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AN UNCONFORMITY IN THE THE POLE CANYON AREA (SEVIER PLATEAU) WEST OF ANTIMONY, WESTERN GARFIELD COUNTY, UTAH, AND ITS BEARING ON THE SEVIER GRAVITY SLIDE

Peter D. Rowley, Robert F. Biek, and David B. Hacker

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Cover

View south of unconformity on Hoodle Creek. The vertical light-colored beds of the Brian Head strata are truncated under gently east-dipping, well-bedded brownish-colored gravels likely of the Sevier River Formation.

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An Unconformity in the Pole Canyon Area (Sevier Plateau) West of Antimony, Western Garfield County, Utah, and its Bearing on the Sevier Gravity Slide

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ABSTRACT

Pole Canyon is cut into the western backslope of the Sevier Plateau of southwestern Utah, a gently-tilted, block-faulted range that extends north from Bryce Canyon National Park through the eastern part of the Marysvale volcanic field. The canyon exposes a spectacular angular unconformity that separates brecciated, intensely deformed, and steeply dipping Eocene to Oligocene sedimentary and volcanic rocks below, from gently east-dipping Miocene volcanic rocks above. Although identified in 1968 by the senior author, it took renewed geologic mapping in 2015 by all three authors to discover that the rocks below the unconformity were deformed by gravity sliding. We named it the Sevier gravity slide, one of the largest terrestrial landslides on Earth. The ages of the volcanic rocks above and below the unconformity constrain the age of sliding at between 25.8 and 23.1 Ma; later dating elsewhere put the slide movement at between 25.2 and 25.1 Ma.

INTRODUCTION

The Sevier Plateau is a 75-mile (120-km) long, north-trending range in the High Plateaus of Utah that was uplifted on its western side at least 6000 feet (1800 m) by the Sevier fault zone and tilted about 3 degrees to the east. Pole Canyon, whose mouth is just west of Antimony in southern Grass Valley, is cut in the eastern backslope of the Sevier Plateau (figure 1). Pole Canyon affords a visit to a spectacular angular unconformity that separates brecciated, intensely deformed, and steeply east-, north-, and west-dipping Eocene to Oligocene sedimentary and volcanic rocks below from undeformed, gently (3 degrees) east-dipping Miocene volcanic rocks above (figure 2). The unconformity is exposed for more than a mile (1.6 km) about 50 feet (15 m) above a dirt road in the bottom of the canyon. The deformed rocks below the unconformity are part of the Sevier gravity slide, perhaps the third largest terrestrial landslide on Earth. The unconformity provides information on the age of the gravity slide.

LOCATION

The geosite is a series of rock exposures extending along the northern side of east-draining Pole Canyon, which is between 400 and 800 feet (120-240 m) deep and whose mouth is about a half mile (0.8 km) west of Antimony. Pole Canyon is in the northern part of the Deep Creek 7.5-minute quadrangle, Garfield Coun-

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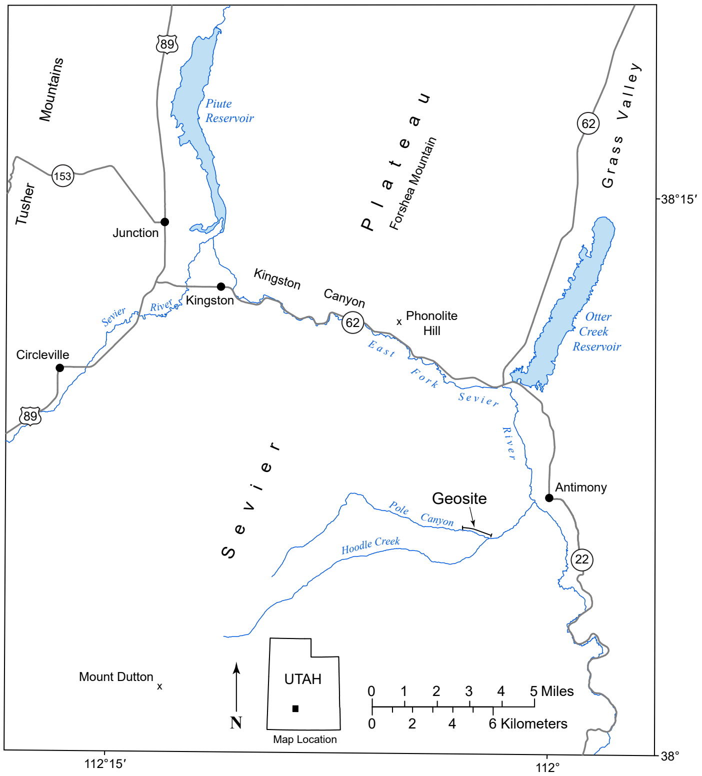

Figure 1. Location map of the Kingston Canyon and Pole Canyon areas, Piute and Garfield Counties, Utah. The geosite is a mile-long (1.6 km) span in Pole Canyon.

Figure 2. View east down Pole Canyon showing gently east-dipping, undeformed Osiris Tuff (To) and underlying volcanic mudflows of the Mount Dutton Formation (Td) that unconformably overlie variously dipping and deformed white Brian Head (Tbh) strata in the lower half of the slope.

ty, Utah. A dirt road goes 3 miles (5 km) up the bottom of the canyon to a spring whose water is piped to Antimony. The eastern end of the geosite (coordinates 38º05'52"N., 112º02'03" W., circled location #1 on figure 3) is where Hoodle Creek joins the canyon from the south, a point that is about 2 miles (3 km) up the canyon. The western end of the geosite (38º06'03" N., 112º03'12" W., circled location #2 on figure 3), a little more than a mile (1.6 km) farther west, is where the dirt road ends at the spring.

Two words of caution about this geosite: (1) it requires fording the East Fork of the Sevier River and (2) the Pole Canyon road is tricky to find. Fording the river requires a high-clearance 4-wheel-drive vehicle—the river bottom has a cobble floor that may be potholed and the banks may be oversteepened by erosion—and the crossing should not be attempted in winter, spring, or when the river is high. To deal with point number two, take Utah Highway 22 to the Antimony Mercantile and Trailer Park in Antimony. Go south for 0.1 mile (0.15 km), where the highway bends sharply left to head east. At that point a good gravel road to Mt. Dutton enters the highway from the south. Turn right off the highway onto the Mt. Dutton road and go 0.4 miles (0.6 km) to a bridge across an irrigation canal, just beyond which a lesser dirt road comes in on the right (north) just before the Mt. Dutton road bends left to a bridge across the Sevier River. Take the lesser dirt road (an unnumbered road that leads to Forest Road 1073) north for a little more than 0.1 mile (0.15 km), where it will bear left at a gate in a north-south fence; open the gate and drive through (then close the gate). Go north-northwest for about 0.3 miles (0.5 km) to where you can see the road cross the river, just north of where the gulch in Pole Canyon joins the river. Cross the river and head up the northern side of the gulch in Pole Canyon.

If the river crossing is impassable, an overlook into nearby Hoodle Creek, where the unconformity is also well exposed, is 4.0 miles up the well-graded gravel road to Mt. Dutton (Forest Road 125). There, a small pullout on the right affords a view down into Hoodle Creek (figure 3a).

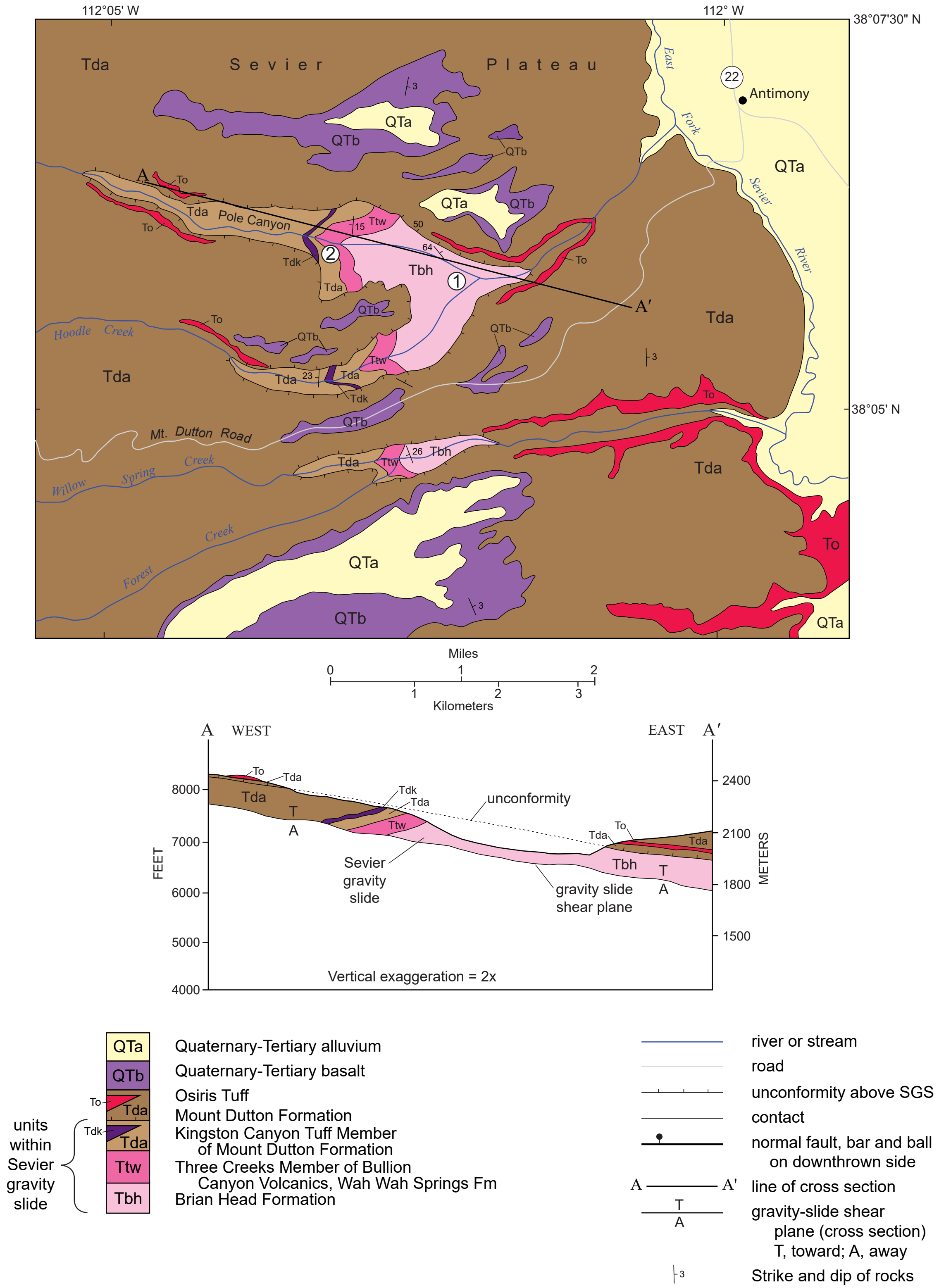

Figure 3. Geologic map and cross section of the Pole Canyon area, Garfield County, Utah, showing location of the mile-long (1.6 km) geosite area between areas labeled 1 and 2. Geologic map after Rowley (1968) and Rowley and others (2005). Vertical exaggeration (vertical scale) on the cross section is two times (the horizontal scale). The Sevier gravity slide moved south, toward the viewer, then during later basin-range deformation all rocks including the slide were tilted east.

Figure 3a. View north to unconformity on Hoodle Creek from overlook on Forest Road 125. Here, west-dipping, severely fractured Three Creeks Tuff (Tbtc) and Mount Dutton Formation volcanic mudflow deposits (Td) in the bottom of the canyon are unconformably overlain by gently east-tilted gravels of the Sevier River Formation (Tsr) and a remnant of a Pliocene basaltic lava flow (Tb).

GEOLOGIC SETTING

The geosite described here provides a glimpse of the geologic history before the present topography formed. The present topography consists of a range within the High Plateaus, a subprovince of the Colorado Plateau. But in fact the High Plateaus is a transition zone between the Great Basin to the west and the main part of the Colorado Plateau to the east. The Great Basin has been undergoing basin-range deformation, which is characterized by east-west crustal extension (pulling apart of the crust in an east-west direction) for the last 20 million years. The result of the deformation is north-trending ranges that alternate with north-trending basins, all created by north-trending normal faults. Normal faults are those in which the sense of displacement between one side of the fault with respect to the other is largely vertical, and the faults are high-angle, with an average dip of 60° in the downthrown direction. Although this deformation started at about 20 Ma, its main phase that produced the present topography dates only to about 10 Ma (Rowley and others, 1981, 2005). In contrast to such deformation, the main part of the Colorado Plateau is largely undeformed, being made up of plateaus and mesas of flat-lying rocks. However, the High Plateaus is more closely allied with the Great Basin, differing only by having fewer and smaller faults. The ranges and plateaus of the High Plateaus were uplifted along the normal faults, and adjacent valleys were downthrown along the normal faults.

The rocks making up the northern High Plateaus are largely volcanic rocks that have an age of early Oligocene to Pleistocene (about 33 Ma to several tens of thousands of years), if not younger, formed as part of the huge (75 miles [120 km] in diameter) Marysvale volcanic field. In the southern High Plateaus, the volcanic rocks sit on a light-gray sedimentary sequence deposited by streams in channels and floodplains and by lakes, known as the Brian Head Formation of late Eocene to early Oligocene age (figure 2) (Biek and others, 2015a). The Brian Head contains beds of airfall tuff that represent the start of volcanism in the Great Basin and Marysvale field; these beds have weathered (altered) to smectite clays that are weak and prone to landsliding. South of Pole Canyon in the southern Sevier Plateau, the Brian Head in turn rests on the Claron Formation, a late Paleocene(?) and Eocene sequence of stream and lesser lake strata, mostly altered to paleosols (ancient soils) and all predating middle Tertiary volcanism. The Claron is famous for its erosion into pink hoodoos at Bryce Canyon National Park and Cedar Breaks National Monument (Biek and others, 2015a). Claron strata underwent rapid facies changes northward from Bryce Canyon such that, near Antimony, equivalent strata are yellow-brown sandstone, siltstone, mudstone, and conglomerate that lack the bright colors and fossil soils of typical Claron.

The geologic setting of the Pole Canyon area is identical to that of nearby Kingston Canyon to the north (see the Kingston Canyon geosite by Rowley and others). The Kingston Canyon geosite describes evidence that documents the age of the basin-range deformation that resulted in the uplift of the Sevier Plateau. The Pole Canyon geosite, in contrast, bears on an entirely different topic, much older than the story told by Kingston Canyon. This story is the Sevier gravity slide.

As with the geologic story of Kingston Canyon, Pole Canyon was mapped as part of a dissertation study of the southern Sevier Plateau by the senior author (Rowley, 1968). The unconformity was recognized at this time, for it is well exposed along the northern wall of Pole Canyon. It was also mapped to the south, where it extends for more than a mile (1.6 km) along both walls of the canyon of Hoodle Creek, a tributary to Pole Canyon. And it was mapped along Forest Creek, the next east-draining canyon south of Hoodle Creek; there its outcrops extend for about 1.5 miles (2.5 km) along the canyon walls near the confluence of Forest Creek and Willow Spring Creek. Only Pole Canyon is accessible by a maintained dirt road.

Rowley (1968) interpreted that the rocks beneath the unconformity represent the result of an old fault that offset and tilted older rocks, which were then eroded to form the unconformity, after which additional volcanic rocks were deposited on the unconformity. The Sevier Plateau was remapped by Rowley during the late 1970s as part of a major study by the U.S. Geological Survey (USGS) of mineral resources of the Marysvale volcanic field. The remapping found that the unconformity of Pole Canyon was also exposed at the western crest (Mt. Dutton) of the Sevier Plateau. Extreme southern parts of the dissertation area were also published (Rowley and others, 1987). The Marysvale study, with T.A. Steven, C.G. Cunningham, and Rowley as principals but with many colleagues, lasted almost a decade and resulted in more than 200 publications. One final publication was the Richfield 1° x 2° quadrangle (1:250,000 scale), which included the geosite area and most of the Marysvale field and extended west almost to the Nevada border (Steven and others, 1990). Most of the Marysvale effort, however, was concentrated in the heart of the Marysvale field north of Kingston Canyon, where most of the intrusive, caldera, and vent sources (the most likely sites for mineral resources) of the volcanic rocks were exposed, and this area was mapped as 1:24,000-scale quadrangles. Summary geologic maps were published by Cunningham and others (1983), Steven and others (1990), and Rowley and others (2002). Later, under contract with the Utah Geological Survey (UGS), the Beaver 1:100,000-scale quadrangle (Rowley and others, 2005), which covered most of the volcanic field, was compiled. None of these studies recognized the real significance of the angular unconformity.

The significance, of course, is that the rocks below the unconformity had been deformed by movement of a huge gravity slide. That realization, however, first required the recognition of another, even larger gravity slide that mantled high points of the Markagunt Plateau, the next range west of the southern Sevier Plateau. Initial recognition, yet never realizing its great size, was by Professor John J. Anderson and his graduate students at Kent State University, who did extensive mapping in the late 1970s, the 1980s, and the early 1990s, resulting in theses, published maps, and a final report that named it the Markagunt Megabreccia (Anderson, 1993). Florian Maldonado of the USGS found more outcrops of gravity slides in the western Markagunt Plateau and the next range to the west, the Red Hills (e.g., Maldonado, 1995). Putting these pieces of old gravity slides together, then totaling about 200 mi^2 (500 km^2), then expanding the mapping was the work of Bob Biek of the UGS, who had been assigned in 2006 to geologically map the Panguitch 1:100,000-scale quadrangle, south of the Beaver quadrangle. Over multiple years, as he compiled areas in the Panguitch sheet mapped by Anderson, students, and Maldonado, then mapped those quadrangles in-between that had not been studied, he found that the individual pieces of slides correlated with each other and interpreted that many intervening areas were underlain by the same slide plane, thus first recognizing that he was seeing a slide of truly monumental proportions. Realizing that he needed more expertise to study the features of gravity slides, he enlisted the help of Professor Dave Hacker of Kent State University, whose areas of research included gravity slides, notably in the Iron Springs and Bull Valley mining districts southwest of Cedar City (e.g., Hacker, 1998; Hacker and others, 2002, 2007). Then Dave discovered, on the Markagunt Plateau, the first veins of pseudotachylyte! Pseudotachylyte (frictionite) is a friction-generated melt rock typically produced on deeply buried (>6 miles [10 km]) fault zones and in meteorite impacts; rarely is it associated with gigantic landslides that formed near the earth's surface. Pseudotachylyte is important to demonstrate high temperatures on slip surfaces, hot enough to melt rock and thus implying high slip rates to generate enough heat so near the earth's surface. This and other evidence shows that the Markagunt slide moved catastrophically, probably over the span of minutes, south from highlands in the active center of the volcanic field. Together we realized that the Markagunt slide was enormous, rivaling the one other known great slide, the famous Heart Mountain gravity slide, of Eocene age, in the Absaroka Mountains of northwestern Wyoming (see, for example, Hauge, 1993; Malone and Craddock, 2008; Beutner and Hauge, 2009). The first writeups of the story of this large slide, and the name Markagunt gravity slide (MGS), came from Hacker and others (2014), then Biek and others (2014). At this time, the MGS was estimated to have a size of 1300 mi^2 (3400 km^2), larger than Rhode Island and the same size as the Heart Mountain slide. But the outer boundaries of the Markagunt slide had not all been found, and additional tracing of these into adjacent mapped areas continued over the next several years. The Panguitch sheet, which contained the southern part of the slide, was published in final form by Biek and others (2015a), at which time the MGS size was estimated to be 1600 mi^2 (4160 km^2). Much of the slide by then was found to be in adjoining 1:100,000-scale sheets, notably the Tushar Mountains of the Beaver sheet where the breakaway area was.

In the field season after publication of the Panguitch sheet, Biek and Hacker gave a second look at canyons cutting the eastern Sevier Plateau south of Forest Creek, an area within the Panguitch sheet and within the areas mapped by Rowley (1968) and Rowley and others (1987). Although some of the same rock units that were exposed beneath the Pole Canyon unconformity had been mapped in these southern canyons by Rowley (1968) and Rowley and others (1987), no unconformity had been recognized. Biek and Hacker, however, noticed that these same units (those beneath the Pole Canyon unconformity) were significantly deformed, with features that resembled deformed rocks within the MGS. All of a sudden, it became clear that another huge landslide caused not only these southern deformed rocks, but those beneath the unconformity as well. This overall feature was named the Sevier gravity slide (SGS). Again, boundaries were sought in outlying areas by the authors, including in the breakaway area in the Beaver sheet and in the Loa sheet (Biek and others, 2015b) east of the Beaver map. A week-long international field conference, the Thompson Field Forum sponsored by the Geological Society of America, Utah

Geological Association, and UGS was held September 2017. It allowed landslide experts to visit and help interpret the MGS and SGS (Biek and others, 2017), which we then interpreted to be 2000 mi^2 (5000 km^2, about the size of Delaware) and 600 mi^2 (1500 km^2), respectively, in size. Interestingly, new field work by Malone and others (2014) had by then suggested that the Heart Mountain slide was also about 2000 mi^2 (5000 km^2) in size. A large summary report on the field stops of the Field Forum and their meaning, distributed in draft form to forum participants, was prepared for publication (Biek and others, 2019). The Beaver sheet is being revised, one quarter at a time (Rowley and others, 2019, 2020), and parts of the Loa and Panguitch sheets will also be remapped, showing the extent of the slides.

THE SITE ITSELF

After crossing the Sevier River, most of the outcrops you will see in Pole Canyon, until Hoodle Creek enters on the south, consist of undeformed volcanic mudflow breccia, overlain by a ledge about 20 to 50 feet (6-15 m) thick of similarly undeformed Osiris Tuff, all dipping east at about 3° (figure 2). The Osiris Tuff is a distinctive, tan and gray, densely welded ash-flow tuff with K-Ar ages (Anderson and Rowley, 1975) and ^{40}Ar/^{39}Ar ages (Cunningham and others, 2007; Ball and others, 2009; UGS unpublished data) of about 23.1 Ma. It is widely exposed throughout the Marysvale volcanic field and was derived from the Monroe Peak caldera, the largest in the field and almost 30 miles (50 km) north of Pole Canyon (Rowley and others, 2002). All these rocks are above the unconformity and postdate the SGS. Furthermore, they put an upper age limit on the SGS. (In contrast, the Osiris was deformed by the MGS, and the age of overlying undeformed rocks indicate that the MGS slid sometime between 23.1 and 22.75 Ma). Based on the rocks exposed at the geosite and elsewhere, we can closely constrain the age of movement of the SGS, demonstrating that it is about 2 million years older than the MGS. Incidentally, the view south towards Hoodle Creek reveals a second, younger angular unconformity. Although we have not yet studied this area in detail, it appears that Osiris Tuff and Mount Dutton strata are eroded away so that volcaniclastic gravels, likely of the Sevier River Formation, rest directly on vertical Brian Head strata (figure 4).

Upon reaching the easternmost point of the geosite, which is just before where Hoodle Creek joins the canyon, white cross-bedded sandstone and mudstone of the Brian Head Formation are exposed low on the northern wall of the canyon, beneath the gently east-dipping mudflows. Although these rocks do not look badly deformed, they are dipping 28° toward the northeast and underlie the unconformity.

As one goes westward up the canyon, where the stream has cut a little more deeply into the rocks, the steeply dipping rocks that underlie the unconformity are better exposed. The unconformity, dipping eastward at about 3°, is obvious about 50 feet (15 m) above the bottom of the canyon. It is overlain by mudflow beds and locally the Osiris Tuff, all dipping east the same amount. Brian Head rocks below the unconformity are mostly tan and light-gray, pebbly to bouldery, tuffaceous sandstone, with some debris flows, mudstone, and conglomerate. Most of the pebbles, cobbles, and boulders are volcanic, but perhaps 10 percent are white limestone and quartzite. In most places these rocks are clearly deformed by shears of mostly low-angle, and beds are locally broken and churned within overlying or underlying beds (figure 5). These beds are in places weathered into hoodoos. Some of the larger clasts (as much as 3 feet [1 m] in diameter) in the sandstone are shattered, and many quartzite clasts (which seem to be the most brittle clasts) are broken into pieces that have moved with respect to each other, a feature called jigsaw deformation that is considered characteristic of large landslides (and also of debris avalanches) (e.g., Pierson and others, 2018; Biek and others, 2019). Dips as steep as 64° were measured, but most of the section may be overturned, for dips are in different directions, although most are northerly.

At the western end of the geosite, where the dirt road ends at the spring, are massive, tan and light- to medium-gray, crystal-rich ash-flow tuffs of the 30.5 Ma Wah Wah Springs Formation (Rowley, 1968; Anderson and Rowley, 1975) and the overlying 27 Ma Three Creeks Member (Steven and others, 1979) of the Bullion Canyon Volcanics (the section is at least 100 feet [30 m] thick), locally sheared and brecciated (figure

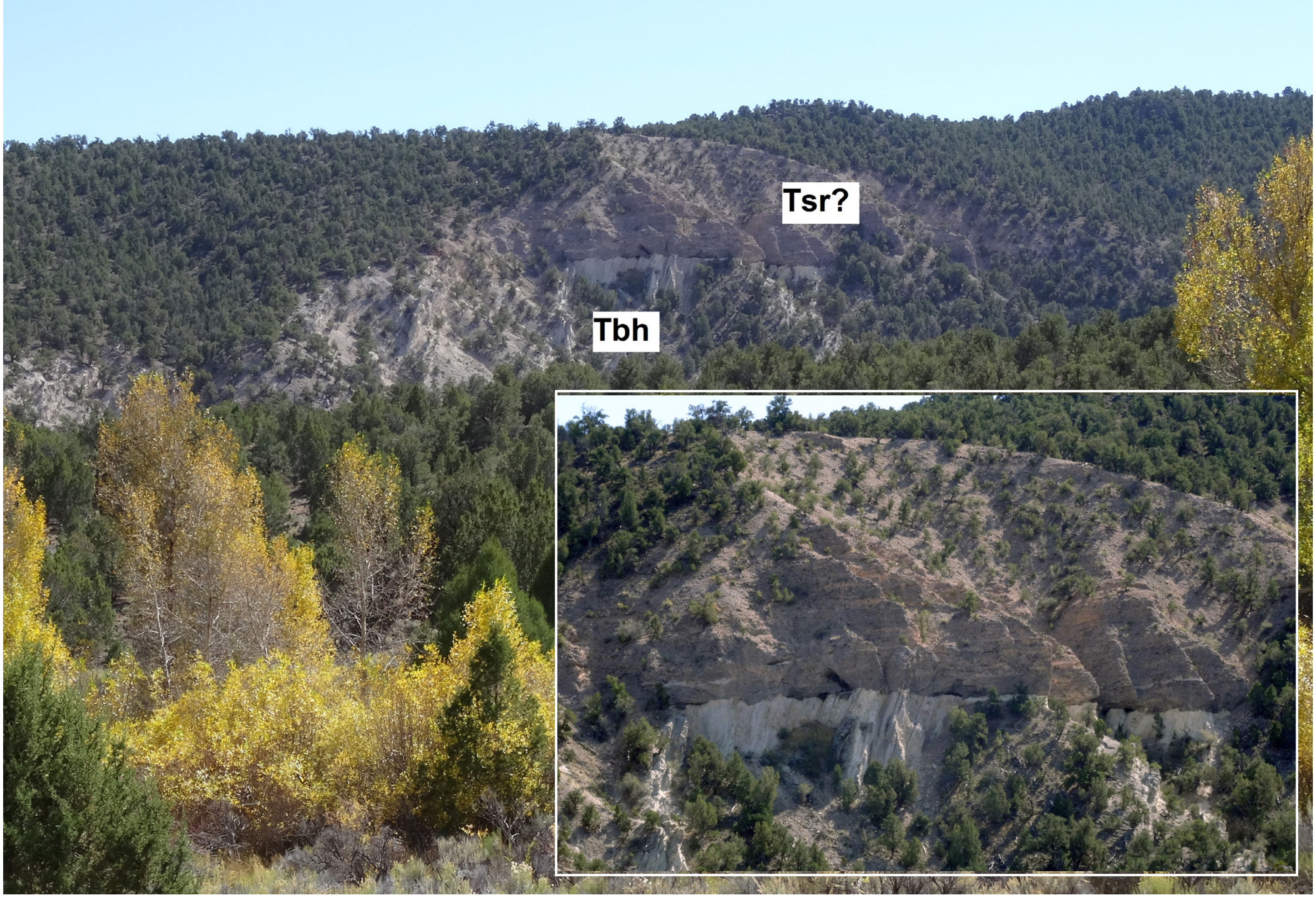

Figure 4. View south to unconformity on Hoodle Creek; inset photograph shows vertical Brian Head strata (Tbh) truncated under gently east-dipping, well-bedded gravels likely of the Sevier River Formation (Tsr?).

6), and dips westerly at about 15º, and is locally cut by clastic dikes (figure 7). These two tuff units are exposed in both the northern and southern walls of the canyon, with the spring developed in joints and shears in these tuffs. The base of the Wah Wah is brecciated but crumbly and poorly exposed and not photogenic. Some of the sandstone below this contact has deformation bands, a strange hardening of beds at various angles that is distinctive in some sandstones that have been compressed (Davis, 1999). Farther west up the canyon, beyond the road and spring, a deformed 30-foot-thick (9 m), red, crystal-poor, densely welded ash-flow tuff known as the Kingston Canyon Tuff Member of the Mount Dutton Formation, which also overlies the Three Creeks Member in other places too, is exposed dipping westward beneath the unconformity, which is visible on the canyon walls above. The tuff has a K-Ar age of 25.8 Ma (Anderson and Rowley, 1975; Fleck and others, 1975), which makes it one of the youngest rocks involved in the SGS.

The significance of the Pole Canyon geosite is that its unconformity provides clear evidence of deformation of rocks below it. And with the evidence of similar deformed rocks as far north as the undeformed margin of the Monroe Peak caldera, and as far south as the southernmost Sevier Plateau, it is easy to interpret this as another huge gravity slide. The slide mass broke away from a highland of erupting stratovolcanoes to the north, which were being uplifted by a rising underlying batholith (large plutonic mass) that was the source for the volcanoes in the volcanic field. At the time the

Figure 5. Steeply northeast-dipping Brian Head Formation exposed in the northern wall of Pole Canyon. Tan ledge in upper right is undeformed Osiris Tuff (To) above the unconformity, dipping gently east (right). Hammer for scale.

southern Sevier Plateau, including the Kingston and Pole Canyon areas, were southern lowlands, and that is where the slide headed. It was only later, during basin-range deformation, that the Sevier Plateau assumed its present topography.

Pole Canyon constrains the age of SGS landslide failure at a catastrophic instant in Miocene time, somewhere between 25.8 and 23.1 Ma, the ages of the Kingston Canyon Member and the Osiris Tuff. Another red, crystal-poor, densely welded ash-flow tuff, the 25.1 Ma Antimony Tuff Member of the Mount Dutton Formation, underlies the Osiris Tuff in Kingston Canyon and is similarly not deformed. And along the west flank of the Sevier Plateau north of Kingston Canyon, still another slightly older, densely welded ash-flow tuff, the tuff of Tibadore, is deformed. It recently yielded an age of about 25.2 Ma, so that we now know that the SGS was emplaced between about 25.2 and 25.1 Ma. Emplacement is thus constrained to a short interval of time between the eruptions of two similar densely welded ash-flow tuffs. It is tempting to talk about such eruptions as a trigger for the SGS, and that mystery is one we continue to ponder.

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Figure 6. Brecciated and sheared Wah Wah Springs Formation on the northern wall of Pole Canyon (north of the spring). (A) Two large fractured clasts can be seen below the pick of the rock hammer, and small breccia clasts can be seen between them and left of the pick of the hammer. (B) Fractured blocks commonly exhibit puzzle-like patterns with small offsets between pieces, a fabric we call jigsaw fractures.

Figure 7. Clastic dike (injectite) in Wah Wah Springs Formation. Clastic dikes are evidence of overpressured fluids at the base of the slide that serve to facilitate sliding. The dike rock is a breccia of mostly ground up Wah Wah Springs injected under pressure into cracks in upper-plate rocks.

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