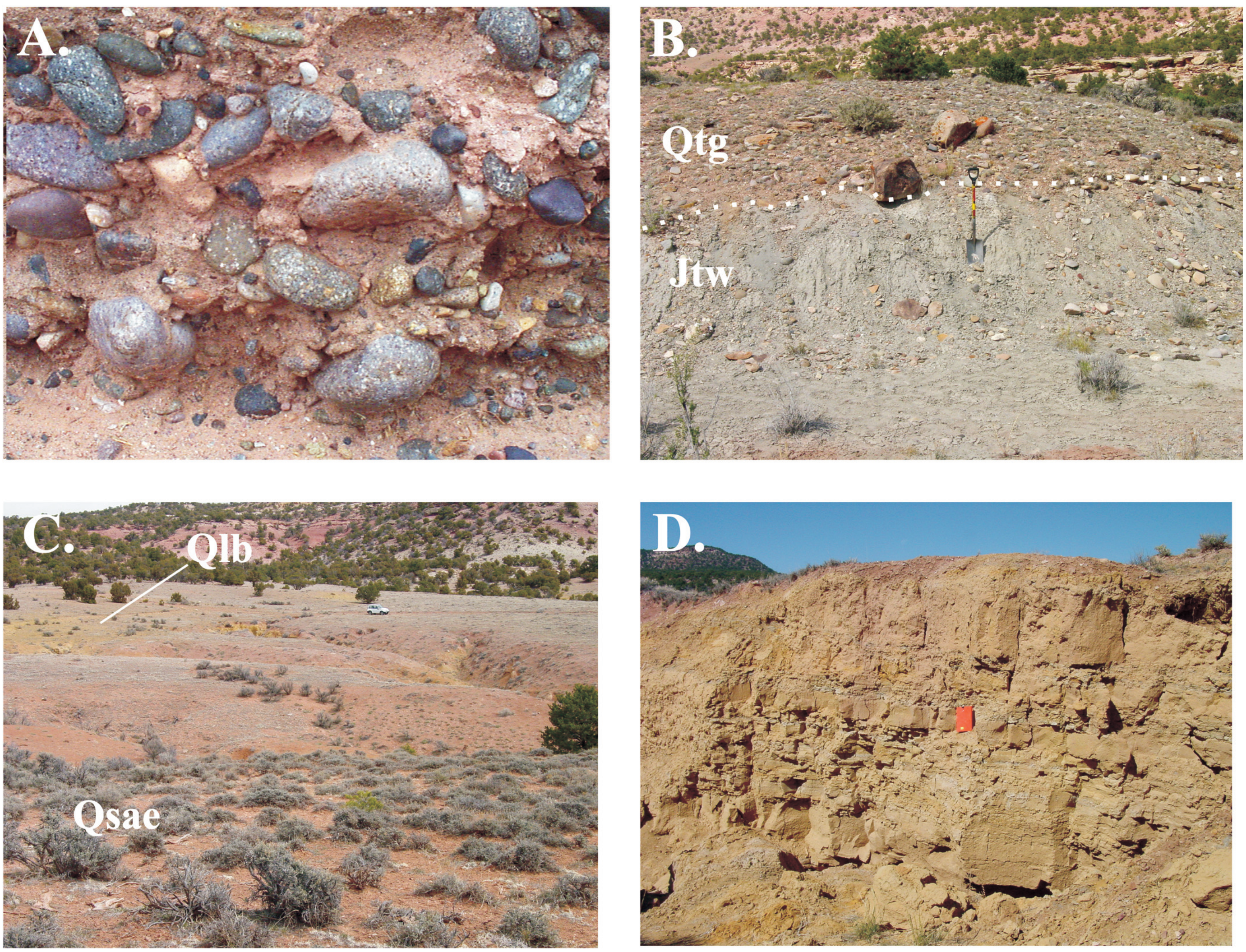

Figure 13. Field photographs of the Cactus Park area. (A) Volcanic-dominated river gravels of the ancestral Gunnison River as seen in the main gravel pit. (B) Gunnison River gravels (Qtg) mixed with local gravels overlying Jurassic mudstones of the Tidwell Member of the Morrison Formation (Jtw). A well-expressed strath is present in the base of the gravels. (C) Yellow color of Pleistocene(?) Cactus Park lake beds (Qlb), which are typically covered by Holocene slopewash, alluvium, and eolian sediments (Qsae). (D) Cactus Park lake beds exposed in gully. These well-bedded deposits consist primarily of interbedded clay and silt.

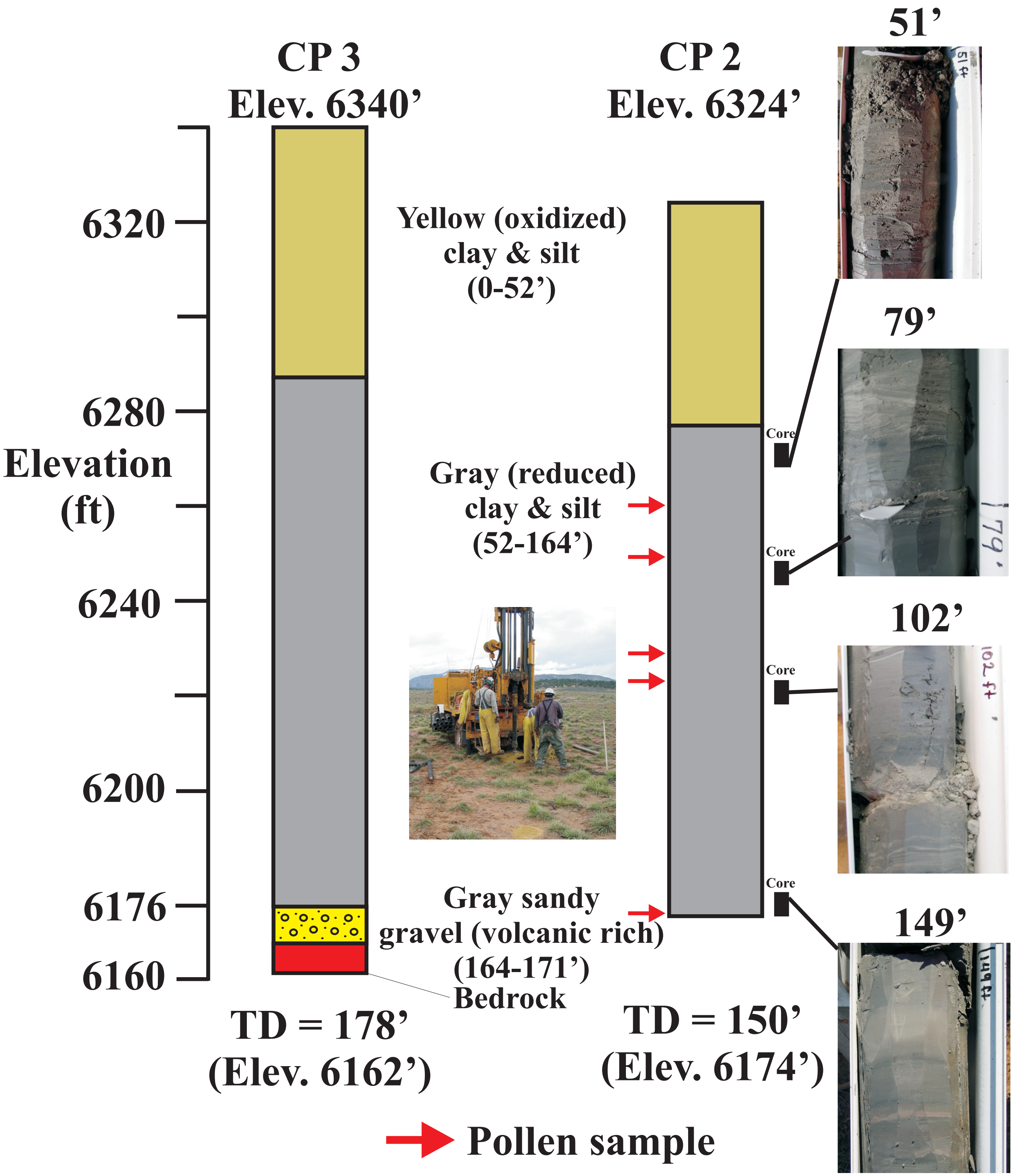

Figure 14. Lithologic logs (CP2, CP3) and core photographs of two of the Cactus Park drill holes. See Figure 12 for locations of the cores.

It is plausible that the Cactus Park lake beds accumulated after Cactus Park and Unaweep Canyon were abandoned (Fig. 15C). Possible natural dams in the western United States include glacial ice, tectonic uplift, and landslides. The low elevation of the region argues against a glacial ice dam, although Cole and Young (1983) postulated a glacial origin for Unaweep Canyon. Large ice dams, not glacial, have been observed on many local rivers, but they disappear quickly in the modern climate. A tectonic dam has been suggested previously for the Cactus Park lake (Scott et al., 2002). We argue that it is more likely that a landslide dam created the Cactus Park lake, although the location of this dam is not well constrained (see discussion at Stop 11; Oesleby, 2005c). Because of the relatively long amount of time that must have been required to accumulate >50 m of lacustrine sediments as well as the difficulty of damming large rivers, we suggest that the dam probably developed after the Gunnison River had already abandoned Cactus Park and Unaweep Canyon. In this scenario, most of the sediment filling the lake was probably derived locally from Mancos Shale outcrops associated with uplands of the Uncompahgre Plateau. Tributaries would have continued to flow through the area as underfit streams and are represented stratigraphically by the local gravels that typically overlie Gunnison River gravels in Cactus Park. Long-term damming of these underfit streams is more plausible than that of

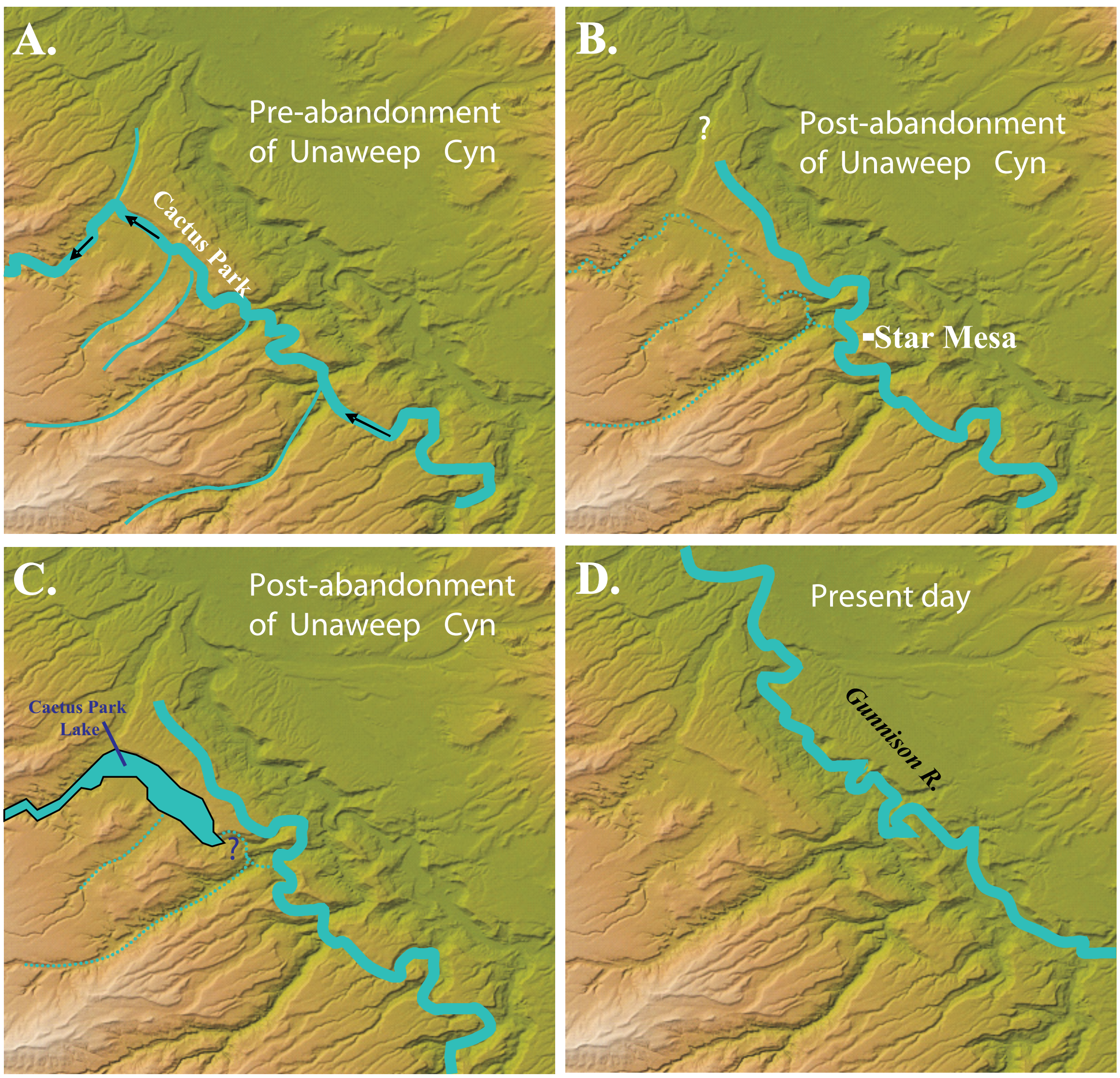

Figure 15. Summary of fluvial activity in Cactus Park. (A) Ancestral Gunnison River flows northwest through Cactus Park. As it incises, it leaves behind a series of down-stepping river terraces. (B) The Gunnison River abandons Cactus Park and Unaweep Canyon, probably some time before 1 Ma. Stream piracy probably occurred in the vicinity of Star Mesa. (C) Damming of residual underfit streams occurs, which produces the Cactus Park and Unaweep lakes. The Gunnison River continues to migrate northeast down the Dakota–Burro Canyon dipslope. (D) Present-day location of the Gunnison River.

the Gunnison River, and is consistent with the strong correlation between Mancos Shale mineralogy, fossils, and chemistry and the Cactus Park lake beds. This interpretation, however, differs from Soreghan et al. (2007) in that these authors found significant percentages of volcanic rock fragments in the sand fraction of lacustrine deposits present in the valley fill of western Unaweep Canyon. The volcanic composition of the sand strongly suggests that the filling of this lake occurred while the Gunnison River still occupied Unaweep Canyon. If the Cactus Park lacustrine sediments were deposited after the Gunnison River abandoned Cactus Park, then the two lakes (Cactus Park, western Unaweep Canyon) cannot be correlative.

Stop 9—Divide Road Overlook of Unaweep Canyon

Summary of Unaweep Canyon Hypotheses

This stop affords an excellent view into Unaweep Canyon. Here we will review the history of thought about the canyon: which river carved it, how thick is the valley fill in the canyon, and has it been modified by glaciers?

The debate over which river carved Unaweep Canyon began with two members of the Hayden Survey of 1875. Peale (1877), noting the presence of Cactus Park and the nearby Gunnison River, concluded that the Gunnison River carved the canyon. Gannett (1882), observing the alignment of the Colorado River as it comes out of DeBeque Canyon with Unaweep Canyon, thought that the Colorado River cut the canyon. Subsequent writers have generally sided with one or the other of these opinions, although until Cater's (1966) work none had provided any evidence to support their position. Cater found gravel that he concluded was Gunnison River gravel on the western end of Unaweep, thereby offering the first evidence that the Gunnison River passed through the canyon. This conclusion was supported by Kaplan et al. (2005) and Kaplan (2006). Soreghan, in a series of abstracts and culminating in a recent paper (Soreghan et al., 2007), proposed that the canyon was originally a Permian-age glacial valley that was filled with Paleozoic or Mesozoic sediment and later exhumed by Cenozoic rivers. This hypothesis is quite controversial. Other workers had suggested earlier that Unaweep Canyon had been modified by Pleistocene glaciation (Cole and Young, 1983).

A second item of debate concerns the depth of the valley fill. Many workers assumed it to be shallow and from this assumption deduced that Unaweep Divide represents late Cenozoic differential uplift of the Uncompahgre Plateau (Lohman, 1981; Scott et al., 2002). The first serious challenge to that idea was the work of Oesleby (1977, 1978, 1983, 2005a, 2005b), who concluded from geophysical work that there is a thick valley fill under Unaweep Divide. He concluded that his data were consistent with a deep, V-shaped bedrock valley that was subsequently filled. His geophysical work was verified when Soreghan et al. (2005, 2007) drilled through 329 m (1079 ft) of valley-fill sediments before reaching bedrock. The drillhole data and Oesleby's geophysical depth estimates are consistent with a bedrock valley floor that slopes westward from Cactus Park to the west end of the valley with a gradient of 7.5–7.7 m/km.

Abandonment of Unaweep Canyon by the Gunnison and/or Colorado River has often been thought to have been driven by Plio-Pleistocene uplift of the Uncompahgre Plateau (Cater, 1966; Lohman, 1981; Sinnock, 1978, 1981; Perry, 1989; Scott et al., 2002; Steven, 2002). First Stokes (1948) and later Lohman (1961, 1965, 1981) argued that a Colorado River tributary eroding headward through soft Mancos Shale around the plunging nose of the Uncompahgre Plateau captured the Colorado River and diverted it to a more northerly course (Figs. 16A and 16B). Lohman also thought that subsequent Plio-Pleistocene uplift of the Uncompahgre Plateau created a tectonic dam that blocked the flow of the Gunnison River, which again led to stream piracy and final abandonment of Unaweep Canyon and Cactus Park by major rivers (Figs. 16C and 16D). Recently, Oesleby (2005c) mapped a large landslide that could have dammed the canyon near the west end and created a large lake, ultimately leading to abandonment of the canyon.

Timing of the abandonment of the canyon is uncertain. Hood et al. (2002) estimated the age of the highest Colorado River terrace in the Grand Valley below Unaweep Canyon to be 1.1 Ma, indicating that the Colorado River would have abandoned the canyon at some point earlier than that. R.B. Scott (2003, personal commun.) sampled the Cactus Park lake beds for paleomagnetism and obtained normal polarity. He thought that the Oldavai subchron (1.78–1.96 Ma) would be a reasonable age for the lake beds. However, if one uses the regional incision rate of the Colorado River, the lake beds would be on the order of 3.1 Ma. Kaplan (2006), applying the regional incision rate to terraces at the west end of the canyon, concluded that the Gunnison River abandoned Unaweep Canyon ca. 800 ka.

Stop 10—Unaweep Divide

Thickness of Alluvial Fill in Unaweep Canyon

The thickness of fill at Unaweep Divide has been one of the most controversial subjects surrounding the debate of Unaweep Canyon origins. The divide itself is what led many authors to conclude that the Uncompahgre Plateau has undergone localized tectonic uplift relative to the surrounding basins during the late Cenozoic (Fig. 17A). Lohman (1981) stated that he believed that the amount of fill in the central segment of Unaweep Canyon was "relatively shallow—a few meters at most." Oesleby (1977, 1978, 1983) concluded that there was between 330 and 395 m of fill at the divide (Fig. 17A). If Oesleby's estimate is correct, the bedrock floor of the canyon slopes to the west from Cactus Park to almost Gateway, Colorado, and the hypothesis of late Cenozoic uplift of the central part of the Uncompahgre Plateau would be incorrect. Recently, Soreghan et al. (2005, 2006, 2007) drilled a hole that penetrated ~1200 ft of valley fill in the western part of the canyon, which strongly argues against localized late Cenozoic uplift of the Uncompahgre Plateau.

The Permian Age Hypothesis

Unaweep Divide is also a good place to discuss the hypothesis that Unaweep Canyon is an exhumed Permian glacial valley, as proposed by Soreghan et al. (2005, 2007). This is a controversial hypothesis because the Permian-age Cutler Formation, which they postulate to be coupled with Unaweep Canyon, has traditionally been interpreted as alluvial fan deposits, not glacial deposits. Furthermore, if Unaweep Canyon were a Permian-age glacial valley, it would require ice down to practically sea level at a time when western Colorado was almost on the equator.

Soreghan et al. (2007) cite several pieces of evidence in support of their argument.

1. The valley has a "U" shape, similar to glacial valleys in mountainous areas.
2. Unaweep contains several features that resemble cirques, hanging valleys, and other landforms present in glaciated mountains.
3. The valley contains both exposed and buried diamictite in which Late Paleozoic palynofloras have been found (the buried diamictite was discovered in a hole drilled by Soreghan et al., 2005).

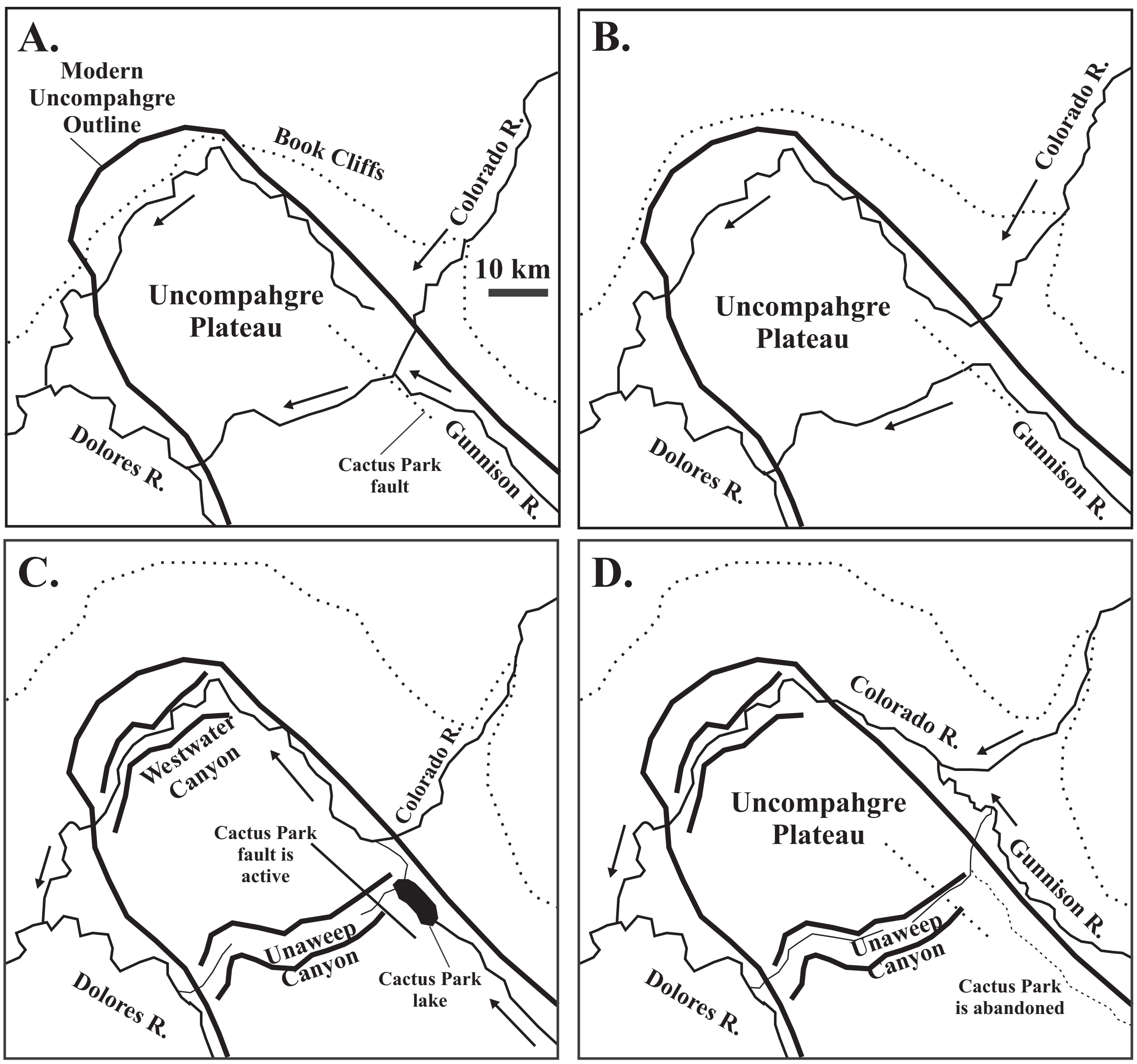

Figure 16. Summary of the commonly held view of how Unaweep Canyon was abandoned. This scenario assumes Plio-Pleistocene uplift along the crest of the Uncompahgre Plateau. Arrows show flow directions. (A) Ancestral Colorado and Gunnison Rivers flow through Unaweep Canyon. (B) Colorado River is captured by a tributary eroding headward through Mancos Shale around the northern edge of the Uncompahgre Plateau. (C) Uplift of the Uncompahgre Plateau occurs and dams the Gunnison River forming the Cactus Park lake. (D) Damming forces the Gunnison River to abandon Cactus Park and relocate to the northeast along the Dakota dipslope. Modified from Lohman (1981) and Scott et al. (2002).

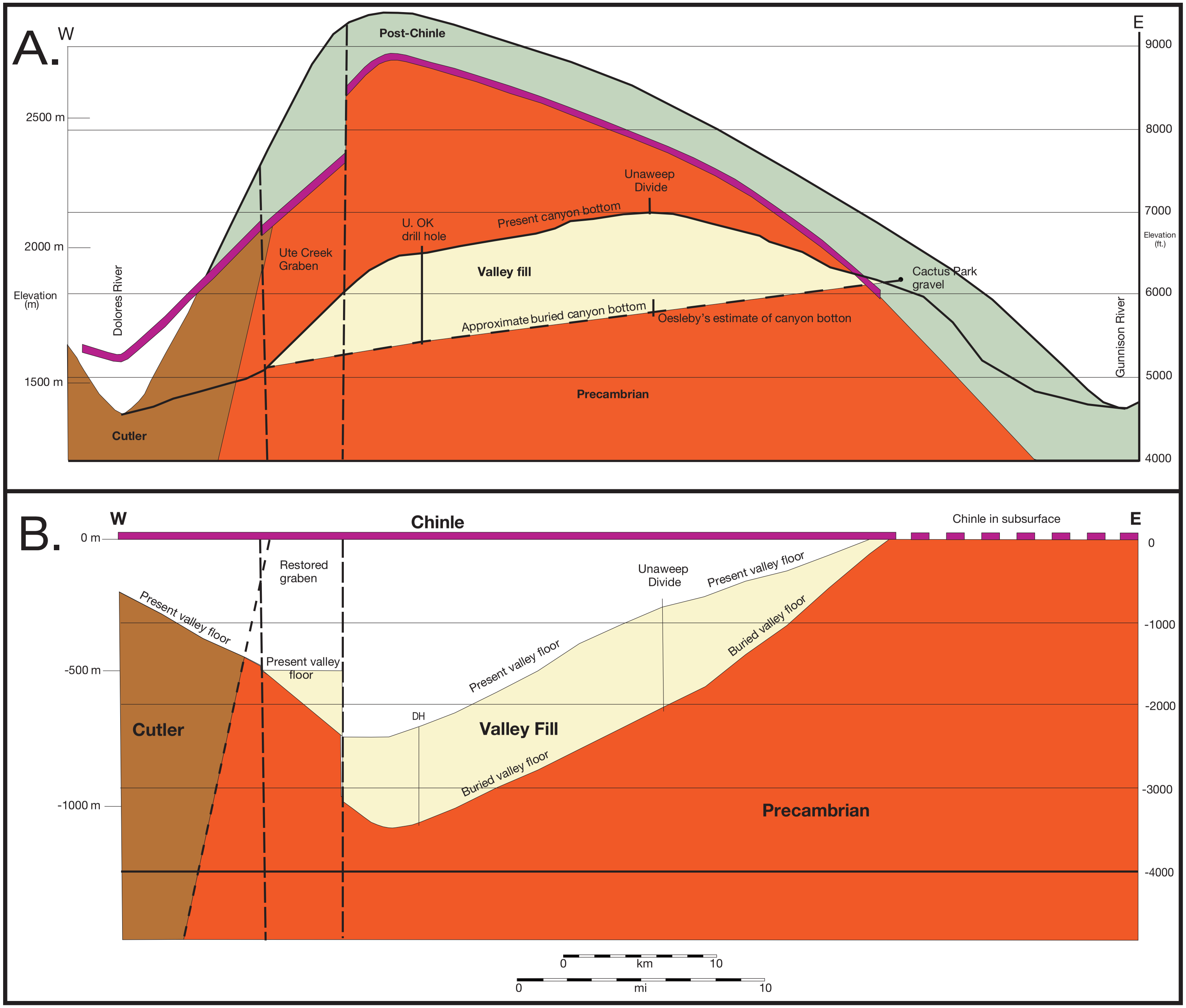

Figure 17. (A) Cross section showing present configuration of rock units in Unaweep Canyon (Modified from Oesleby, 1983). (B) Cross section flattened on the Precambrian-Chinle contact. This cross section shows what Unaweep Canyon would have had to look like if it existed prior to the deposition of the Chinle Formation.

4. Paleomagnetic results from the buried diamictite show low inclination, suggesting that it was deposited in low latitudes, which is where western North America was in Permian time.

However, our view is that these features can all be explained by other means:

1. The bedrock valley is not a classic "U" shape. Oesleby (1978, 1983, 2005a, 2005b) demonstrated with geophysical methods that there is a thick fill at Unaweep Divide. Soreghan et al. (2006, 2007) disproved the U shape by drilling a well that hit bedrock at almost 1200 ft, which requires a very steep-walled V-shaped valley.
2. The glacial features were pointed out by Cole and Young (1983) and can be attributed to Pleistocene glaciers, if indeed they are glacial features. Having such features preserved intact through most of the Triassic while the rest of the Uncompahgre highland was being eroded would be quite unlikely.
3. The exposed diamictite can be interpreted as a landslide deposit. Oesleby (2005c) identified a major landslide in the area. Cutler sediments lap onto the Precambrian basement rocks west of the exposure, and there are patches of material on the Uncompahgre Plateau that might be Cutler. Having some Cutler materials moved into the canyon by a landslide can explain the rare Late Paleozoic palynoflora. The Colorado River drains Late Paleozoic deposits, which could also be the source of the palynoflora. It should be pointed out that the diamictite with Late Paleozoic palynoflora also contains modern pollen, which supports a young landslide origin.
4. The low magnetic inclination is suspect because the sample is at the bottom of a canyon over 1000 m deep at the drill site and surrounded by rocks that contain magnetite and have their own paleomagnetic imprint. Remnant magnetism in the diamictite would not only have been influenced by Earth's magnetic field but also by the surrounding rock mass.

Two additional arguments refute the model that the canyon is a re-exhumed Permian canyon. First, the canyon is deflected both going into and out of the Ute Creek Graben, a probable Laramide structure. The bounding faults displace rocks as young as Cretaceous, suggesting that Unaweep is a post-Cretaceous canyon and would not have been present in Permian time. Second, restored cross sections hung on the Triassic Chinle Formation show that Unaweep Canyon and the Uncompahgre Plateau did not exist in the Triassic—they were beveled flat and covered by the 30-m-thick fluvial Chinle Formation. This is a critical point, because it means that when the Chinle was deposited, this part of what is now the Uncompahgre Plateau was essentially flat.

Figure 17A is a cross section showing the configuration of the Uncompahgre Plateau at Unaweep Canyon. Formations exposed in the canyon walls are projected to the line of the cross section. Also shown are the configuration of the present alluvial-covered valley floor and the approximate bedrock valley floor, as indicated by Oesleby's geophysical work and Soreghan's drill hole. Note that these two data points indicate a thick valley fill overlying a bedrock channel floor. The bedrock channel has a slope of 7.5–7.6 m/km, depending on where one picks the first bedrock at the west end.

To reconstruct the configuration of the area in Late Triassic time, the area must be flattened on the base of the Chinle Formation (Fig. 17B). This is because the only way to have fluvial deposits of nearly uniform thickness crossing what is now the Uncompahgre Plateau is if the arch did not exist at the time of deposition. The second step is to determine the configuration of the valley as it would have existed at that time. This is done by measuring the distance from the Precambrian-Chinle contact down to the modern buried bedrock floor and plotting that distance on the cross section with flattened Chinle. The result of the reconstruction is a longitudinal profile of the hypothesized glacial valley as it would have had to exist in Late Triassic time (Fig. 17B). The reconstruction clearly shows an impossible situation for the longitudinal profile of a stream or glacier. This means that the diamictite in the bottom of Soreghan et al.'s (2007) drillhole cannot be glacial till deposited by a Permian-age glacier, but is likely Quaternary landslide deposits related to the abandonment of Unaweep.

Stop 11—The Seeps

Landslide Dam Hypothesis

The deep windgap of Unaweep Canyon, which transects the Uncompahgre Plateau southwest of Grand Junction, is critical to understanding Colorado River drainage history. A recent test well in the west part of Unaweep Canyon drilled by University of Oklahoma researchers encountered a thick section of fine-grained lacustrine sediments. The test well verifies older seismic and electrical resistivity interpretations of thick valley fill within central Unaweep Canyon, including >150–300 m of fill 2 km northeast of the roadcut breccia. A landslide can explain the abrupt southwestward steepening of West Creek's gradient from 80 m/km to 200 m/km and thinning of valley fill to 20–55 m near the southwest canyon mouth.

New mapping indicates the landslide is much larger than originally suspected, extending ~4 km cross valley, northeast of Highway 141 (Oesleby, 2005c) (Fig. 18). Individual landslide blocks of basement rock capped by Mesozoic sandstone float form rounded hills 200–1000 m across and 135–330 m high. The tops of blocks range from 2035 to 2465 m in elevation and rise above broad alluvial fans at 1900–2135 m (Fig. 18). Four blocks comprise an undulating N-S ridge that descends from the headscarp on the north canyon wall at elevation 2630 m, near a mapped fault and the Uncompahgre structural axis. A fifth block abuts the south canyon wall.

Headward erosion by Colorado River tributary streams set the stage for stream piracy, but diversion was caused by landslide damming and subsequent spill-point overflow at >1926 m, the highest elevation of lake sediments reported from Cactus Park.

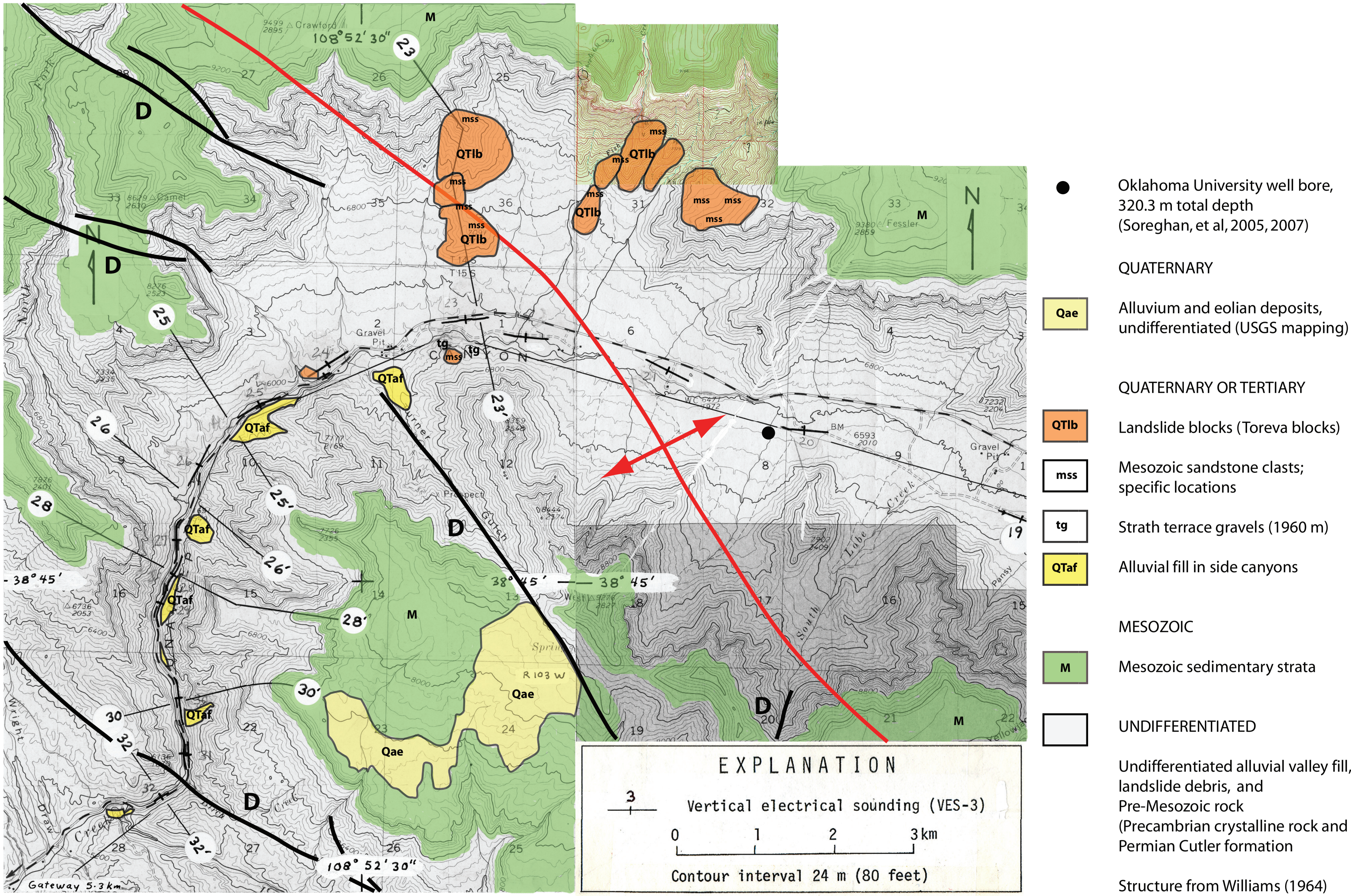

Figure 18. Topographic map of western Unaweep Canyon showing locations of recently discovered landslide blocks (toreva blocks), which are capped by clasts of Mesozoic sandstone (Oesleby, 2005c; modified from Oesleby, 1978). Also shown are locations of perched gravels that were recently discovered downstream of the landslide ~60 m and more above the present channel of West Creek; these are mapped as alluvial fill in side canyons (Williams, 1964) but include terrace gravels and are interpreted as deposited consequent to the landslide.

In the test well, an upward change of pollen from Paleozoic and Cenozoic forms to Cenozoic-only forms might reflect a two-stage abandonment sequence: Colorado River first and Gunnison River second. The substantial rise in local base level resulted in Unaweep streams being superimposed or "pinned" on basement rock at three locations: the northeastern and southwestern canyon mouths and adjacent to the roadcut breccia exposure itself (Fig. 19). These factors effectively halted incision of Unaweep Canyon and may have greatly reduced erosion of the canyon walls, providing a rare opportunity for comparative studies of erosion.

Stop 12—Gateway Gravels

Did the Colorado River Flow through Unaweep Canyon?

Gravels at Cactus Park, an ancient river course that enters the eastern end of Unaweep Canyon, have long been recognized as originating in the Gunnison River drainage. More recently, Kaplan et al. (2005) and Kaplan (2006) identified several other outcrops of ancient river gravels between Gateway and the exit to Unaweep Canyon. Her pebble counts showed that the gravels contain abundant intermediate-composition volcanic rocks, a hallmark of the Gunnison River. She found only a small amount of vesicular basalt and, following in the footsteps of Cater (1966), used these as a criterion to say that the Colorado River never flowed through the canyon.

However, the highest terrace of river gravel that Kaplan (2006) studied in the Gateway area, and first mapped by Cater (1966), contains clasts of red siltstone that appear identical to the Maroon Formation found in the Colorado River but are virtually absent in the Gunnison River. A count of 425 rounded river cobbles in the gravel gave 11 red siltstone cobbles (2.6%). Similar counts of clasts in the Colorado River show ~9% red siltstone above the confluence with the Gunnison River and 3%–4% below the confluence. Pebble counts of Gunnison River gravels at Whitewater and just south of Grand Junction each gave <0.3% of red siltstone, and Cactus Park contained ~0.25%, indicating that this type of gravel could not have been the source of the much more abundant red siltstone clasts in the Gateway terrace. Comparison of thin sections from the Gateway red siltstone with Maroon Formation clasts from the Colorado River shows great similarity in mineralogy, cementation, and grain size. We interpret these clasts to be strong evidence that the combined Colorado-Gunnison Rivers flowed through Unaweep Canyon for much of its history.

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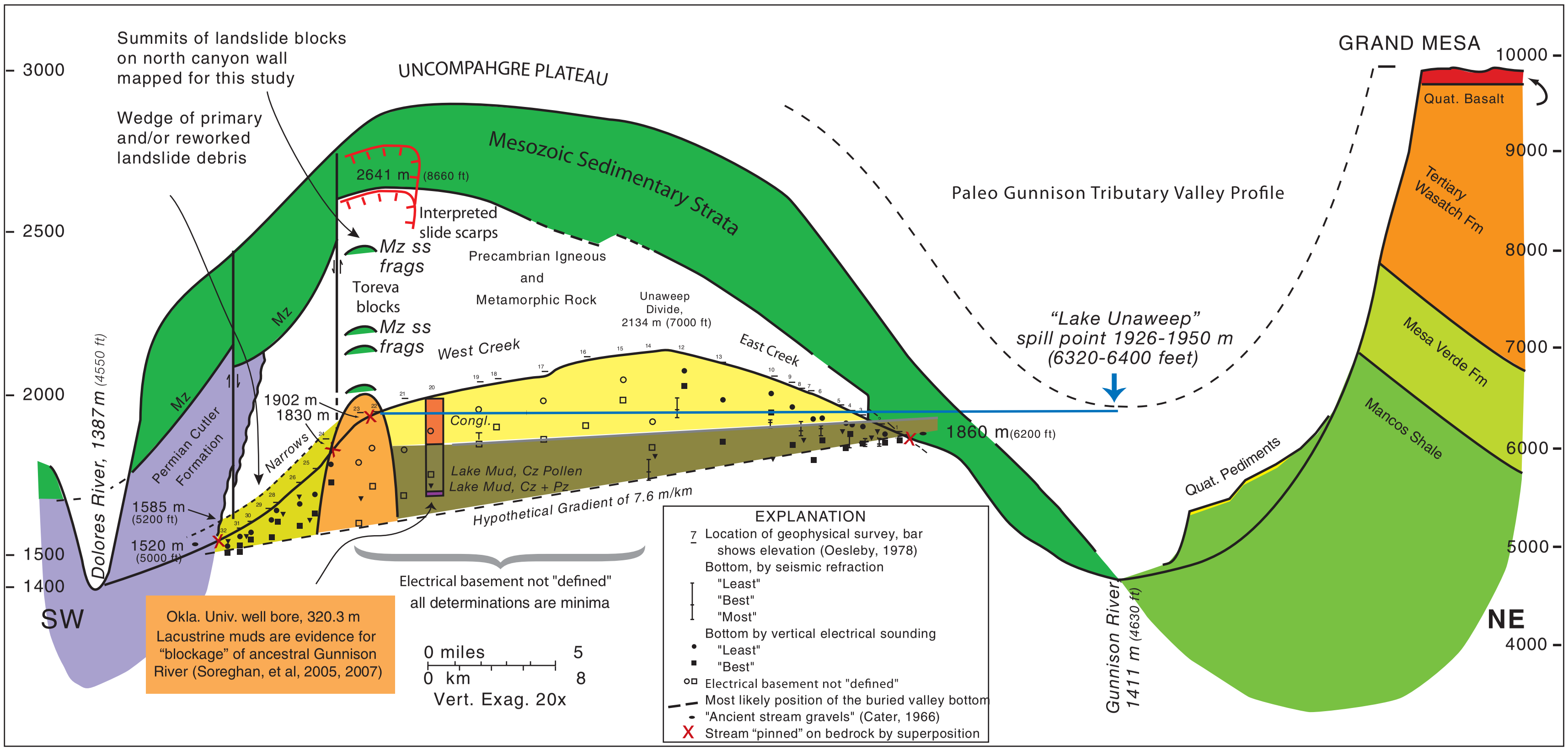

Figure 19. Longitudinal profile of Unaweep Canyon, showing geophysical data and recent well bore, plus interpreted landslide features including paleo-lake and spill point (Oesleby, 2005c; modified from Oesleby, 1978).

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