WYOMING STATE GEOLOGICAL SURVEY
Erin A. Campbell, Director and State Geologist
Laramie, Wyoming

Interpreting the past, providing for the future

OPEN FILE REPORT 2022-4

East Half of the Jackson Lake 1:100,000-scale Surficial Geologic Map

EXPLANATION

DESCRIPTION AND CLASSIFICATION OF MAP UNITS

Alluvium—Sediment deposited by running water in the channel or floodplain of a watercourse where deposition is active or has been active in the most recent geologic period

Alluvium (**a**)

Terrace deposits—Relict alluvial deposits that are above the modern floodplain and form relatively flat, horizontal, or gently inclined surfaces that are bound by steeper erosional scarps on their flanks

Terrace deposits (**t**)

Terrace deposits and active alluvium (**ta**). Mapped primarily along perennial tributary streams in confined valleys; terraces are typically less than 3 m above the active channel

Terraces composed of glacial outwash deposits from the Bull Lake (to_{bl}) and Pinedale (to_p) glacial episodes

Alluvial fan deposits—Sediment deposited by running water in a fan-shaped landform where a stream emerges from a confined catchment onto a plain or valley bottom

Alluvial fan deposits (**f**)

Alluvial fan deposits and active alluvium (**fa**)

Alluvial fan and slopewash deposits (**fs**)

Alluvial fans composed of glacial outwash deposits from the Pinedale glacial episode (fo_p)

Piedmont gravel deposits. Gravels form a 2–5-m-thick cap atop beveled bedrock and grade to above the modern floodplain. Up to three piedmont surfaces are recognized locally but are not differentiated on the map (f_1d)

Glacial till—Unsorted and unstratified sediment deposited directly by a glacier at its flanks, base, or toe in the form of moraines

Glacial till of Bull Lake age (g_{bl}) and Pinedale age (g_p). Pinedale till is locally subdivided into, from oldest to youngest, stage 1 (g_{p1}), stage 2 (g_{p2}), and stage 3 (g_{p3}) along the lower reaches of Pacific Creek, Blackrock Creek, and the Buffalo Fork following the glacial chronology of Pierce and others (2018) and mapping of Love and others (1992)

Lacustrine deposits—Fine-grained sediment deposited in lakes and ponds

Lacustrine deposits (**w**)

Landslide deposits—Soil and rock material that has fallen, slid, or flowed downslope, en masse and under gravitational influence

Landslide deposits (**l**)

Colluvium and slopewash—Colluvium is a loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by raveling or slow continuous downslope creep, usually at the foot of a cliff or on the surface of a slope, and deposited there chiefly by gravity. Slopewash is primarily fine-grained soil and rock material that has moved down slope by gravity, assisted by unchannelized running water

Slopewash and bedrock outcrops with minor components of colluvium (**sRc**)

Colluvium and bedrock outcrops with minor components of slopewash (**cRs**)

Residuum—A residual deposit derived from the in-place weathering of bedrock. Residuum typically forms a thin surface layer concealing the unweathered or partially altered bedrock below

Residuum and slopewash with minor components of colluvium (**rsc**) or bedrock (**rsR**)

Residuum and colluvium with minor components of slopewash (**rcs**)

Residuum and bedrock outcrops with minor components of slopewash (**rRs**)

Bedrock outcrops—Areas where bedrock is exposed and unaltered at the surface

Bedrock outcrops and slopewash with minor components of colluvium (**Rsc**) or residuum (**Rsr**)

Bedrock outcrops and colluvium with minor components of slopewash (**Rcs**)

Bedrock outcrops and residuum with minor components of slopewash (**Rrs**)

Water—Areas covered perennially by standing water

Water in lakes, ponds, and reservoirs

MAP SYMBOLS

Lineaments

Lineament in surficial deposit; possible tectonic origin

Quaternary faults—Faults that show surface offset of Quaternary-age units

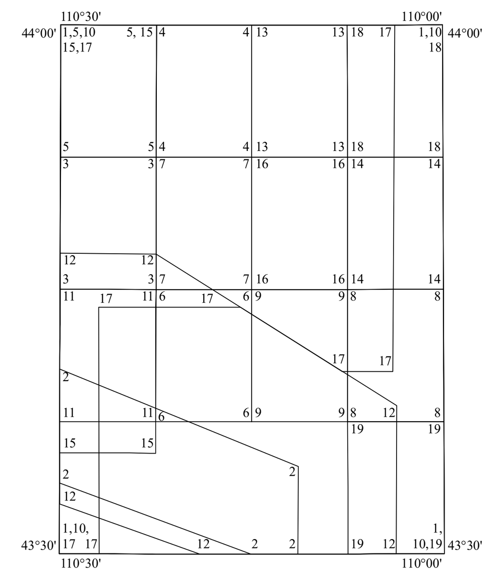
Normal fault, continuous where certain (≤100 m location confidence), dashed where approximate (101–500 m location confidence), dotted where concealed; bar and ball on downthrown block; question mark where extent of surface offset uncertain

Quaternary fault index

1. Uhl Hill fault
2. Davis Hill fault
3. Baldy Mountain fault
4. Togwotee Lodge faults

INDEX TO SOURCES OF GEOLOGIC MAPPING

(Numbers are noted in REFERENCES AND SOURCES OF MAP DATA)



REFERENCES AND SOURCES OF MAP DATA

(Numbers are noted in INDEX TO SOURCES OF GEOLOGIC MAPPING)

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8. _____1982a, Preliminary geologic map of the Lava Mountain quadrangle, Teton and Fremont counties, Wyoming (unpublished): U.S. Geological Survey, scale 1:24,000.
9. _____1982b, Preliminary geologic map of the Tripod Peak quadrangle, Teton County, Wyoming (unpublished): U.S. Geological Survey, scale 1:24,000.
10. Love, J.D., and Christiansen, A.C., comps., 1985, Geologic map of Wyoming: U.S. Geological Survey, 3 sheets, scale 1:500,000. (Re-released 2014, Wyoming State Geological Survey.)
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17. Pierce, K.L., Licciardi, J.M., Good, J.M., and Jaworowski, Cheryl, 2018, Pleistocene glaciation of the Jackson Hole area, Wyoming: U.S. Geological Survey Professional Paper 1835, 56 p.
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Base map from U.S. Geological Survey 1:100,000-scale metric topographic map of the Jackson Lake, Wyoming Quadrangle, 1981

Base hillshade derived from United States Elevation Data (NED), 10-meter Digital Elevation Model (DEM), 2021; azimuth 315º, sun angle 45º, vertical exaggeration 1.3

Projection: Universal Transverse Mercator (UTM), zone 12
North American Datum of 1927 (NAD 27)
10,000-meter grid ticks: UTM, zone 12
25,000-foot grid ticks: Wyoming State Plane Coordinate System, west and west central zones

National Geodetic Vertical Datum of 1929

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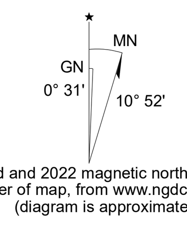


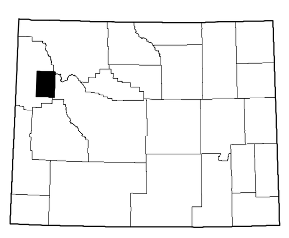
UTM grid and 2022 magnetic north declination at center of map, from www.ngdc.noaa.gov (diagram is approximate)

0 1 2 4 6 8 10 Kilometers

0 1 2 4 6 Miles

0 5,000 10,000 15,000 20,000 25,000 30,000 Feet

SCALE 1:100,000
Contour interval 50 meters



WYOMING QUADRANGLE LOCATION

Digital cartography by James P. Mauch and Nolan C. Barrette
Map edited by James A. Amato

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PRELIMINARY SURFICIAL GEOLOGIC MAP OF THE EAST HALF OF THE JACKSON LAKE 30' x 60' QUADRANGLE, TETON, FREMONT, AND PARK COUNTIES, WYOMING

mapped and compiled by

James P. Mauch, Nolan C. Barrette, and Seth J. Wittke

2022

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Preliminary Surficial Geologic Map of the East Half of the Jackson Lake 30' x 60' Quadrangle, Teton, Fremont, and Park Counties, Wyoming

James P. Mauch, Nolan C. Barrette, and Seth J. Wittke

Open File Report 2022-4
June 2022

Wyoming State Geological Survey

Erin A. Campbell, Director and State Geologist

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Layout by Christina D. George

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INTRODUCTION

The Jackson Lake 30' x 60' quadrangle is in Teton, Fremont, and Park counties, Wyoming. It encompasses the Teton Range, Jackson Hole, and the northern Gros Ventre, northwestern Wind River, and southwestern Absaroka ranges. This study mapped the surficial geology of the east half of the Jackson Lake quadrangle at 1:100,000 scale in an effort to better understand the region's geologic hazards and Quaternary geology.

This work was motivated by a need for more detailed mapping across the study area, where the only pre-existing surficial geologic maps are at a scale of 1:500,000. The map area is bisected by U.S. Highway 26/287—the only major road entering Jackson Hole from the east—which is exposed to unstable slopes and has been damaged on multiple occasions by landslide activity. Northwest Wyoming is a region of elevated seismic hazard influenced by active faulting from both Basin and Range tectonism and the Yellowstone volcanic system, yet several understudied and unmapped Quaternary faults with unknown seismic hazards remain within the quadrangle. These geologic hazards, and their intersection with infrastructure and development pressures in Teton County, compelled this mapping effort. The data presented here are intended to help land managers and local governments improve geologic hazard assessments and make informed land-use decisions in this region of important economic values and celebrated natural beauty.

Key project outcomes include:

- Improved light detecting and ranging (lidar) and field-based mapping of landslides, which updates previous landslide inventories that were completed prior to lidar availability and were not field-verified.

- Detailed field mapping and scarp profile surveys of four poorly understood Quaternary faults, two of which were not previously documented.

- An eastward extension of previously established mapping of Pleistocene glacial deposits in Jackson Hole into lesser studied upland areas in the Absaroka Range, Pinyon Peak highlands, and Gros Ventre River valley.

This project was supported by and completed in cooperation with the U.S. Geological Survey (USGS), National Cooperative Geologic Mapping Program, under USGS award number G21AC10538.

Previous Mapping

The map area encompasses 16 7.5' quadrangles, 13 of which have bedrock geology mapped at a scale of 1:24,000 from prior studies. Three of these 7.5' quadrangles are published (Rohrer, 1969; Love, 1975a, b) and the remaining 10 are unpublished line images on file at the Wyoming State Geological Survey (WSGS; Love, 1973b; Prostka and Love, 1975; Love and Prostka, 1978; Love, 1981a, b; Love and Keefer, 1981; Love 1982a, b; Love and others, 1982; Love and Weitz, 1982). Love and others (1951) mapped the bedrock geology of an area spanning the Gros Ventre River valley, Mount Leidy highlands, and Spread Creek at a scale of 1:48,000. Love and others (1992) mapped the bedrock geology of Grand Teton National Park and its vicinity at 1:62,500 scale, which extends into the western quarter of the study area. Mapping by Love and Christiansen (1985) at 1:500,000 scale provides the highest resolution published bedrock mapping in the Gros Ventre Range.

Richmond and Pierce (1971a, b) mapped the surficial geology of the Mount Hancock and Two Ocean Pass 15' quadrangles directly north of the map area at 1:62,500 scale. Wittke and others (2016) completed 1:100,000-scale surficial geologic mapping of the Jackson 30' x 60' quadrangle, which borders the map area to the south. Mauch and others (2021) mapped the surficial geology of the west half of the Jackson Lake 30' x 60' quadrangle; the mapping herein is a continuation of this effort and completes surficial geologic mapping across the remaining half of the quadrangle. Prior to this study, the only published surficial geologic mapping within the Jackson Lake quadrangle was completed by Case and others (1998) as part of a 1:500,000-scale statewide compilation.

Several studies have mapped Quaternary geologic features within the quadrangle boundary. The WSGS completed unpublished photogeologic mapping of landslides across the study area at 1:24,000 scale as part of a statewide inventory (Case and others, 1996). Lagas (1984) mapped the distribution of till, outwash gravel, and other Quaternary deposits in the Gros Ventre River valley in an M.S. thesis on the glacial geology of the region. As part of an extensive summary of the Pleistocene glacial history of the Jackson Hole region, Pierce and others (2018) mapped ice extents and glacial geomorphic features associated with the Pinedale and Bull Lake glaciations. These maps and annotated photographs cover parts of the northern and far southwestern study area and range in scale from 1:20,000 to 1:600,000.

GEOLOGIC SETTING

The southern third of the quadrangle contains the northwestern limit of the Wind River Range and northern flank of the Gros Ventre Range (fig. 1), both of which are basement-cored Laramide uplifts. Within the map area the faulted and folded rocks of the Wind River Range are buried beneath flat-lying Eocene volcaniclastic rocks that post-date deformation and today form the uplands along the Continental Divide (Rohrer, 1969; Stevens and others, 2016). The Gros Ventre Range is bound to the southwest by the Cache Creek thrust (Nelson and Church, 1943), which exposes Precambrian crystalline rocks in its hanging wall. In contrast with the faulted escarpment along the southern margin, the northern flank of the Gros Ventre Range is characterized by regionally northeast-dipping Paleozoic and Mesozoic strata and several northwest-trending folds (Love and others, 1951; Simons and others, 1988). The Gros Ventre Range is a remnant of the ancestral Teton-Gros Ventre uplift, which extended northwest into present-day Idaho from late Cretaceous to Miocene time (Love, 1977). During the Miocene, movement along the Teton fault and other faults oblique to the Cache Creek thrust initiated the breakup of the Teton-Gros Ventre uplift, setting the stage for the development of the modern Teton Range and Jackson Hole (Love, 1977; Lageson, 1987).

Extending north from the Gros Ventre River to the northern and western map boundary is a series of rugged hills and dissected uplands broken only by the broad valley of the Buffalo Fork. These forested hills—known as the Mount Leidy highlands south of the Buffalo Fork and the Pinyon Peak highlands north of the Buffalo Fork (Love and others, 2003)—are underlain by parts of a thick sequence of Cretaceous to Paleocene sedimentary rocks that accumulated in the downwarp adjacent to the Teton-Gros Ventre and Targhee uplifts (Behrendt and others, 1968; Love, 1973a; Love, 1977). Structural and stratigraphic relations between these units reveal a complex history of localized tectonic and depositional events during this time (Love, 1977). Among these strata, the upper Cretaceous Harebell Formation and uppermost Cretaceous–Paleocene Pinyon Conglomerate are noteworthy for their thick sequences of quartzite pebble-to-boulder conglomerates sourced from erosion of the Targhee uplift (Love, 1973a). The resistant quartzite clasts have been recycled through multiple episodes of erosion and deposition and are important components of Quaternary glacial deposits in the region (Pierce and others, 2018). Modern erosion plays a prominent role in shaping the relatively weak rocks of the Mount Leidy and Pinyon Peak highlands into steep slopes, owing to the geologically recent down-dropping of Jackson Hole and subsequent drainage integration with the Snake River. These factors make this region highly susceptible to slope instability, as evidenced by the 1925 Lower Gros Ventre Slide (Blackwelder, 1912; Alden, 1928; Keefer and Love, 1956; Voight, 1978).

The southwestern Absaroka Range occupies the northeast quadrant of the map area. These mountains are composed of flat-lying volcanic and volcaniclastic rocks of the Eocene Absaroka Volcanic Supergroup that overlie and mostly conceal older Laramide structures. The prominent underlying Laramide structure in this region is the Washakie Range, which is a northwest-trending basement-cored asymmetric anticlinal uplift (Love, 1939; Behrendt and others, 1968). The Precambrian core is exposed in the canyons of the North and South Buffalo forks, and overlying Paleozoic strata form the flat top of Terrace Mountain and the narrow ridge of Angle Mountain on the steeply dipping south flank of the range. The Buffalo Fork thrust represents the western margin of the Washakie Range (Behrendt and others, 1968) and becomes buried beneath rocks of the Absaroka Volcanic Supergroup several kilometers north of the map boundary (Love, 1974).

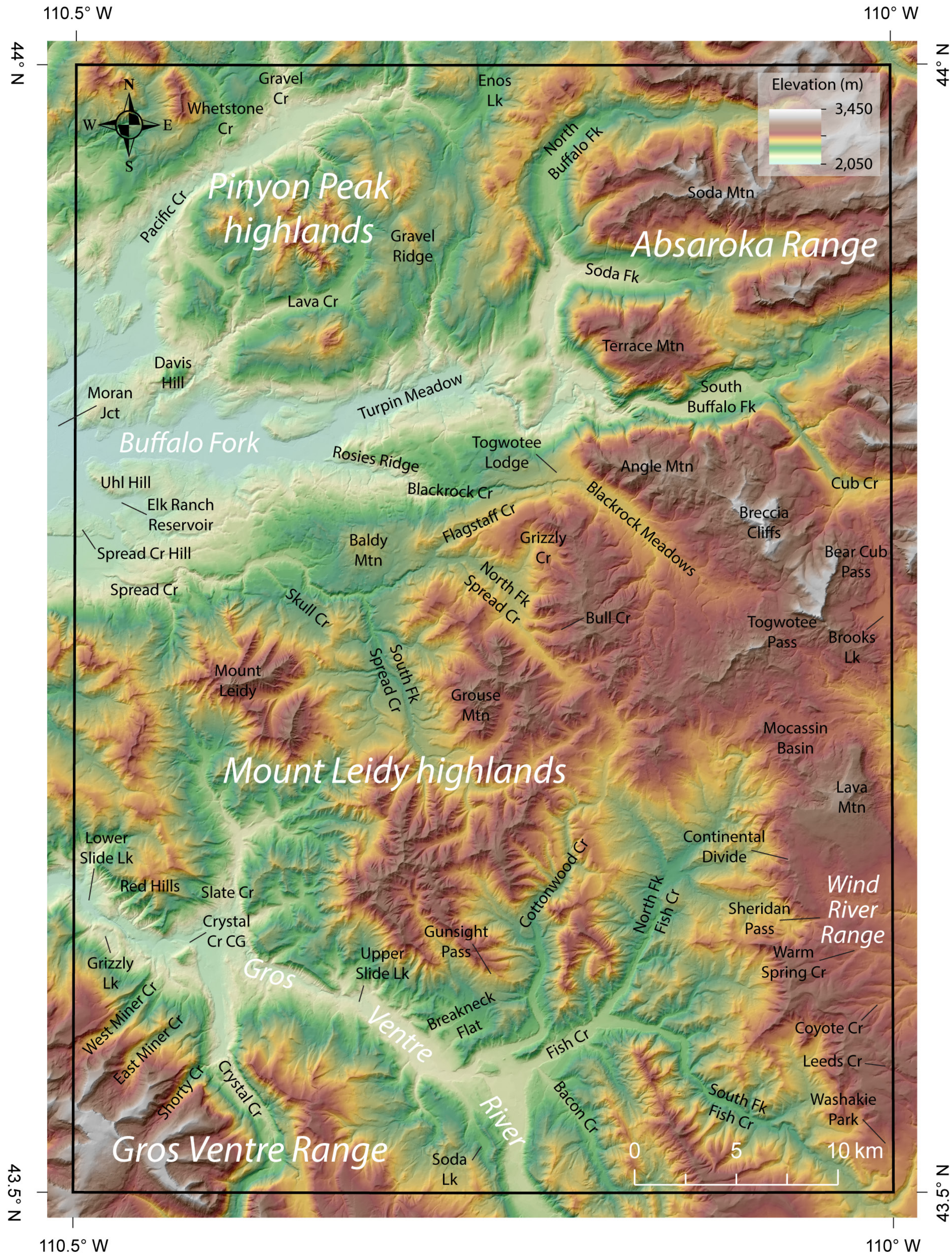

Figure 1. Shaded relief location map showing place names referenced in this report. Map boundary is solid black line. Abbreviations: CG = Campground, Cr = Creek, Fk = Fork, Jct = Junction, Lk = Lake, Mtn = Mountain.

The andesitic and basaltic rocks of the Absaroka Volcanic Supergroup extend from the Gallatin Range in Montana to the Owl Creek Mountains in central Wyoming and are represented by a wide variety of vent and alluvial facies (Smedes and Prostka, 1972). Within the quadrangle the Wiggins Formation, which forms the Breccia Cliffs north of Togwotee Pass and the highest terrain in the northeast map corner, and the Aycross Formation, which caps the Continental Divide uplands south of Lava Mountain, are the most prominent constituents of the Supergroup. In contrast with the underlying Laramide structures, rocks of the Absaroka Volcanic Supergroup are affected by only minor warping and faulting and generally dip less than 5 degrees (Keefer, 1957; Smedes and Prostka, 1972). Today these rocks form elevated, remnant plateaus dissected by steep-walled drainages formed from fluvial and glacial erosion.

The map area is bordered to the west by Jackson Hole, a west-dipping, asymmetric structural basin lying between the Teton, Gros Ventre, and Absaroka ranges. Quaternary alluvium, glacial till, and volcaniclastic rocks overlie older basin-fill deposits in much of Jackson Hole, where the Neogene- to Holocene-age, east-dipping Teton normal fault has accommodated the most recent and ongoing episode of basin subsidence (Smith and others, 1993). Within the map area, these Quaternary deposits are most prevalent in the valleys of the Buffalo Fork and Pacific Creek.

The map area and surrounding region are well known for Quaternary glacial geology. In the Pleistocene, glaciers covered much of the Absaroka and Wind River ranges, while the Gros Ventre Range hosted smaller valley glaciers originating from high cirques (Pierce, 2003; Pierce and others, 2018). The largest Pleistocene ice mass in the region was the Greater Yellowstone glacial system (GYGS), which covered the Yellowstone Plateau and much of the Absaroka Range and spilled south into Jackson Hole (Pierce and others, 2018).

Glacial till and outwash deposits around Jackson Hole have been dated and record evidence for two periods of Pleistocene glaciation: the Bull Lake (~150 ka) and Pinedale (~12 to 24 ka; Licciardi and Pierce, 2008; Pierce and others, 2018). During the Bull Lake glaciation the southern lobe of the GYGS extended south to Munger Mountain (30 km southeast of the map area) and covered the valley of Jackson Hole beneath hundreds of meters of ice (Licciardi and Pierce, 2008, 2018; Pierce and others, 2018). During the Pinedale, glacial lobes flowed south down the valleys of the Snake River, Pacific Creek, and the Buffalo Fork and terminated near the southern end of modern-day Jackson Lake (Pierce and others, 2018). The Pinedale glaciation is subdivided into three stages based on cosmogenic exposure dating of GYGS moraine boulders in Jackson Hole. The Pinedale-1 (designated as Burned Ridge in older publications) advance occurred around 20 ka, the Pinedale-2 (Hedrick Pond) advance has been dated to 15.5 ka, and the Pinedale-3 (Jackson Lake) advance has been dated to 14.4 ka (Licciardi and Pierce, 2008, 2018; Pierce and others, 2018).

METHODS

The study area was mapped through a combination of field mapping and interpretation of digital aerial imagery and lidar data. Field mapping was completed over five weeks between July and September 2021. Areas with high landslide density, abundant glacial deposits, discrepancies in prior mapping, and sites accessible from U.S. Highway 26/287 and the Gros Ventre River Road—the two primary road corridors in the map area—were prioritized as field targets. Additionally, five days were spent ground truthing fault scarps and surveying scarp profiles along the length of Quaternary-active faults in the map area. Not all parts of the study area were visited in the field due to time and access limitations.

Remote parts of the study area were mapped through photogeologic interpretation and consultation of existing bedrock maps. These methods were most heavily used in the North and South Buffalo forks and Pinyon Peak highlands of the Teton Wilderness, as well as in the Mount Leidy highlands and upper forks of Fish Creek. Lidar-derived bare-earth digital elevation models, hillshades, and slope maps were used as the primary datasets for digital interpretation in Grand Teton National Park (U.S. Geological Survey, 2015), the lower Buffalo Fork valley, and in Fremont County along the eastern map boundary (U.S. Geological Survey, 2020). In areas without lidar coverage, National Agriculture Imagery Program imagery from 2015, 2017, and 2019 and 3D Elevation Program 10-m digital elevation models and hillshades (U.S. Geological Survey, 2021) were used for photogeologic mapping.

MAP UNITS

Surficial geologic unit components include bedrock, residuum, colluvium, slopewash, landslide deposits, glacial till, and alluvial deposits. The surficial geology of much of the map area consists of bedrock, its weathering products, and landslide deposits. Glacial till is most prevalent in the northern half of the quadrangle, whereas active alluvium and terrace deposits are found along the arterial drainages of Pacific Creek, the Buffalo Fork, and the Gros Ventre River.

Bedrock, Residuum, and Hillslope Deposits

Units composed of bedrock, residuum, and hillslope deposits are given a three-component name, with the components listed in order of relative abundance within the zone of consideration (a volume extending across the footprint of the map unit and down 1.5 m from the surface). These components are abbreviated *R* for bedrock, *r* for residuum, *c* for colluvium, and *s* for slopewash. For mapping purposes, colluvium was defined as an unconsolidated, coarse-grained hillslope deposit transported primarily by gravity through processes like dry ravel. Hillslope material that is part of a mass movement or total slope failure is excluded from this classification, which distinguishes colluvium from rockfalls, rockslides, and other mass wasting deposits.

Unit *Rcs* was mapped in two geomorphic settings where bedrock and colluvium are the dominant surficial deposit components. The first setting is along cliff faces and weathering-limited hillslopes in high-relief terrain, such as the steep walls of glaciated valleys in the Gros Ventre and Absaroka ranges. *Rcs* was also mapped among bedrock units that weather to produce clasts that are readily transported downslope as colluvium, such as the Pinyon Conglomerate and Harebell Formation in the Mount Leidy and Pinyon Peak highlands. The conglomeratic beds in these units weather to large volumes of rounded quartzite cobbles, which are uniquely susceptible to dry ravel erosion and can be found in colluvial aprons at the base of slopes or as an in-transport mantle of colluvium mid-slope (fig. 2).

Unit *Rsc* is common on steep slopes and valley walls among Paleozoic and Mesozoic sedimentary units. These locations, which are spread throughout the map area, are marked by outcrops of resistant strata interspersed with recessive layers that are mantled by slopewash and colluvium. The limestone and sandstone that form the resistant layers tend to weather to fine-grained sediment that is more commonly mobilized as slopewash than colluvium. Unit *Rsr* was mapped primarily in the southern half of the quadrangle and is characterized by gentler topography than *Rsc*. Recessive Cretaceous and Paleogene sedimentary units like the Frontier and Wind River formations, which weather to fine-grained and platy clasts that are not typically transported as colluvium, are frequently associated with *Rsr*.

Unit *Rrs* occurs on flat to gently sloping upland plateaus where bedrock is exposed at the surface. Dip slopes of Paleozoic carbonate units in the Gros Ventre Range, interfluves and clifftops composed of the Wiggins Formation in the Absaroka Range, and the basalt-capped Lava Mountain are among the variety of settings where *Rrs* was mapped.

Figure 2. Photograph of unit *Rcs* on a steep hillside near Gunsight Pass in the Mount Leidy highlands. Bedding is part of the Cretaceous–Paleocene Pinyon Conglomerate. Note prevalence of quartzite cobble colluvium at the surface.

Residuum is the primary surficial component in areas that have gentle topography or are underlain by recessive lithology. This has allowed for greater soil development than in areas that have resistant bedrock, steep slopes, or that are geologically unstable. Of the residuum units, *rRs* is the most common and is present in all parts of the quadrangle outside the Absaroka Range. This unit is prevalent in the southeast map area where recessive Paleogene sedimentary and tuffaceous lithologies, such as those of the Aycross and Wind River formations, are exposed in broad basins. A similar unit, *rsR*, was mapped in heavily weathered Cretaceous shales in the Mount Leidy highlands where there is very little exposed bedrock. Units *rsc* and *rcs* were mapped in select locations where no bedrock is exposed at the surface over a widespread area, which typically coincides with dense vegetative cover and thick soils. Areas where the weathered parent material is Pinyon Conglomerate were mapped as *rcs*, whereas locations underlain by all other lithologies were mapped as *rsc*.

Unit *sRc* occurs in the Mount Leidy highlands and upper Gros Ventre River valley on concave valley sides that often extend from cliffy terrain above to a distal slopewash apron in the valley bottom. The bedrock component of this unit is most commonly Cretaceous sandstone and shale. Colluvium is a primary surficial component in the headwalls and margins of cirques in the Gros Ventre Range as well as below the basalt cap of Lava Mountain, where it forms extensive talus slopes at the angle of repose. Unit *cRs* was mapped in these settings. This unit was also mapped in select locations in the Mount Leidy and Pinyon Peak highlands where quartzite cobble colluvium derived from the Pinyon Conglomerate is more abundant than in-place bedrock.

Landslide Deposits

The landslide mapping presented here is part of a broader WSGS effort to update a previous landslide inventory (Case and others, 1996) and to inform forthcoming landslide susceptibility analyses in Teton County. With the benefit of lidar interpretation and ground truthing, many of the landslides mapped by Case and others (1996) were confirmed to be present but were modified in terms of their contacts, spatial extent, or classification. In other instances, the high-resolution lidar data allowed a previously mapped landslide to be broken into separate features or to be mapped as glacial till instead of a landslide. Finally, several recent landslides were mapped that occurred in the 26 years since the inventory of Case and others (1996).

Because a key motivation of this project is to build upon prior WSGS mapping and generate data for future landslide studies, landslides were mapped according to WSGS conventions. As such, map polygons comprise a landslide's full aerial footprint, extending from the headscarp or initiation point through the transport path to the deposit. Exceptions to this practice were made where the transport zone is less than 50 m wide and could not be displayed at the map scale, which was the case for some debris flow chutes in steep terrain. In these instances, the mapped landslide polygon only includes the debris flow deposit. Also by WSGS convention, individual landslides were first mapped as separate polygons before adjacent polygons were merged, eliminating internal contacts on the final map.

Mass movements are a prominent geomorphic process throughout the map area, and their deposits and erosional scarps have greatly shaped the local topography. Landslide susceptibility in this region is controlled by bedrock structure, parent material composition, slope steepness, and topographic relief. Landslide triggers include precipitation or meltwater events, seismicity, and slope undercutting (Keefer and Love, 1956; Bailey, 1971; Smith and others, 1976; Zung and others, 2009). Landslides (unit *l*) are especially numerous in the southern half of the quadrangle in the Gros Ventre River valley, Mount Leidy highlands, and upper forks of Fish Creek. On the south side of the Gros Ventre River valley, large translational block slides occur in the northeast-dipping Paleozoic and Mesozoic strata. Slope-parallel bedding combined with alternating layers of highly variable competence and permeability make these areas particularly prone to dip slope translational slides (Keefer and Love, 1956; Bailey, 1971). An example of a large translational slide is south of the Gros Ventre River near the western map boundary, where a landslide that slid atop the Sundance and Gypsum Springs formations forms an arcuate ridge confining Grizzly Lake (Love and Love, 1988).

Elsewhere in the Gros Ventre area, translational landslide and earthflow complexes spill into the Gros Ventre River valley. These complexes typically begin as block slides and rockslides in upper catchments that are reworked during periods of soil saturation, when they can travel far downstream as earthflows. The Upper Gros Ventre Slide, which impounds Upper Slide Lake along the Gros Ventre River, is one example. Other examples include the Lavender and Slate Creek slides north of the Gros Ventre River (fig. 3) and the Soda Lake slide, which dams Soda Creek near the southern map boundary (Keefer and Love 1956). A final noteworthy mass movement in the Gros Ventre area is the Crystal Creek landslide, a rockslide/rockfall complex that has been active in recent years. In 2007 part of the northern face of Crystal Peak collapsed into the valley floor 700 m below. Additional smaller movements occurred in subsequent years and the unstable deposit was extensively reworked by debris flows in 2012, which deposited a large fan that now impounds Crystal Creek (fig. 4).

Slump/flow and debris flow complexes are prevalent in the steep, dissected terrain of the Mount Leidy highlands. Here, the poorly cemented Pinyon Conglomerate is susceptible to rapid downcutting and the formation of deep gullies, which can undermine hillslopes and convey debris flows downward to form broad, coalescing fans in the valley bottoms (fig. 5). In part because of this, Slate Creek and its tributaries contain the highest density of mapped landslides in the quadrangle. Though still present, landslides are less common in the gentler topography of the Pinyon Peak highlands of the northwest map area.

Large block slide/flow complexes are found on the flanks of escarpments in the Absaroka Range in the northeast quadrant of the map. In these areas the relatively competent volcanic breccia of the Wiggins Formation rests atop bentonitic and tuffaceous claystone of the Aycross Formation. The loss of lateral confinement during post-Pinedale glacial recession and subsequent undercutting by fluvial incision have destabilized these escarpments, leaving them susceptible to mass wasting (Bailey, 1971). Examples of block slide/flow complexes in this setting are on the southwest side of Soda Mountain, northwest of Brooks Lake, and southwest of the Breccia Cliffs surrounding Lost Lake.

In the vicinity of the Breccia Cliffs, Brooks Lake, and Lava Mountain are extensive regions that were previously mapped as undivided landslide and glacial deposits (unit Qlg) by Love (1982a) and Love and others (1982). The present study attempted to differentiate between landslide deposits and glacial till in this region on the basis of clast composition observed in the field as well as landform surface texture visible in lidar-derived hillshades and slope maps. Landslide deposits in this area were recognized by commonly having uniform volcanic clast lithology and forming sharp escarpment-parallel ridges interpreted as rotated blocks transported from the cliffs above. Glacial deposits form slightly smoother topography and contain exotic clast compositions, such as quartzite, limestone, and crystalline lithologies. Despite this evidence, there is elevated uncertainty in distinguishing between landslide and glacial deposits in this part of the map due to younger landslides that formed within glacial till and Pleistocene glaciers that reworked older landslide deposits.

Glacial Till

Though less prominent than the textbook glacial geology exhibited farther west in the Teton Range and Jackson Hole, Pleistocene glaciations had important influences on the topography and surficial geology of the east half of the Jackson Lake quadrangle. Till deposits are present in the Gros Ventre River valley and its tributaries, along the Continental Divide in the eastern map area, in the headwater valleys and cirques of the Absaroka Range, in the Buffalo Fork valley and its major tributaries, and throughout the Pinyon Peak highlands. In addition to original field mapping and lidar and aerial imagery interpretation, the mapping herein builds upon the work of Lagas (1984) in the Gros Ventre River valley, Rohrer (1969) in the southeast corner of the quadrangle, and Pierce and others (2018) in the Buffalo Fork and Pacific Creek areas.

In several parts of the eastern map area, till is found only as a thin, discontinuous veneer capping upland surfaces and is not preserved in drainage bottoms. Small gullies or landslide headscarps cut into these upland plateaus expose shallowly buried bedrock and residuum and allow for estimates of till thickness. Till was mapped only where it was observed to be more than one meter thick. Consequently, there are places where glacial erratics are present but where the till deposit is not thick or continuous enough to map as a surficial unit; these locations were mapped as bedrock or residuum units instead. Conditions like this were commonly encountered in Moccasin Basin, Washakie Park, and in the tributaries of Warm Spring Creek.

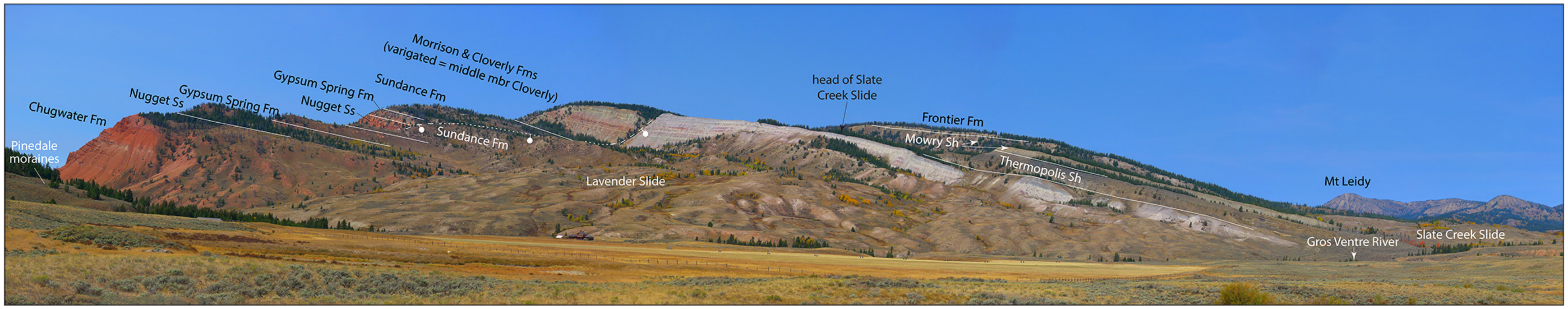

Figure 3. Photograph of the Lavender and Slate Creek landslides from near the mouth of Crystal Creek in the Gros Ventre River valley. Both mass movements initiated as translational block slides along bedding planes in Mesozoic strata before transitioning into earthflows. Bedrock annotations based on mapping of Love and others (1992). Panorama spans from west (left) to north (right). Abbreviations: Fm = Formation, mbr = member, Mt = Mount, Sh = shale, Ss = Sandstone.

Figure 4. Photograph of Crystal Creek landslide near the southern map boundary. This rockslide/rockfall complex experienced major activity at least as recently as 2012. The headscarp exposes the yellow-gray Tensleep Sandstone, and the red debris incorporated into the landslide deposit is from the underlying Amsden Formation. A newly formed lake, impounded behind the debris flow fan at the base of the landslide, is just visible through the trees to the right. Panorama spans from east (left) to south (right).

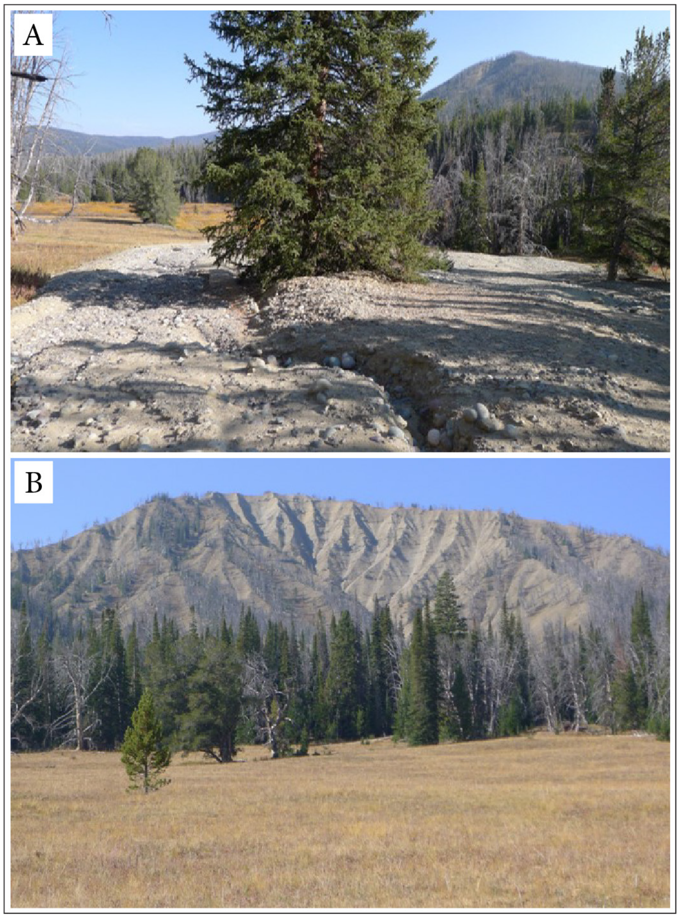

Figure 5. Photographs of debris flows in North Fork Spread Creek. A) A recent debris flow that buried tree trunks to a depth of 1 m and advanced over a closed forest road (faintly visible at left). B) Photograph taken from a broad apron built by many generations of debris flows that initiated in the steep, heavily gullied terrain visible in the background. View is to the southwest, and the dissected cliffs are formed from the weakly indurated Pinyon Conglomerate.

Bull Lake till

Till from the Bull Lake glaciation (~150 ka) is only sparsely preserved in the map area and is most easily observed in the Gros Ventre River valley. Bull Lake till (unit g_{bl}) composes lateral moraines that are recognized as high ridges along Crystal Creek and East and West Miner creeks near their confluences with the Gros Ventre River. These moraine complexes are at higher elevations and exhibit much smoother surface textures than the more extensive and hummocky Pinedale moraines inset below them (fig. 6). The Bull Lake till mapped in this area corresponds in places with the Grizzly Lake and Red Hills tills of Lagas (1984), which were interpreted as pre-Bull Lake and Bull Lake in age, respectively.

Field observations of moraine morphology and position from the Miner Creek and Grizzly Lake area suggest only two generations of moraines (Pinedale and Bull Lake), with possible subsets relating to pulses during the Pinedale advance. This differs from the interpretation of Lagas (1984) of three generations of moraines. As such, of the moraines Lagas (1984) mapped as Bull Lake in age, only those that sit at a higher elevation and outside of Pinedale lateral moraines, and that exhibit a muted surface texture, were similarly mapped as Bull Lake in age for the present study.

Small perched deposits of Bull Lake till are also mapped on ridges along the flanks of the Gros Ventre River valley. These discontinuous deposits record ice at much higher elevations and greater spatial extents than during Pinedale time, and they imply that Bull Lake glaciers flowed down the forks of Fish Creek and overtopped the valleys of Crystal Creek and East and West Miner creeks. Some of these deposits were mapped as Grizzly Lake till and Bacon Ridge gravel (both defined as pre-Bull Lake in age) by Lagas (1984), and others were mapped as Leidy Formation by Love (1994). The Leidy Formation is a sequence of interfingering till, fluvial gravel, and lacustrine clay described by Love (1994) that is preserved intermittently along 50 km of the Gros Ventre River valley from North Fork Fish Creek to downstream of Lower Slide Lake (west of the map area). Love (1994) did not attempt to temporally correlate the Leidy Formation with other Pleistocene tills in the region, but Pierce and others (2018) have since interpreted the formation as Bull Lake in age. The mapping herein follows this interpretation, which is supported by the observations that the Leidy Formation interfingers with mapped Bull Lake till between Lower Slide Lake and the town of Kelly (Mauch and others, 2021) and often has a geomorphic position just outside and downstream of Pinedale moraines. Furthermore, the Gros Ventre River valley is now known to have been dammed by ice flowing south through Jackson Hole during Bull Lake time (Pierce and others, 2018), which provides a mechanism for lacustrine sedimentation.

Elsewhere, Bull Lake till is present between Blackrock Creek and North Fork Spread Creek above the Pinedale trimline mapped by Pierce and others (2018), as well as in the southeast map area near Sheridan Pass and Washakie Park. The glacial deposits in the southeast map area were mapped by Rohrer (1969) as Washakie Point and Cedar Ridge till, which have been interpreted as pre-Bull Lake in age (Richmond, 1962). Field observations near Sheridan

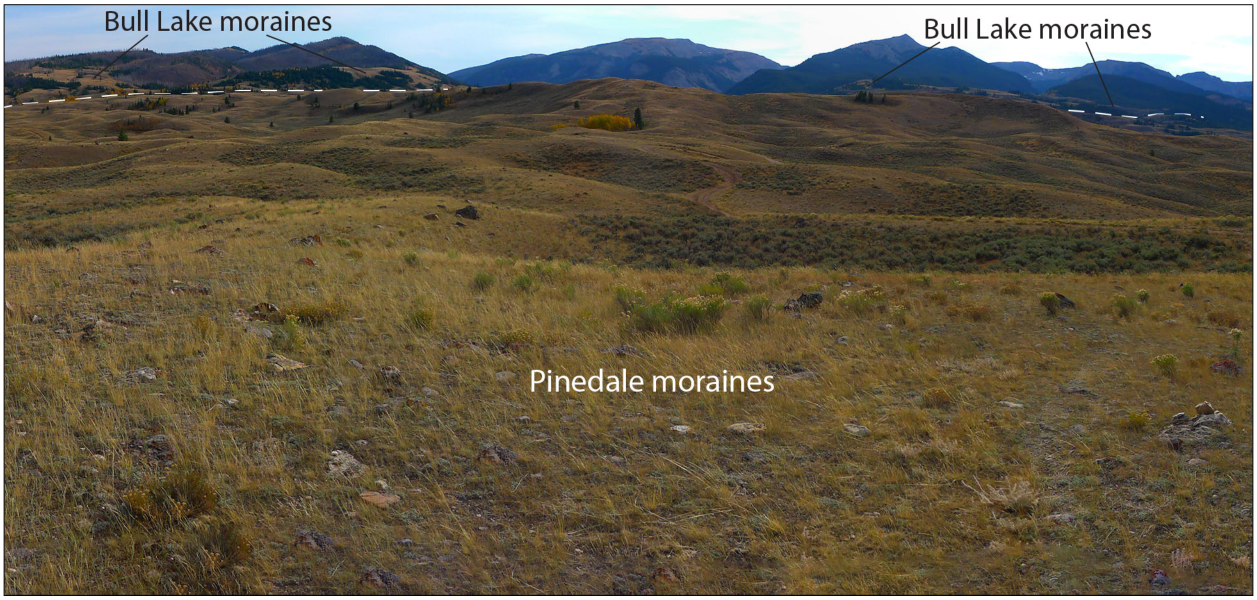

Figure 6. Photograph of Bull Lake and Pinedale moraines in the Gros Ventre River valley near the mouth of Crystal Creek. The older Bull Lake moraines are only preserved at relatively high elevations on the valley walls and have subdued surface morphology. Inset below them are more extensive Pinedale moraines that feature numerous closed depressions. White dashed line shows the contact between Bull Lake and Pinedale till where it is visible in the image. View is to the south.

Pass show what Rohrer (1969) mapped as the Sacajawea Ridge till (also defined as pre-Bull Lake in age by Richmond [1962]) to exhibit sharp-crested, nested moraines mantled by boulders and to form an abrupt contact with smoother, till-veneered topography to the south. Lidar data confirm the stark difference in surface texture between these tills (fig. 7). Because of their strikingly fresh morphology, the moraines mapped by Rohrer (1969) as Sacajawea Ridge till are here reinterpreted as Pinedale in age, and by extension, the next older till to the south that these moraines crosscut is interpreted to be Bull Lake rather than pre-Bull Lake in age.

The reinterpretation of the pre-Bull Lake tills of Rohrer (1969) and Lagas (1984) as younger, Bull Lake-age deposits in this study is consistent with the mapping of Mauch and others (2021) on the west half of the Jackson Lake quadrangle. It is also consistent with Quaternary geochronology studies in northwest Wyoming (e.g. Licciardi and Pierce, 2008, 2018) and across the Rocky Mountain region (e.g. Pierce, 2003) that suggest many of the tills originally hypothesized to have a pre-Bull Lake age instead date to the Bull Lake glaciation. This more recent work has benefited from the development and widespread application of numerical dating methods such as cosmogenic radionuclide dating, which were not available to the earlier authors who mapped extensive deposits of pre-Bull Lake till.

One of the mapping objectives in the southeast corner of the quadrangle was to define the extent of Bull Lake glaciers entering the area from the north and south, and to determine if ice from these disparate sources might have converged. This region—roughly bound by Bacon and North Fork Fish creeks to the west, Lava Mountain to the north, and extending off the map area to the south and east—would have been near the nexus of north-flowing glaciers from the Gros Ventre Range, northwest-flowing glaciers from the Wind River Range, and south-flowing glaciers from the Absaroka Range during Bull Lake time (Rohrer, 1969; Pierce and others, 2018). The spatial and temporal interactions of glaciers from these three sources remain incompletely understood, in part due to lack of study, poor exposure, and low preservation potential in heavily dissected terrain. Though this study does not completely resolve these questions, field observations of clast composition in till provides some insight given the fundamental differences in rock type between the source areas.

The nearest source of volcanic clasts in this region are to the north, with andesite and breccia originating from Lava Mountain and the southern Absaroka Range, respectively. Granitic rocks likely come from the Wind River Range, the closest and most abundant source of crystalline lithologies in the region. Carbonate rocks are likely derived

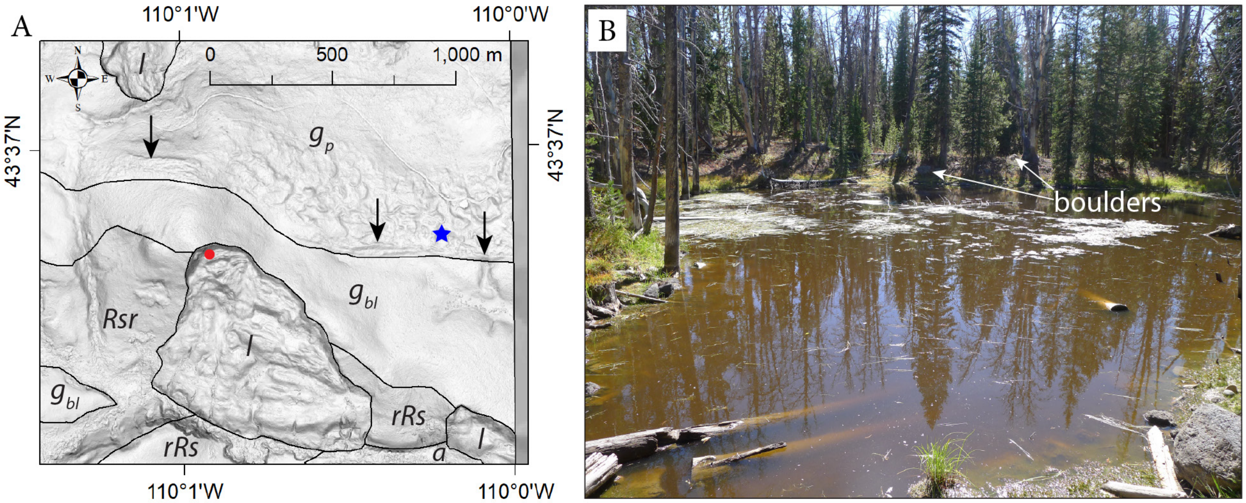

Figure 7. Lidar slope map (A) and photograph (B) of till near Sheridan Pass. The younger Pinedale till forms sharp-crested moraines that are mantled by volcanic boulders and host closed depressions with small ponds (photograph). The older Bull Lake till to the south forms a rubbly surface veneer and lacks pronounced moraines. The contact between these two tills is inferred to represent the southernmost advance along the Continental Divide of glaciers from the Absaroka Range during the Pinedale glaciation. Black arrows denote moraine crests, blue star shows location of photograph, and red dot shows location of figure 8. Eastern map boundary is at right side of lidar slope map, Sheridan Pass is off the northwest corner of the frame. Units: g_p = Pinedale till; g_{bl} = Bull Lake till; *l* = landslide; *a* = alluvium; *Rsr* and *rRs* = bedrock, residuum, and slopewash.

from the northeast flank of the Gros Ventre Range, where there are extensive dip slopes formed on Paleozoic units (Love and Christiansen, 1985). Rounded quartzite cobbles, which often litter the surface in this region and are commonly incorporated into tills, are interpreted to be locally derived, and hence, their presence is inconclusive in determining glacial provenance. Quartzite conglomerate beds are described in the Aycross Formation by Love and Christiansen (1985), and Rohrer (1969) mapped several stream-channel quartzite conglomerate units in the Wind River Formation. The conglomerate beds assigned to different formations by these separate authors may in fact be equivalent, as the Aycross Formation of Love and Christiansen (1985) is coincident with the conglomerate units mapped by Rohrer (1969) in the Warm Spring Creek and Leeds Creek basins. Regardless, the present study interprets surfaces mantled by rounded quartzite clasts with no exotic lithologies to be residuum and lag from local conglomerate units rather than glacial till. This inference is supported by an observation on the north end of Washakie Park from a landslide headscarp, where petrified wood-bearing conglomerate bedrock is exposed directly beneath a 2-m-thick residuum cap of unconsolidated quartzite cobbles.

South of the sharp-crested Pinedale end moraines between Sheridan Pass and Warm Spring Creek, Bull Lake till is composed of roughly 80 percent andesite from Lava Mountain, 15 percent locally derived quartzite cobbles, and 5 percent volcanic breccia from the Absaroka Range. A landslide headscarp in this area exposes a large breccia erratic (fig. 8) but does not expose bedrock, suggesting the till is greater than 4 m thick.

Less than 2 km to the south in Warm Spring and Indian creeks, Rohrer (1969) documented the northernmost appearance of granitic clasts sourced from the Wind River Range. Workers for the present study did not observe granitic clasts on the next ridge to the south between Indian and Coyote creeks and instead only found scattered andesite cobbles, but their field reconnaissance was likely not as thorough as that of Rohrer (1969). Though Rohrer (1969) mapped the upland ridges in this area as Washakie Point till, field observations from the present study indicate that the discontinuous veneer of exotic andesite clasts is not thick enough to map as a till deposit. A lag of rounded quartzite cobbles is ubiquitous on these ridges, and the gullies and landslide scarps expose tuffaceous siltstone and sandstone bedrock. Because of this, *rRs* and *Rrs* were mapped in this area.

Farther south still, the clast composition in Bull Lake till shifts dramatically around Washakie Park. Here, till is composed of approximately 50 percent granitic clasts from the Wind River Range, 40 percent locally derived quartzite cobbles, 5 percent Flathead Sandstone from the Wind River Range, and 5 percent volcanic rocks from Lava Mountain and the Absaroka Range. Granitic boulders are common at the surface in Washakie Park and in areas southeast of the map boundary (fig. 9). Collectively, these observations suggest that during the Bull Lake glaciation, ice from the Absaroka Range and Lava Mountain met, or at least overlapped spatially at different times, with ice from the Wind River Range. The location of this confluence is hypothesized to be between Warm Spring Creek and Washakie Park, where exotic clasts of volcanic and crystalline rock types are found together. Importantly, no carbonate clasts from Paleozoic units were found in any of the till deposits in the southeast map area, suggesting that glaciers from the Gros Ventre Range, where Paleozoic carbonate bedrock is prevalent, did not extend this far northeast.

Figure 8. Photograph of glacial erratic between Sheridan Pass and Warm Spring Creek in the eastern map area. This boulder is composed of volcanic breccia from the Wiggins Formation, the nearest outcrops of which are 13–15 km north near Brooks Lake, and is exposed in a landslide headscarp cut into Bull Lake till. Photograph location shown in figure 7 (A). Hiking pole, 1.3 m tall, for scale.

Pierce and others (2018) described evidence for ice filling the Gros Ventre River valley in Bull Lake time, and field observations from this study support that hypothesis. Granitic and volcanic lithologies, which are exposed as bedrock only in localized pockets in the extreme headwaters of the Gros Ventre River catchment, were observed as far downstream as the Bull Lake till mapped between the Red Hills and Grizzly Lake near the western map boundary. In fact, this location is the type section for the Leidy Formation, where Love (1994) similarly documented granitic clasts. Love (1994) also described granitic boulders farther upstream in the Gros Ventre River valley in additional exposures of the Leidy Formation. Several of these deposits cap ridges near the forks of Fish Creek (Love, 1994), extending the breadcrumb trail closer to the hypothesized confluence zone of Bull Lake glaciers. Given these observations, it is hypothesized that in Bull Lake time, glaciers from the Absaroka Range and Wind River Range converged along the Continental Divide in the area between Warm Springs Creek and Washakie Park. From there the collective ice mass likely descended into the South Fork Fish Creek drainage system, eventually joining with ice from the Gros Ventre Range to flow down the Gros Ventre River valley.

Pinedale till

Extensive till deposits in the northern map area are the result of the southward advance of the Greater Yellowstone Glacial System (GYGS) during the Pinedale glaciation. In the lower valleys of the Buffalo Fork, Spread Creek, and Pacific Creek, Pinedale till is subdivided into stage 1 (g_{p1}), stage 2 (g_{p2}), and stage 3 (g_{p3}) following Pierce and others (2018). Elsewhere on the quadrangle, Pinedale till is mapped as undifferentiated (unit g_p) in areas where the subdivision is uncertain—such as where multiple lobes or pulses of the GYGS are superimposed—or where Pinedale glaciers were not connected to the GYGS.

In Pinedale-1 time (~20 ka) the Buffalo Fork lobe of the GYGS flowed out of the Absaroka Range and down the Buffalo Fork drainages, leaving behind ground moraines in tributaries and across many of the lower interfluves (Pierce and others, 2018). The large area of Pinedale-1 till mapped between the Buffalo Fork and Spread Creek was deposited during this time. The g_{p1} in this region is composed of a wide variety of clast types reflecting the large source area of the GYGS, though quartzite, limestone, volcanic breccia, and granitic lithologies appear to be the most prevalent. Boulders are rarely observed at the surface and are generally less than 1 m in diameter, perhaps

Figure 9. Photograph of granitic glacial erratic in Washakie Park, southeast map area. Granitic clasts are common in the Bull Lake till in this area and were sourced from the Wind River Range 20 km to the southeast. Boulder is 1.5 m tall.

owing to the great transport distance from the source areas in the high Absaroka Range. The extensive deposits of Pinedale-1 till in this area form rolling, hummocky topography containing several concentrations of kettle ponds (fig. 10). It is noteworthy that these glacial deposits were the type section for the Buffalo glaciation of Blackwelder (1915), who inferred the till to be pre-Bull Lake in age based on its position up to 300 m above the modern drainages. Later workers, however, recognized that the high landscape position and fresh morphology of these deposits recorded a great thickness of ice flowing down the Buffalo Fork valley in the latest Pleistocene, rather than a long period of post-glacial incision (Richmond, 1965; Richmond, 1976; Pierce and others, 2018).

The main mass of the Buffalo Fork lobe as it exited the Absaroka Range was likely confined to the south by the high ridge of Angle Mountain. This inference is supported by the lack of till above 2,800 m on Angle Mountain as well as the existence of southwest-trending lateral moraines near Togwotee Lodge that contain granitic clasts sourced from the South Buffalo Fork (Love and Weitz, 1982; Pierce and others, 2018). Mapping and field observations from the present study suggest that a southern extension of the Buffalo Fork lobe overtopped the Continental Divide at Bear Cub Pass and flowed south through the gap between Sublette Peak and Pinnacle Buttes near Brooks Lake. Evidence for this hypothesis includes prominent south–southeast-trending Pinedale ground moraines near Bear Cub Pass (fig. 11) as well as the presence of granitic clasts in till deposits near Brooks Lake and Barbers Point, the nearest source for which is the South Buffalo Fork. It is unknown how far south this extension of the Pinedale-1 Buffalo Fork lobe reached. Unit g_p is mapped around Lava Mountain and as far south as Sheridan Pass, but these deposits are composed almost exclusively of volcanic clasts. Granitic lithologies were not observed in Pinedale till south of U.S. Highway 26/287.

Farther west, extensive till deposits in and southeast of Blackrock Meadows suggest that ice from the Buffalo Fork lobe of the GYGS may have also overtopped the drainage divide through the pass between Angle Mountain and the Breccia Cliffs. Near the west end of Blackrock Meadows and extending west to the map boundary, Pinedale till is present below the trimline mapped by Pierce and others (2018), which is inferred to mark the southern extent of the

Figure 10. Photograph of hummocky topography in Pinedale-1 till near Baldy Mountain. Note sweeping moraine crests and closed depression at center of photograph. Lily Lake, a kettle pond (Pierce and others, 2018), is visible through the trees in the middle ground to the right. Panorama spans from east (left) to south (right).

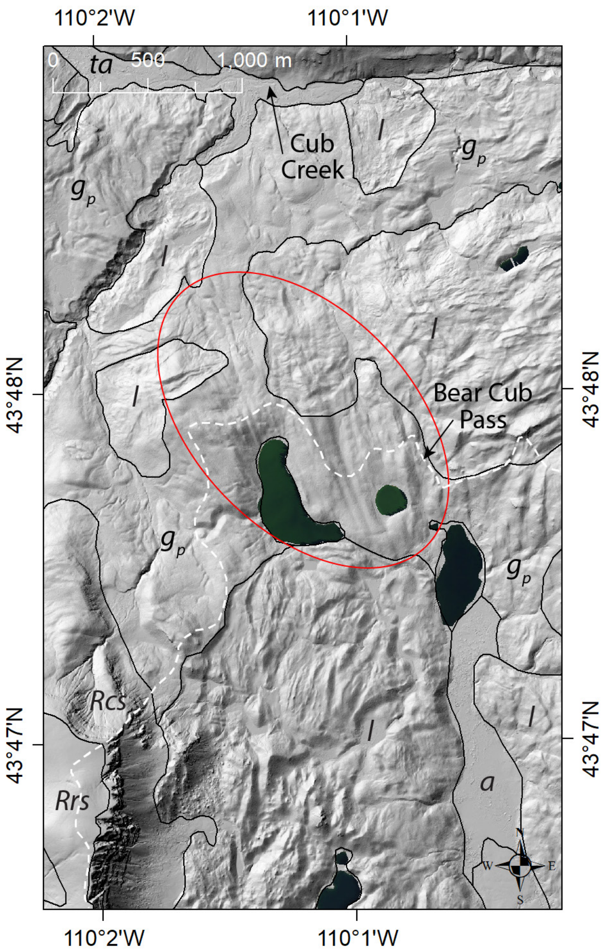

Figure 11. Lidar hillshade of Pinedale till around Bear Cub Pass. South–southeast-trending ground moraines (red ellipse) indicate that ice from the Absaroka Range crossed the Continental Divide (white dashed line) in this location during the Pinedale glaciation. Holes in the hillshade denote lakes. Units: g_p = Pinedale till; *l* = landslide; *a* = alluvium; *ta* = terrace deposits and alluvium; *Rrs* and *Rcs* = bedrock, residuum, colluvium, and slopewash.

Buffalo Fork lobe in this area. Minor discontinuous till deposits in the headwater basins of North Fork Spread Creek and Cottonwood Creek, which are south of the mapped Pinedale-1 extent of Pierce and others (2018), may indicate a farther southward advance of the GYGS than previously recognized, may represent small Pinedale alpine glaciers disconnected from the GYGS, or may be remnant Bull Lake-age deposits.

In Pinedale-2 time (~15 ka) the Buffalo Fork lobe receded around 20 km up-valley, likely to the vicinity of Togwotee Lodge, and the Pacific Creek and Snake River lobes became the dominant southern extensions of the GYGS in Jackson Hole (Pierce and others, 2018). Within the quadrangle, it's possible that the till mapped in the Pinyon Peak highlands and along Pacific Creek dates to this period, although there is substantial uncertainty because this area was covered in ice for all three Pinedale advances. Because of this, Pinedale till in these regions is mapped as undifferentiated g_p.

As observed south of the Buffalo Fork with g_{p1} deposits, Pinedale till in the Pinyon Peak highlands forms a semi-continuous veneer across gently undulating upland surfaces. South-trending flow lineations in Pinedale ground moraines between Enos Lake and Gravel Ridge suggest deposition beneath the Pacific Creek lobe. Till in Pacific Creek is rich in rounded quartzite cobbles recycled from the local Pinyon Conglomerate and Harebell Formation. These deposits also contain lesser proportions of breccia from the Absaroka Volcanic Supergroup, rhyolite from the Yellowstone Plateau, and sandstone from either local Cretaceous units or more distant outcrops of Paleozoic strata to the east. Boulders are relatively rare in this till, and most are of volcanic lithology (fig. 12). Because of the prevalence of quartzite cobbles in till deposits in this area, it is difficult to distinguish till from residuum derived from the Pinyon Conglomerate and Harebell Formation. Except where field evidence indicated otherwise (e.g. clear moraine morphology, variable clast composition), the mapped extent of Pinedale till in Pacific Creek follows that of Love (1975a, b).

In Pinedale-3 time (~14 ka) the Pacific Creek lobe of the GYGS receded from its maximum position. Within the map area, likely the only notable change in ice extent from Pinedale-2 time was along the lower Buffalo Fork, where a plug of ice from the Pacific Creek lobe that had pushed upstream to near the present-day Grand Teton National Park boundary receded 2.5 km downstream (Pierce and others, 2018). In fact, the only Pinedale-2 and Pinedale-3 till deposits in the study area are mapped in this location, where lidar hillshades allow determination of contrasting moraine texture and ice flow direction. On the hill immediately east of Moran Junction between Pacific Creek and the Buffalo Fork, Pinedale-2 ground moraines are recognized by streamlined south-trending crests where ice overtopped the low ridge, whereas Pinedale-3 ground moraines are lower on the hillside and are streamlined in the southwest direction where ice wrapped around the hill (fig. 13).

Pinedale till is undifferentiated in the southern map area, where local valley glaciers were disconnected from the GYGS and likely did not advance in synchrony with the large glacial lobes farther north. The Gros Ventre Range was host to valley glaciers during the Pinedale, some of which flowed north into the quadrangle. At the mouth of Crystal

Creek in the Gros Ventre River valley is an approximately 10 km^2 area blanketed by Pinedale till that was deposited by a valley glacier sourced from Crystal Creek. These deposits are continuous to the west with till derived from East and West Miner creeks, implying that near their termini, glaciers from all three drainages coalesced into a piedmont lobe that wrapped around several bedrock hills and likely pushed the course of the Gros Ventre River to the north. This complex of Pinedale moraines exhibits more typical morphologies than the ground moraines in the Buffalo Fork region. For example, there are sharp-crested lateral moraines and arcuate terminal moraines in West Miner Creek, and the moraines east of the mouth of Crystal Creek are sharp, hummocky, and contain numerous closed depressions (fig. 6). The till here is also a more typical unsorted mix of clay to boulder-size particles with boulders commonly perched on moraine crests, which differs from the cobble-rich till in the Buffalo Fork valley and Pinyon Peak highlands. The till is composed almost exclusively of limestone and sandstone clasts, which reflects the Paleozoic bedrock exposed in the source areas of the northern Gros Ventre Range.

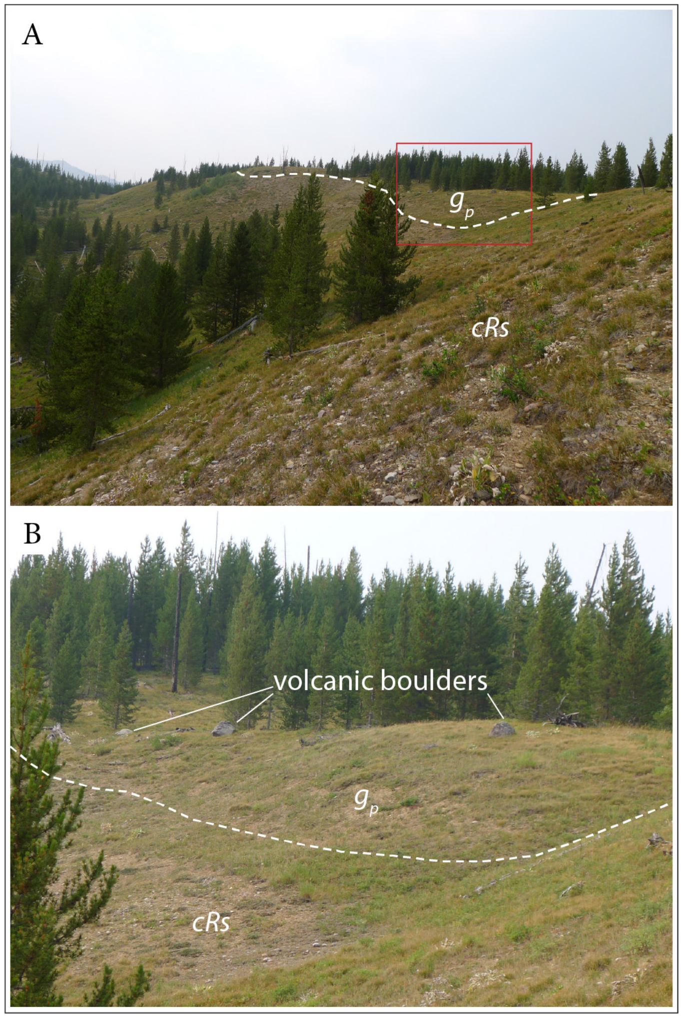

Figure 12. Photograph of Pinedale glacial deposits in Pacific Creek. A) Pinedale till (unit g_p) draped over recessive colluvium, bedrock, and slopewash (unit *cRs*) derived from the Pinyon Conglomerate. Red box shows extent of zoomed-in lower photograph (B), white dashed lines show contact between till and *cRs*. Pinedale till in this area is recognized by the presence of sparse volcanic boulders derived from the Absaroka Range and Yellowstone Plateau.

The Pinedale till mapped in the Crystal Creek and Miner Creek area corresponds with the Crystal Creek till of Lagas (1984). Mapping by Lagas (1984) does not extend into the headwaters of these drainages, but the present study mapped similar deposits interpreted as Pinedale till in the cirques of East Miner Creek, Shorty Creek, and Hidden Basin, which likely also correlate with the Crystal Creek till. Several of the low elevation deposits near the Gros Ventre River and Crystal Creek Campground that Lagas (1984) mapped as Red Hills till (Bull Lake age) are here mapped as Pinedale in age because their moraines have numerous closed depressions and boulders exposed at the surface (fig. 14)—similar to Pinedale moraines east of Crystal Creek (fig. 6). Furthermore, these moraines' position on the floor of a constricted reach of the Gros Ventre River valley suggests low preservation potential for any deposits predating the last glaciation, making a Bull Lake age unlikely. This interpretation is consistent with that of Pierce and others (2018), who considered the Miner Creek terminal moraines to be Pinedale in age based on their fresh morphology.

Farther east is another Pinedale moraine complex near the mouth of Fish Creek that was formed by a glacier that advanced north down the valley of the upper Gros Ventre River. Similar to those at Crystal Creek, these moraines are sharp and hummocky with numerous closed depressions, and they fan out to fill a wide reach of the Gros Ventre River valley. The modern river floodplain roughly bisects the moraine complex, and on the east side the moraines mantle a bedrock ridge that rises to the south, implying that the trunk glacier may have overtopped the valley walls south of the map area. Well-preserved Pinedale recessional moraines are found alongside the Gros Ventre River at the southern quadrangle boundary (Lagas, 1984). The Pinedale till mapped in this area corresponds to the Fish Creek (Pinedale) and Soda Mountain (Bull Lake) tills mapped by Lagas (1984). Similar to in the Crystal Creek region, the present study interprets some of the Bull Lake-age Soda Mountain till of Lagas (1984) to instead be Pinedale in age

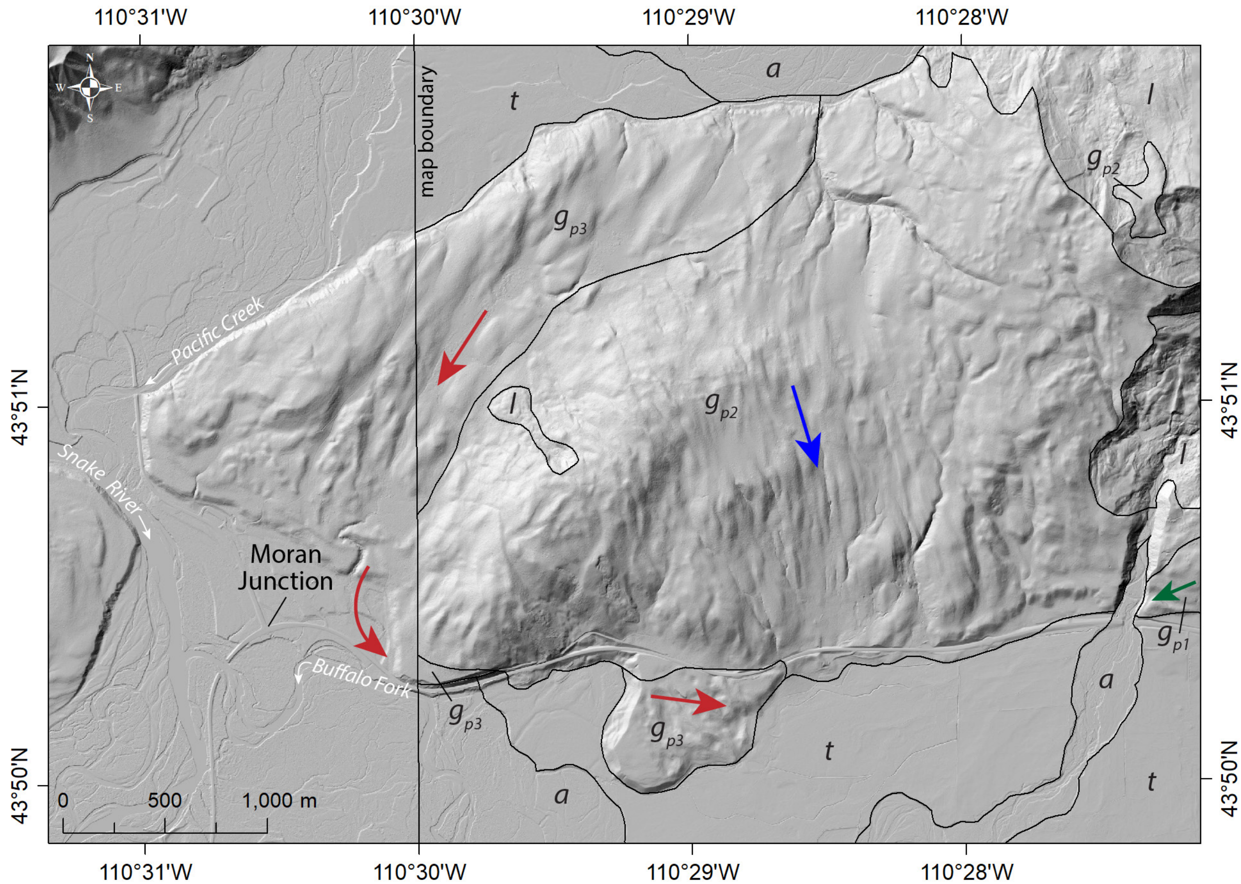

Figure 13. Lidar hillshade of till from the three Pinedale glacial advances near Moran Junction in the western map area. Ground moraines streamlined in different directions reflect the changing sources, termini, and volumes of ice through the three advances. Ice in Pinedale-1 time advanced down the Buffalo Fork valley and produced west-trending moraines (green arrow). Pinedale-1 moraines near Moran Junction were overprinted by ice from Pacific Creek during Pinedale-2 time, which formed south-trending ground moraines on the hill to the east (blue arrow). In Pinedale-3 time, a smaller glacier flowed down Pacific Creek and wrapped around the hill east of Moran Junction, eventually pushing one kilometer up the Buffalo Fork valley. This glacier left behind southwest-trending ground moraines along Pacific Creek and a plug of till in the lower Buffalo Fork valley (red arrows). Mapping and interpretation follow Pierce and others (2018). Units: g_{p1} = Pinedale-1 till; g_{p2} = Pinedale-2 till; g_{p3} = Pinedale-3 till; *l* = landslide; *a* = alluvium; *t* = terrace deposits.

based on fresh, hummocky surface texture and connected moraines crests. Lagas (1984) subdivided the Fish Creek till into two units, the younger of which composes the recessional moraines near the southern map boundary; this distinction was not made in the present mapping.

Alluvial Deposits

Alluvial deposits are found in the valleys and tributaries of the Gros Ventre River, Buffalo Fork, and Pacific Creek and consist of glacial outwash, fan deposits, terrace deposits, and active alluvium.

Glacial outwash

Glacial outwash deposits are most prevalent in the valleys of the Gros Ventre River, Pacific Creek, and Spread Creek. Outwash units are mapped according to the landform they compose—*to* for outwash terraces and *fo* for outwash fans—and their equivalent glacial episode—*p* for Pinedale and *bl* for Bull Lake. Pinedale outwash is undifferentiated because most deposits in the map area are disconnected from and cannot be correlated with the large outwash fans and terraces in Jackson Hole that Pierce and others (2018) used as the basis for the Pinedale-1, 2, and 3 subdivisions.

Figure 14. Photograph of glacial moraines on the floor of the Gros Ventre River valley near Crystal Creek Campground. These moraines are interpreted as Pinedale in age due to their hummocky topography, closed depressions (right), and boulders at the crests (left). View is down-valley to the west, with the Red Hills in the background.

Bull Lake outwash is uncommon in the map area due to overprinting by Pinedale glaciers as well as low preservation potential in steep terrain. Bull Lake outwash terraces (to_{bl}) were mapped only where a clear relationship in landscape position with Pinedale outwash terraces (to_p) could be established. Specifically, Bull Lake terrace treads are 10 or more meters higher than Pinedale terrace treads, and must occur in close enough spatial proximity to Pinedale terraces to be compared by hand level or rangefinder in the field. No terraces or fans outside of this range were assigned a Bull Lake age because landscape position relative to other outwash deposits is uncertain and there are no absolute age constraints in the study area.

Two Bull Lake outwash terraces are recognized in the map area, both of which are in the Gros Ventre River valley. One is a fill terrace of Fish Creek that is approximately 65 m above grade and is located east of the mouth of Bacon Creek. This outwash deposit was mapped as the Bull Lake-age Soda Mountain gravel by Lagas (1984). The other Bull Lake outwash deposit is along the Gros Ventre River south of the Red Hills and forms a composite fill-cut terrace with treads approximately 50 m and 40 m above the modern grade. This deposit was mapped by Lagas (1984) as the Bull Lake-age Red Hills gravel.

Lagas (1984) mapped other gravel deposits of hypothesized Bull Lake and pre-Bull Lake age in the Gros Ventre River valley. These deposits were not mapped for the present study because they were interpreted in the field to be till rather than outwash, have landscape positions that suggest a younger age, or are too small for the map scale. Notably, Lagas (1984) considered some gravel deposits in Breakneck and Cottonwood creeks to belong to the Bull Lake-age Soda Mountain drift based on projecting fan and terrace gradients downstream to Bull Lake terraces along the Gros Ventre River. The present study mapped these deposits as piedmont gravels (f_1d) of unassigned age because they are sourced from low elevation tributaries in the Mount Leidy highlands where no other glacial deposits were mapped and evidence for glacial activity during the Bull Lake and Pinedale is not documented. Consequently, these gravels are not designated as glacial outwash. Though likely not of glaciofluvial origin, it is still possible that these deposits are contemporaneous with the Bull Lake glaciation.

Pinedale outwash is more common than Bull Lake outwash in the map area. In the Gros Ventre River valley, Pinedale outwash terraces and fans are found distal to the major moraine complexes near the mouths of Crystal, East and West Miner, and Fish creeks. Outwash fans in these settings are confined by existing topography and are not spatially extensive, and their toes are commonly incised by modern drainages. Outwash terraces are more common and are mostly clustered along the Gros Ventre River, though some outliers in tributary drainages occupy a hypothesized ice-marginal position adjacent to lateral moraines. Pinedale terrace treads decrease in height above grade in the downstream direction, from approximately 40 m near the confluence of Fish and Bacon creeks, to 25 m near the Goosewing Guard Station, and to 10 m at the mouth of Crystal Creek. Bedrock straths are visible beneath many of the Pinedale terraces along the Gros Ventre River, and gravel thicknesses are typically 5–10 m. The Pinedale outwash deposits mapped in the Gros Ventre River valley correspond to both the Fish Creek gravel-1 and Crystal Creek gravel alloformations of Lagas (1984).

In the northern map area, Pinedale outwash deposits are mapped in Pacific, East Fork Pilgrim, and Lava creeks along with the North Buffalo, South Buffalo, and Soda forks. Because the entirety of this area was glaciated beneath the Buffalo Fork lobe of the GYGS in Pinedale-1 time (Pierce and others, 2018), these outwash deposits are interpreted to be no older than the Pinedale-1 deglaciation (post-20 ka). Pacific Creek hosts the most continuous suite of Pinedale terraces, which range in height above grade from 16 m at Gravel Creek to 24 m near the western map boundary. At the western map boundary immediately east of Two Ocean and Emma Matilda lakes is a hypothesized abandoned Pinedale outwash channel that wraps around the west side of a till-capped knob before rejoining the modern course of Pacific Creek.

Thick and extensive Pinedale gravel deposits form conspicuous high terraces in Skull Creek and the north and south forks of Spread Creek. The terraces in lower Skull Creek and North Fork Spread Creek were hypothesized by Pierce and others (2018) to have been deposited during deglaciation following the Pinedale-1 maximum, as they are located within (north of) the mapped southern extent of the Buffalo Fork lobe during Pinedale-1 time. This hypothesis is consistent with field observations from near the confluence of Skull and Spread creeks, where terrace deposits consist of well-sorted fluvial gravels that cap a basal strath eroded into unsorted till. There are at least five terrace levels in this area with treads at approximately 30 m, 50 m, 60 m, 80 m, and 100 m above the modern grade. This suggests that the long-term, post-Pinedale incision of Spread Creek has been punctuated by periods of deposition and lateral planation that were perhaps related to pulses in sediment supply.

The broad fill terraces in South Fork Spread Creek are anomalous in that they are upstream from the hypothesized Pinedale-1 limit of the Buffalo Fork lobe (Pierce and others, 2018) and there are no glacial deposits mapped in the headwaters of the catchment. There are two primary terrace levels in this drainage, a lower terrace that is 25–36 m above grade and a much more extensive upper terrace that is 43–59 m above the modern channel. Exposures of the upper terrace show the gravel to be around 10 m thick on top of bedrock (fig. 15). Pierce and others (2018) referred to these terrace gravels as "inwash deposits" that were deposited upstream from the southern margin of the Pinedale-1 Buffalo Fork lobe, which would have dammed the present-day mouth of South Fork Spread Creek. Though it is unclear if these gravels were sourced from small upstream glaciers whose deposits have since been removed or if they are not of

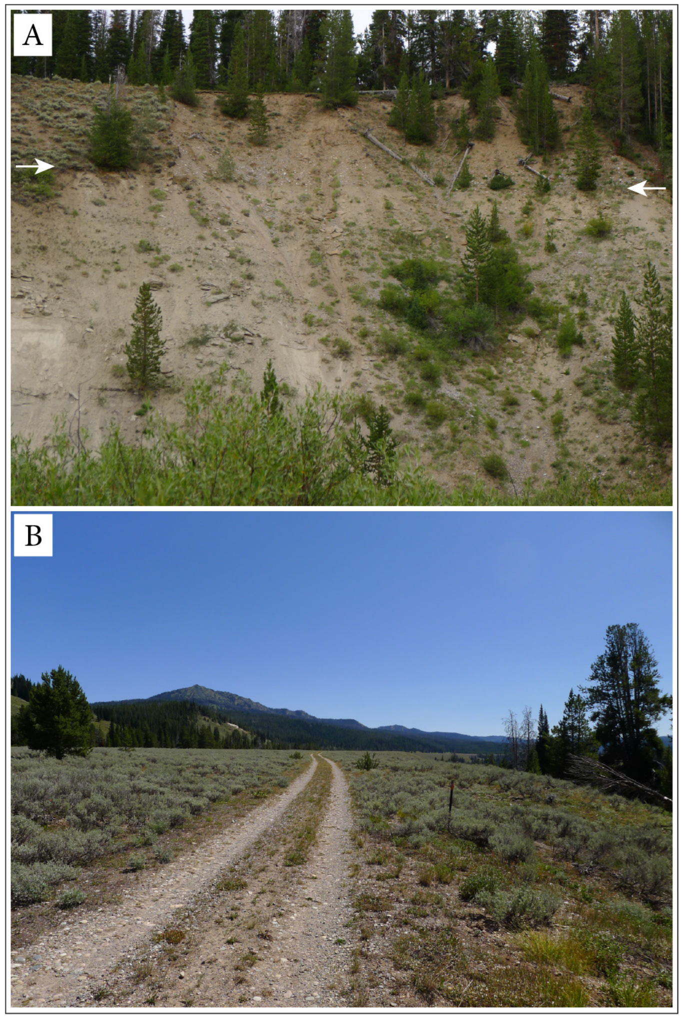

Figure 15. Photographs of terraces in South Fork Spread Creek. Large volumes of gravel are preserved in this drainage and form broad fill terraces immediately upstream of the hypothesized Pinedale-1 margin of the Buffalo Fork lobe of the GYGS. A) Photograph of gravel 10 m thick atop bedrock of the Cretaceous Sohare Formation; white arrows mark base of gravel deposit. B) Photograph of an expansive terrace tread; view is southeast toward Grouse Mountain.

glacial origin, they are mapped as to_p because of a proposed genetic and temporal link with the Buffalo Fork lobe of the GYGS less than 5 km downstream.

Together with piedmont gravel deposits (discussed below) preserved throughout the basin, the Pinedale terrace gravels in South Fork Spread Creek constitute a substantial volume of stored sediment that is unique for the erosional landscape of the Mount Leidy highlands. There are several factors which, in combination, may explain the anomalous gravel deposits in this drainage. First, the damming effect of the Buffalo Fork lobe during the Pinedale-1 glaciation would have raised the local base level at the basin outlet, requiring South Fork Spread Creek to deposit sediment in the valley bottom to remain graded with the basin outlet. No lacustrine deposits were observed in South Fork Spread Creek, suggesting that gravel deposition was able to keep pace with base level rise from the impounding ice. Second, the South Fork Spread Creek catchment is underlain by a greater percentage of Pinyon Conglomerate than most other drainages in the Mount Leidy highlands (Love, 1981a, 1982b). These relatively weak rocks are concentrated in the headwaters of the basin in relatively high and steep terrain, which makes them uniquely primed to produce large volumes of weathered sediment. Third, weathering of the Pinyon Conglomerate produces abundant free quartzite cobbles that do not easily break down and instead become incorporated into other Quaternary deposits. Pierce and others (2018) used similar reasoning to partially explain the great depth of Pinedale outwash deposits in Jackson Hole.

Alluvial fan deposits

In addition to fans composed of outwash correlated to glacial episodes, several other types of alluvial fan deposits are present in the map area. In the tributaries of the Gros Ventre River and Spread Creek are gravel deposits that form dissected piedmont fans. These piedmont gravels (unit f_1d) have built a wide spectrum of fan-shaped landforms with several common characteristics. All mapped piedmont fans have slopes that are perpendicular to axial valleys, as these fans originate in small tributaries or are perched along valley walls. The concave slopes of piedmont fans project to well above the modern stream grade, and all piedmont fans are incised at the toe. Clasts are primarily cobbles with lesser boulders and pebbles, and clast composition follows the local lithology. Existing within this framework are variations in landform size, steepness, height above the modern channel, and implied age. For instance, piedmont fans are found near the mouths of Coal Mine Draw and Breakneck Creek in the Gros Ventre River valley that are spatially extensive, have low slopes, and are incised 6–20 m at their toes. Other piedmont fans occupy positions much higher in the drainage network, such as those in upper Cottonwood Creek that range from approximately 50 to 100 m above grade and exist only as isolated gravel deposits perched on steep valley walls. These small f_1d deposits that are found in higher landscape positions are typically 2–5 m thick on top of a basal bedrock strath. In some localized reaches, such as upper South Fork Spread Creek, up to three piedmont surfaces were recognized but were not differentiated on the map.

The age and origin of the piedmont fan gravels is unclear, though it's probable there have been multiple depositional episodes given the variety of landscape positions that these deposits occupy. In Breakneck and Cottonwood creeks, where Pinyon Conglomerate bedrock is exposed throughout the basin, f_1d deposits are primarily composed of quartzite cobbles, which suggests that the prevalence and size of these piedmont fans may be related to sediment production from the weathering of poorly indurated lithologies upstream. These same piedmont fans project downstream to mainstem terraces of the Gros Ventre River, which Lagas (1984) used to infer Pinedale and Bull Lake ages for gravels composing two surfaces in Breakneck Flat. Other piedmont fans in the Gros Ventre River valley and Spread Creek project well above Pinedale outwash terraces, implying older deposition. More detailed mapping and geochronology are needed to determine the ages, genesis, and possible relation to glacial outwash deposits of the diverse suite of piedmont gravels in the map area.

Alluvial fans that are only shallowly incised were mapped as unit *f* and are interpreted to have been active since the Pinedale glaciation. These fans exhibit a radial planform shape and typically have one or only a few active, incised channels, with the remaining fan surface being inactive. Unit *fa* was used for alluvial fans that exhibit evidence for widespread deposition in modern times. This evidence includes multiple wide and braided channels, sparse vegetation, recent channel avulsions, and no incision of the toe. Both of these fan units are present throughout the map area, with concentrations in the broad valleys of the Buffalo Fork, Pacific Creek, and Gros Ventre River. The largest alluvial fan in the map area is the Spread Creek fan, which extends off the western boundary, and an exemplary *fa* deposit occurs at the confluence of Whetstone and Pacific creeks (fig. 16).

Mixed alluvial fan and slopewash deposits (unit *fs*) form smooth, broad aprons in valley openings and at the foot of bedrock slopes. These deposits are commonly formed by slopewash that fills the seams between neighboring alluvial fans that emanate from tributary drainages. This map unit is present throughout the study area, with several large and accessible examples crossed by the Gros Ventre River Road south of the Red Hills.

Figure 16. Photograph of active alluvial fan at the mouth of Whetstone Creek. Note recently abandoned channel (foreground) and new channel inundating trees (middle ground). New channel here is perched at a higher elevation than abandoned channel, attesting to the lateral instability of Whetstone Creek across the alluvial fan.

Terrace deposits

Terrace gravel deposits that post-date or are not correlated with the Pinedale glaciation were mapped as *t* or *ta*. Low terraces (unit *t*) are found in the three major drainage systems in the map area and are most widespread in Pacific Creek, where they are inset below Pinedale outwash terraces. In lower Pacific Creek two terrace levels are recognized below the 24-m Pinedale terrace, one at 9–12 m and another at 5–6 m above grade. Unit *ta* was mapped in narrow tributary valleys where terraces and the active alluvial channel could not be differentiated at the map scale. The terraces in these valleys are typically less than 3 m above the modern channel. Tributary valleys where *ta* was mapped include Slate, Cottonwood, South Fork Fish, and Cub creeks.

Alluvium

Active alluvium (unit *a*) was mapped along the river channels and floodplains of the Buffalo Fork, Pacific Creek, Spread Creek, Blackrock Creek, Gros Ventre River, and their tributaries. Most valleys in the map area are narrow and incised, affording only a thin channel of active alluvium between bedrock walls. The largest alluvial valley on the map is the lower Buffalo Fork, which is nearly 3 km wide in places. In this reach the Buffalo Fork has a sinuous, low-gradient channel and has left behind numerous abandoned meanders across its broad floodplain.

QUATERNARY FAULTS

Four faults that display surface offset of Quaternary-age units were mapped for this study. Faults were mapped as certain where clear and linear fault scarps are present, approximate where there are discontinuous fault scarps or scarps of potential non-tectonic origin, concealed where younger surficial deposits obscure the fault between areas of well-expressed fault scarps, and queried at the ends of some segments where the continuation of fault scarps is unclear in the field. The Uhl Hill and Davis Hill faults are defined here as two newly recognized Quaternary-active faults in the western map area. The Baldy Mountain and Togwotee Lodge faults were described and compiled at 1:250,000 scale in the U.S. Geological Survey Quaternary Fault and Fold Database by Pierce (1999a, b). Scarp profiling methods, figures, and a summary data table are presented in the appendix.

Uhl Hill Fault

The Uhl Hill fault is the proposed name for a 4.5-km-long, north- to northeast-trending, east-dipping normal fault in easternmost Grand Teton National Park that offsets Pinedale glacial till and Quaternary alluvial fan deposits (fig. A-1). Offset Cretaceous bedrock units are visible along this fault in an exposure on the south side of Uhl Hill, where northeast-dipping beds of the Meeteetse Formation are down dropped to the east against northeast dipping beds of the older Mesaverde and Sohare formations (fig. 17). Love (1973) and Love and others (1992) mapped this 300-m-long bedrock fault and extended concealed segments a short distance north and south in the surrounding Quaternary deposits. Field relations in this exposure suggest that stratigraphic offset is at least 240 m, which is the minimum thickness of the Mesaverde Formation documented in the neighboring Moran quadrangle (Love, 2003).

Aligned with the underlying bedrock fault and extending northeast across the top of Uhl Hill is a linear fault scarp in Pinedale-1 till (unit g_{p1}) that was not mapped by Love (1973) or Love and others (1992). Farther south, an aligned fault scarp similarly offsets Pinedale-1 and Pinedale-2 (unit g_{p2}) till on "Spread Creek Hill" between Elk Ranch Reservoir and Spread Creek (fig. 18). This scarp extends south onto the Spread Creek alluvial fan (unit *f*), where it decreases in height and becomes undetectable approximately 500 m north of the active channel of Spread Creek. Between Uhl Hill and Spread Creek Hill no fault scarp is visible across alluvial fan deposits. Mapping of the Uhl Hill fault was aided by interpretation of available lidar data (U.S. Geological Survey, 2015).

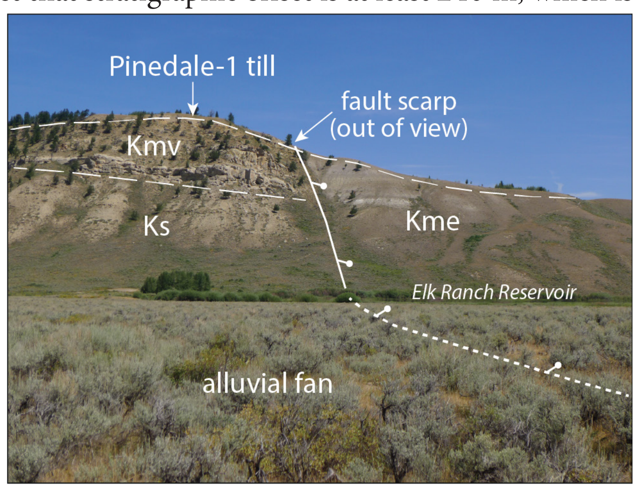

Figure 17. Photograph of offset bedrock along Uhl Hill fault (solid white line with ball-and-bar) with overlying mantle of Pinedale-1 till. View is to the northeast with the summit of Uhl Hill on the skyline. Quaternary activity of this fault is documented by offset Pinedale-1 till on top of Uhl Hill, beyond the view of the photograph. No fault scarp is present across the alluvial fan south of Uhl Hill (dotted white line with ball-and-bar marks concealed fault trace). Abbreviations: Ks = Sohare Formation, Kmv = Mesaverde Formation, Kme = Meeteetse Formation. Thin dashed lines mark unit contacts.

Eleven fault scarp profiles were measured along the Uhl Hill fault (table A-1; figs. A-2, A-3, A-4, and A-5). Two were surveyed in the field with a laser rangefinder, and the remainder were extracted from the bare-earth lidar digital elevation model. Vertical surface offset (VSO) values from these profiles are reported as the mean plus or minus one sample stan-

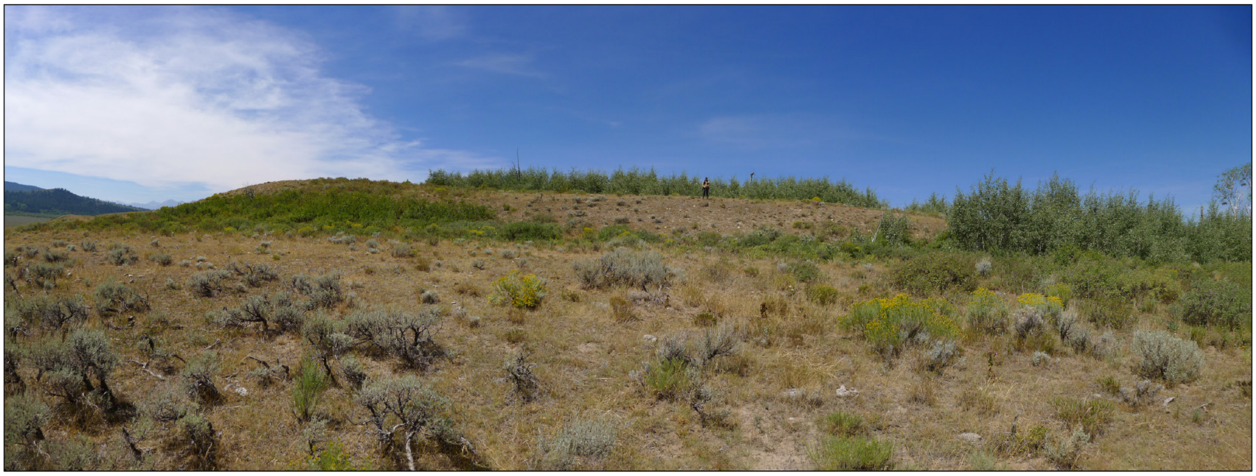

Figure 18. Photograph of scarp of Uhl Hill fault in Pinedale-1 till on Spread Creek Hill. View is to the west, geologist at top of scarp for scale. Pinedale-2 end moraine is obscured behind trees in the background to the right. Location of photographer shown in figure 19.

dard deviation, calculated over five iterations. VSO values along the Uhl Hill fault range from 0.9 ± 0.3 m on Pinedale-2 till to 3.7 ± 0.2 m on Pinedale-1 till (fig. 19). The average VSO from six profiles measured across scarps in Pinedale-1 till is 2.5 m, whereas the average VSO from three profiles across scarps in Pinedale-2 till is 1.0 m.

The observation of faulted Pinedale-2 till indicates that the Uhl Hill fault has been active in the past 15–16 kyr, as Pinedale-2 terminal moraines have been dated to 15.5 ± 0.5 ka in nearby Jackson Hole (Licciardi and Pierce, 2018). The fact that average VSO across Pinedale-1 till is more than two times greater than VSO across Pinedale-2 till also suggests that the Uhl Hill fault experienced one surface rupturing earthquake sometime after 15–16 ka and one or two surface rupturing events between roughly 20 and 15–16 ka, assuming modest per-event displacements of 0.8–1.5 m. For comparison, paleoseismic studies along the Teton fault 20 km to the west indicate full-length surface rupturing earthquakes occurred at approximately 5 and 10 ka and a partial rupture occurred at roughly 8–9 ka (DuRoss and others, 2021). Finally, the average VSO in Pinedale-2 till is identical to the average VSO from profiles measured across the Spread Creek alluvial fan north of its attenuation point. Consequently, this part of the Spread Creek alluvial fan is likely composed of deposits older than those of the fan between Elk Ranch Reservoir and Spread Creek Hill, where no fault scarps were observed. Because these older fan deposits were deformed by the most recent surface rupturing earthquake along the Uhl Hill fault—the same earthquake recorded in Pinedale-2 deposits—it is possible that they date to deglaciation from the Pinedale-2 or -3 stages.

Davis Hill Fault

The Davis Hill fault is a newly recognized normal fault in the lower Buffalo Fork valley that is expressed by a 1.5-km-long, north–northeast-trending, east-facing scarp in Pinedale-1 glacial till (fig. A-6). This scarp is aligned to subparallel with the scarp of the Uhl Hill fault, which is 4.3 km to the southwest across the alluvial valley of the Buffalo Fork, suggesting that these two sets of scarps may be related to the same structure. Additional subsurface and paleoseismic data are needed to test this hypothesis, however, and for descriptive purposes the Davis Hill fault is here proposed as a unique name.

The scarp of the Davis Hill fault is confined within Pinedale-1 till and crosses a hillside that rises north from the Buffalo Fork valley to a sharp divide with Lava Creek. At least three moraine ridges are offset by the scarp (fig. 20). The scarp attenuates at its southern end shortly before reaching the alluvial valley of the Buffalo Fork. Near the north end the scarp crosses the divide into the canyon of Lava Creek, where for 250 m an uphill-facing scarp is visible across a west-sloping hillside. Farther northeast the scarp merges with the ridge crest separating the steep canyon of Lava Creek (northwest) from the gradual till-mantled slope that descends to the Buffalo Fork (southeast). No scarps were identified beyond this point, though it is possible that the fault continues to the northeast and that scarps are not preserved on the sharp ridge crest or in a young landslide farther northeast. Because of this uncer-

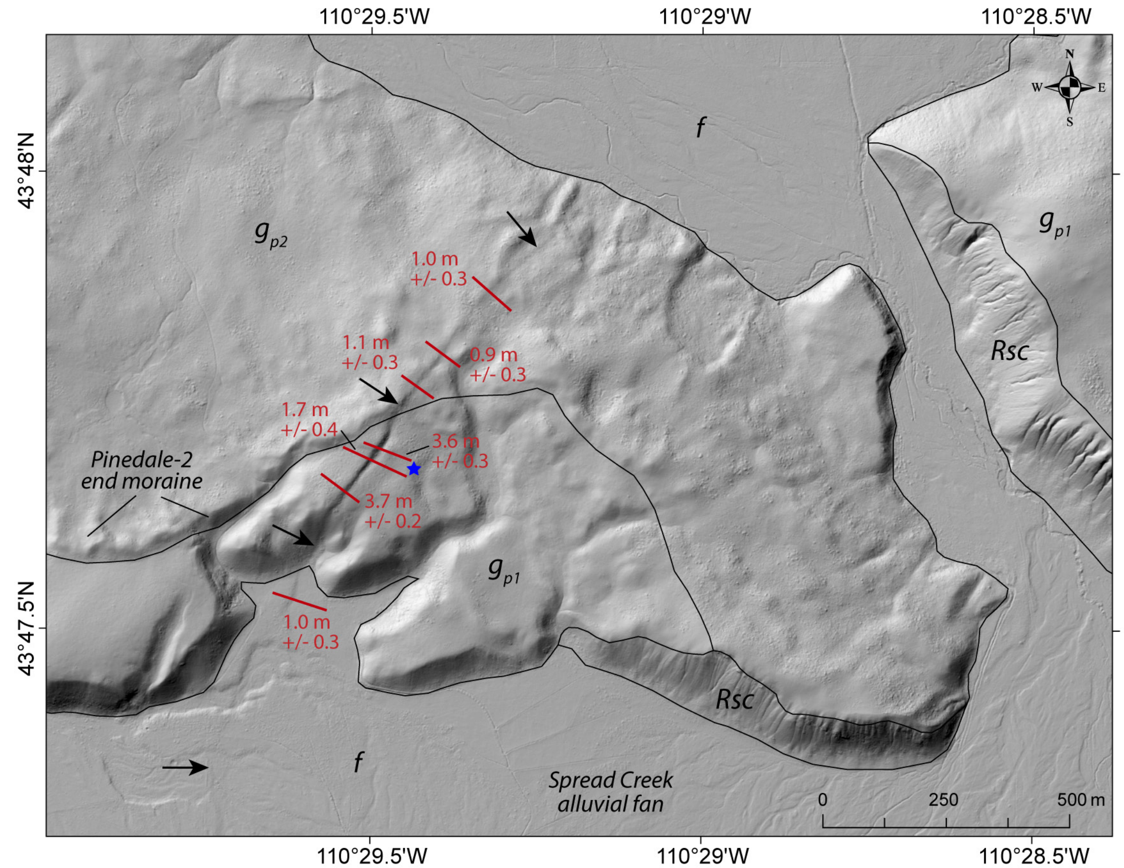

Figure 19. Lidar hillshade of southern part of Uhl Hill fault across Spread Creek Hill. Fault scarp marked by black arrows, scarp profiles with calculated vertical surface offset values shown in red, blue star shows location of photographer in figure 18. Fault scarp is higher in the older Pinedale-1 till than in the younger Pinedale-2 till. Units: g_{p1} = Pinedale-1 till; g_{p2} = Pinedale-2 till; *f* = alluvial fan deposits; *Rsc* = bedrock, slopewash, and colluvium.

tainty, the northern extent of the Davis Hill fault was mapped as approximate along the ridge crest and queried where it enters the landslide.

Two field-surveyed profiles and four lidar-extracted profiles were measured across the scarp of the Davis Hill fault (table A-1; figs. A-7, A-8, and A-9). VSO values range from 1.9 ± 1.1 m near the north end of the scarp to 3.4 ± 0.5 m near the midpoint of the scarp (fig. 21). The average VSO of the six profiles is 2.7 m, which is similar to the 2.5 m average VSO of the profiles measured in Pinedale-1 till along the scarp of the Uhl Hill fault. This suggests that the Davis Hill fault scarp likely records the same number of surface rupturing earthquakes as do the scarps that offset Pinedale-1 till along the Uhl Hill fault.

Baldy Mountain Fault

The Baldy Mountain fault is a 2.2-km-long, north-trending, east-dipping normal fault near the summit of Baldy Mountain that offsets Pinedale-1 glacial till for its entire mapped length (fig. A-10). This fault was compiled in the U.S. Geological Survey Quaternary Fault and Fold Database (QFFD) by Pierce (1999b) at 1:250,000 scale based on unpublished mapping and field notes from 1984. The present study field verified the existence of a scarp along the length of this fault and surveyed two scarp profiles with a laser rangefinder.

The fault mapping from this study largely matches the mapping of Pierce (1999b). The southern end of the Baldy Mountain fault is well constrained by a scarp that terminates on the north side of a shallow valley and does not continue south on the opposite hillside. The two sag ponds described by Pierce (1999b) along the southern section of the fault were not found in the present study. There is more uncertainty regarding the northern extent of the fault, where the scarp gradually decreases in height and becomes aligned with a linear gully that may not be tectonically related. The fault is mapped as certain to the northernmost clear uphill-facing scarp on a west-sloping Pinedale-1 moraine, which is only 110 m north of the terminus mapped by Pierce (1999b). North from this point to the linear gully are multiple sub-meter-high, subparallel topographic breaks and swales of possible tectonic origin, along which the fault is mapped as approximately located. The northern tip of the fault is mapped as queried because it is uncertain if it extends farther north along the gully. It is difficult here to distinguish between subtle fault scarps and hummocky moraine topography, and mapping of this part of the fault should be revisited once lidar data are available.

A scarp profile surveyed at the crest of Baldy Mountain near the midpoint of the fault has a VSO of 4.3 ± 0.3 m (fig. 22), which is close to the approximately 5 m of surface offset measured in this same location in 1984 (Pierce, 1999b). A second scarp profile was surveyed 300 m north on the treed flank of Baldy Mountain and yields a VSO of 2.0 ± 0.2 m (fig. A-11). With the exception of where it follows gullies that artificially boost its apparent height, the scarp continues to decrease in height north from this second profile location, suggesting that the fault is attenuating in this direction and may not extend much farther north than currently mapped.

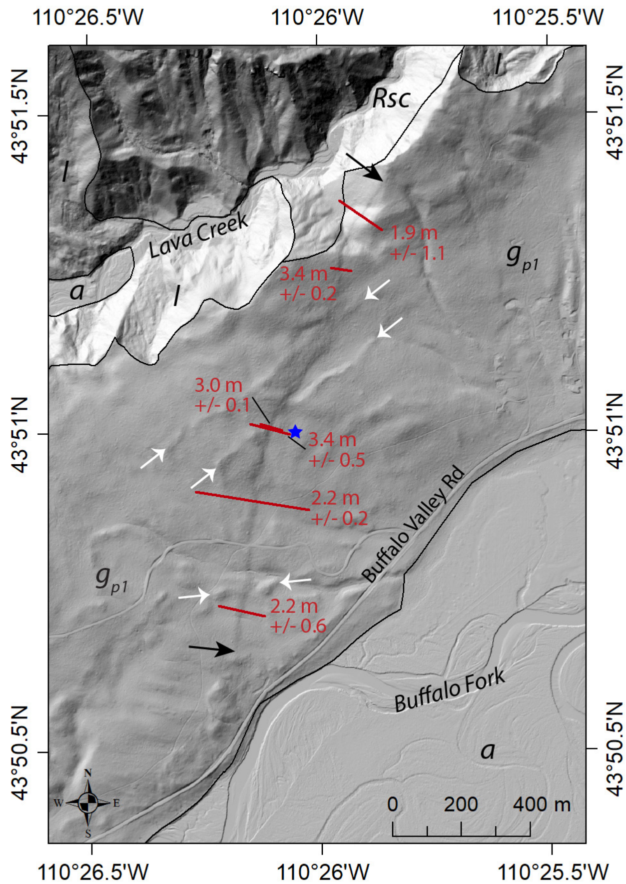

Figure 20. Lidar hillshade of Davis Hill fault. Northern and southern extent of visible scarp marked by black arrows, scarp profiles with calculated vertical surface offset values shown in red, small white arrows denote moraine crests offset by the scarp, blue star shows location of photographer in figure 21. Units: g_{p1} = Pinedale-1 till; *l* = landslide; *a* = alluvium; *Rsc* = bedrock, slopewash, and colluvium.

Togwotee Lodge Faults

A series of north–northwest-trending, east-facing fault scarps up to 3.5 km long marks the Togwotee Lodge faults. These fault scarps, which cross U.S. Highway 26/287 approximately 15 km west of Togwotee Pass, offset Pinedale-1 till, Bull Lake till, slopewash and colluvium, and some landslide deposits (fig. A-12). The faults are mapped as approximately located in areas where scarps are discontinuous or difficult to locate in the field owing to steep, heavily treed terrain and complex cross-cutting relationships in landslide deposits. The Togwotee Lodge faults were first documented in unpublished mapping by Love and Weitz (1982), were briefly described by Love and Love (1983), and were compiled in the QFFD by Pierce (1999a) at 1:250,000 scale based on unpublished mapping and field notes from 1989 and 1991. Pierce (1999a) noted that the lateral extent of the Togwotee Lodge faults is poorly constrained due to limited study, rugged terrain, and vegetative cover; the present study field mapped and surveyed profiles across these fault scarps to build upon the previous mapping efforts.

Field mapping indicates that the Togwotee Lodge faults comprise an east strand, marked by three parallel to en echelon scarps, and a west strand expressed by a single scarp. The east strand is most recognizable where it crosses U.S. Highway 26/287 and forms an east-facing scarp in Pinedale-1 till with a sag pond at the base, which was noted by Love and Love (1983). Pierce (1999a) reported surface offsets of 8.0–12.6 m based on four surveyed scarp profiles in this vicinity. The present study surveyed one profile south of the highway to avoid the effects of deposition and erosion on the east block (hanging wall) from the sag pond and its outlet drainage, which are north of the highway. This profile has a VSO of 6.9 ± 0.7 m, which is lower than the values reported by Pierce (1999a; table A-1, fig. A-13).

Figure 21. Photograph of scarp of the Davis Hill fault (highlighted in red brackets) in Pinedale-1 till. Photograph was taken near the midpoint of the scarp, location shown in figure 20. View is to the west, geologist at top of scarp for scale.

The east strand continues north from U.S. Highway 26/287 where it forms a sharp, fresh-looking scarp in Pinedale-1 till (fig. 23). The fault makes a 50 m right step 0.5 km north of the highway, where parallel scarps are present for a length of approximately 200 m before rapidly attenuating in height near their tips. North of the step-over point, a scarp profile yields a VSO of 9.8 ± 0.8 m (fig. A-14). From the profile location north, the scarp enters a north–northwest trending drainage and is still traceable as a discrete slope break for another 0.5 km. At this point the fault scarp intersects a slump area near the head of a large landslide complex, where it becomes difficult to distinguish tectonic from mass wasting scarps. It is uncertain if a fault scarp continues toward the canyon of the Buffalo Fork in the Pinedale-1 till north of the landslide, as this area was not visited in the field. Love and Weitz (1982) mapped the fault as concealed beneath the landslide deposit but did not extend it north, and Pierce (1999a) mapped the fault as inferred through the landslide deposit and a short distance into the Pinedale-1 till to the north. Due to the difficulty in tracing the scarp through the slump area, and the uncertainty regarding its continuation north, the east strand of the Togwotee Lodge faults is mapped as approximate through the landslide deposit and queried at its northern extent. Of note is that the 9.8 m VSO calculated from the profile near the step-over point is the largest surface offset measured across the five scarp profiles surveyed along the Togwotee Lodge faults. This profile location is less than one km from the queried northern terminus of the east strand fault as currently mapped, which suggests the possibility that the fault continues farther north. Finding a fault scarp north of the queried northern terminus would be challenging in the field due to the steep and heavily vegetated terrain, but this mapping should be revisited once lidar data are available.

South of U.S. Highway 26/287 the east strand of the Togwotee Lodge faults crosses Blackrock Creek and forms a well-developed scarp in Pinedale-1 till near Flagstaff Road (Forest Road 30100). South from this point the scarp climbs a north-facing hillside and enters a large landslide complex. The fault scarp is traceable through the land-

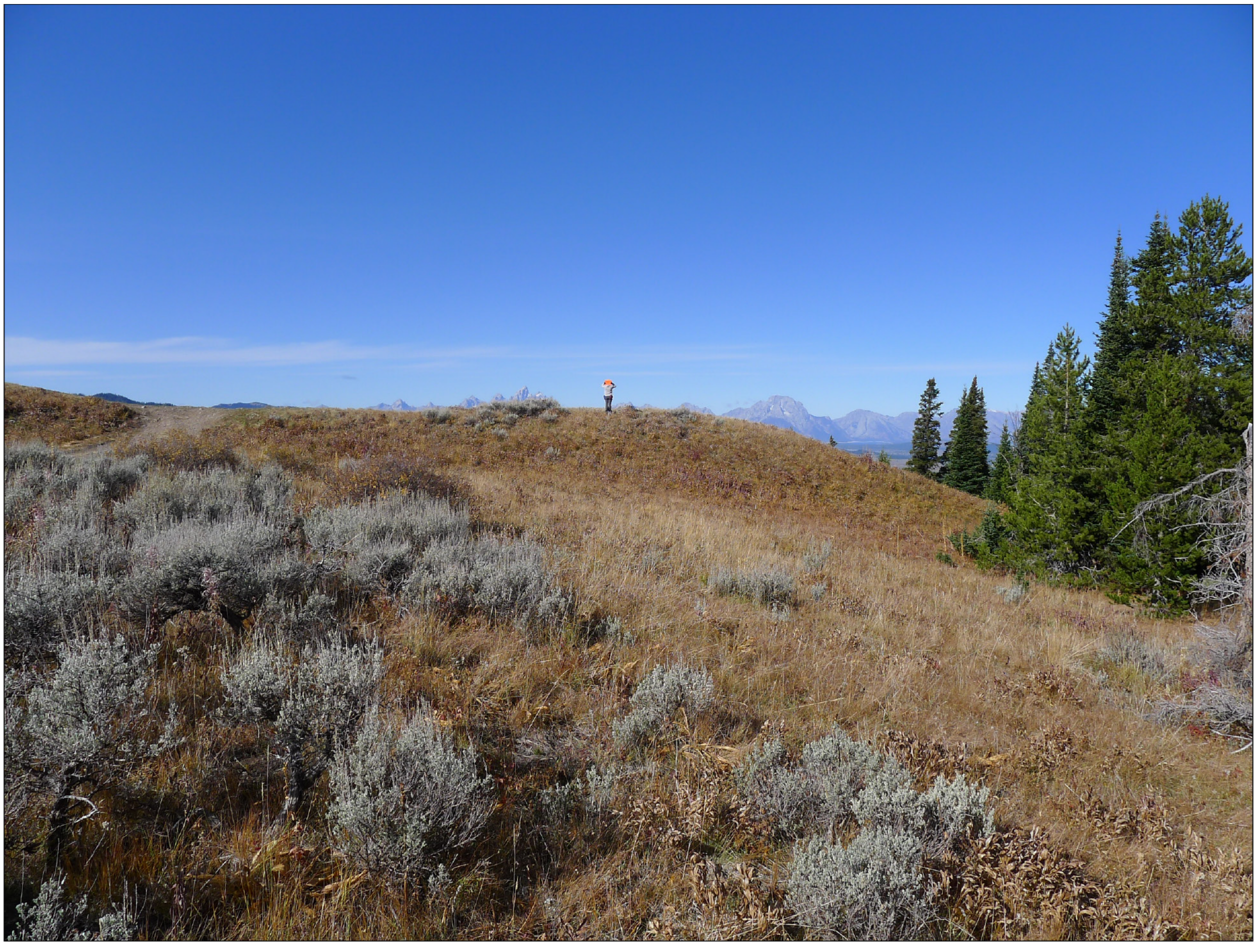

Figure 22. Photograph of scarp of the Baldy Mountain fault in Pinedale-1 till near the summit of Baldy Mountain. A scarp profile surveyed here yielded a vertical surface offset of 4.3 ± 0.3 m. View is to the west, geologist at top of scarp for scale.

slide complex for approximately 250 m before it becomes indistinguishable from multiple slump headscarps. From here to the ridge crest 1.4 km south–southeast, the east strand of the Togwotee Lodge faults is mapped as approximately located through landslide deposits, till, bedrock, and hillslope deposits. This section of the fault was mapped as approximate rather than concealed because 1) it crosses older surficial units like bedrock and Pinedale-1 till; 2) a scarp is present at the north end of the landslide complex, indicating that the scarp post-dates at least part of this composite landslide; 3) scarps are present once again on the ridge crest to the south of this area; and 4) the steep terrain on the north-facing hillside has poor scarp preservation potential.

Figure 23. Photograph of scarp of the east strand of the Togwotee Lodge faults in Pinedale-1 till north of U.S. Highway 26/287. Note the sharp surface morphology of the scarp. View is to the west, geologist at base of scarp for scale.

At the ridge crest 2.2 km south of U.S. Highway 26/287 the east-facing scarp reappears in slopewash and colluvial deposits derived from recessive Paleogene bedrock. The scarp here was surveyed to have a VSO of 3.3 ± 0.5 m (fig. A-13). Pierce (1999a) designated this area as "Fault C" and described two parallel east-facing scarps with 8.5 and 2.2 m of offset, along with an antithetic fault scarp 100 m east with a surface offset of approximately 3 m. Pierce (1999a) attributed the existence of a small saddle on the ridge crest here to the presence of the antithetic and synthetic faults, which would bound a 100-m-wide graben that includes a small pond. The field mapping from the present study is different, however, as the antithetic fault of Pierce (1999a) is interpreted to be a bedrock contact between more resistant volcanic breccia (unit Tvc of Love and Weitz [1982]) to the east and friable quartzite-bearing conglomerate to the west, and there was no clear slope break observed that would indicate a Quaternary fault scarp. The main east-facing fault at the small saddle is mapped as approximately located to the south and queried at its southern extent, as the scarp becomes discontinuous and is lost in steep southwest-facing terrain that was not visited in the field. Neither Love and Weitz (1982) nor Pierce (1999a) mapped the east strand of the Togwotee Lodge faults south from this ridge crest.

The second east-facing scarp of "Fault C" described by Pierce (1999a) was verified to be approximately 100 m west of the first east-facing scarp that is near the ridgetop saddle. This second scarp similarly offsets slopewash and colluvium (fig. 24), and it is paired with a less-than-one-m-high antithetic fault scarp that bounds a 20-m-wide flat-bottomed graben on the otherwise steep ridge crest. Though this scarp has an impressive appearance in the field, its net VSO is relatively modest at 3.7 ± 0.9 m due to the presence of the graben and the steep far-field slopes to the east and west (fig. A-14). This fault scarp is traceable for less than 0.5 km and is confined to the immediate vicinity of the ridge crest. The scarp attenuates rapidly to the south of the ridge crest, and to the north it merges with a northeast-facing hillside and could not be traced in the field—the north extent is thus mapped as queried. A final scarp pair was observed at the ridge crest 50 m west of the second east-facing fault scarp. However, this scarp pair is only 70 m long and is parallel to a northwest deflection of the ridge crest; therefore it is interpreted as a sackung with a sharp uphill-facing scarp rather than a true fault scarp.

The west strand of the Togwotee Lodge faults consists of a single north–northwest-trending, east-facing scarp that was traced in the field for 1.3 km. The south end of this strand crosses the westward continuation of the same ridge where scarps from the east strand were observed. At this ridge crest, the west strand is expressed by a scarp that offsets Bull Lake till just above the Pinedale-1 trimline (Pierce and others, 2018). The scarp here appears substantial in height but does not have as fresh of morphology as some of the scarps along the east strand. Pierce (1999a) reported a surface offset measurement of approximately 21 m for the scarp in the Bull Lake till. The present study was unable to repeat this measurement due to dense forest regrowth in a former logging area that prevented line-of-sight surveying. The west strand of the Togwotee Lodge faults is mapped as approximately located south of the Bull Lake till at the ridge crest, and its southern extent is queried. The fault scarp is not easily traceable south of the ridge crest where it merges with a west-facing bedrock slope in the Grizzly Creek basin, and this area was not explored in the field. Love and Weitz (1982) mapped an east-dipping normal fault well south of this ridge, were it is symbolized as a solid line and shown as displacing glacial till (mapped in the present study as g_{bl}) near the headwaters of Grizzly

Figure 24. Photograph of fault scarp along a ridge near the southern mapped extent of the east strand of the Togwotee Lodge faults. The scarp here offsets slopewash and colluvium and has a vertical surface offset of 3.7 ± 0.9 m. Photograph is taken from a graben between the master scarp and a small west-facing antithetic scarp (out of view). View is to the west, geologist at base of scarp for scale.

Creek. This mapped fault continues for approximately 5 km south from the ridge crest until it merges with and is symbolized as reactivating an unnamed thrust fault on the divide between Grizzly and Bull creeks (Love and Weitz, 1982). However, there is high uncertainty in this area due to the mapping of Love and Weitz (1982) being preliminary, and due to an annotation near the fault of "Needs field check" on the unpublished map. The southern extent of the west strand of the Togwotee Lodge faults is another area that will benefit from refined mapping once lidar data are available.

North of the Bull Lake till-capped ridge crest, the west strand scarp descends a steep and heavily treed north-facing hillside toward Blackrock Creek. The scarp is coincident with, and likely controls the geometry of, a linear gully as it cuts through Pinedale-1 till on the steep hillside below the Pinedale trimline. Near Flagstaff Road, the west strand crosses a small slump that obscures the fault scarp. Due to scale limitations, however, the west strand fault is mapped as certain through the landslide unit on the 1:100,000-scale map plate. On the north side of Flagstaff Road the fault scarp reappears on a west-sloping Pinedale-1 ground moraine, where it was measured to have a VSO of 1.5 ± 0.4 m (fig. A-14). This is much smaller than the approximately 6 m of surface offset reported by Pierce (1999a) in a similar location. On the south canyon wall of Blackrock Creek the west strand fault is mapped as approximately located where it again crosses a landslide deposit and the low scarp becomes indistinguishable from a north-draining gully. The northern extent of the west strand is mapped as queried, as no scarps were observed in the Pinedale-1 till north of Blackrock Creek, but the existence of scarps cannot be ruled out due to the short time the field team was able to spend in this area. Both Love and Weitz (1982) and Pierce (1999a), however, map the west strand of the Togwotee Lodge faults as terminating at Blackrock Creek.

The Togwotee Lodge faults are a good candidate for future mapping and paleoseismic studies. The sharp morphology of the east strand scarps (fig. 23) suggests relatively recent displacement, and the nearly 10 m of vertical surface offset in Pinedale-1 till measured at the northernmost profile implies that this fault system has experienced three to five surface rupturing earthquakes in the last 20 kyr, assuming average per-event displacement of 2–3 m for Quaternary faults in the Basin and Range Province (e.g. Crone and others, 1987; McCalpin, 1993). Despite the apparent Pleistocene, and likely Holocene, activity, the geometry and extent of the Togwotee Lodge faults remains uncertain, especially at the north end of the east strand and the south end of the west strand. Forest road access near the well-developed east strand scarps north of U.S. Highway 26/287 makes this location logistically feasible for a paleoseismic trench, and the future release of lidar data will allow for refined fault mapping in the areas of greatest uncertainty.

Lineaments

Several lineaments visible in surficial deposits were mapped for this study. These features are shorter and/or have smaller surface offsets than the mapped Quaternary faults, but they may still be of tectonic origin. Two parallel, 0.7-km-long, northwest-trending lineaments that form northeast-facing slope breaks in mixed fan and slopewash deposits (unit *fs*) are present on the north side of the Gros Ventre River between the Red Hills and Grizzly Lake (fig. 25). These lineaments were hypothesized to be Holocene fault traces by Love and Love (1988), and they were mapped as northeast-dipping normal faults that parallel the axis of the Red Hills anticline by Love and others (1992). Though they are not included in the QFFD, the linear nature of these features, their uphill-facing scarps, and their alignment with regional structures suggests a tectonic origin.

Three additional suites of lineaments were identified from lidar slope maps and hillshades. A 0.3-km-long, north–northeast-trending lineament that forms an east-facing slope break was mapped in residuum and andesite bedrock atop the western plateau of Lava Mountain (fig. 26). This lineament disappears in bedrock south of the plateau and is obscured by a block slide and rock glacier to the north. Two 0.4-km-long, east–northeast-trending lineaments form parallel uphill-facing scarps in bedrock and glacial till between the Breccia Cliffs and Cub Creek. Because of their slope-parallel orientation, it is possible that these features are sackungs rather than fault scarps. Finally, two lineaments that are 0.3 and 0.7 km long and are north– and east–northeast-trending, respectively, form uphill-facing scarps in a large landslide complex near Angle Lakes in the upper South Buffalo Fork valley. These features are

Figure 25. Photograph of lineaments in alluvial fan and slopewash deposits between the Red Hills (left) and Gros Ventre River (right). The two lineaments (white arrows) form northeast-facing slope breaks visible as darker vegetation in the irrigated field. View is up-valley to the southeast.

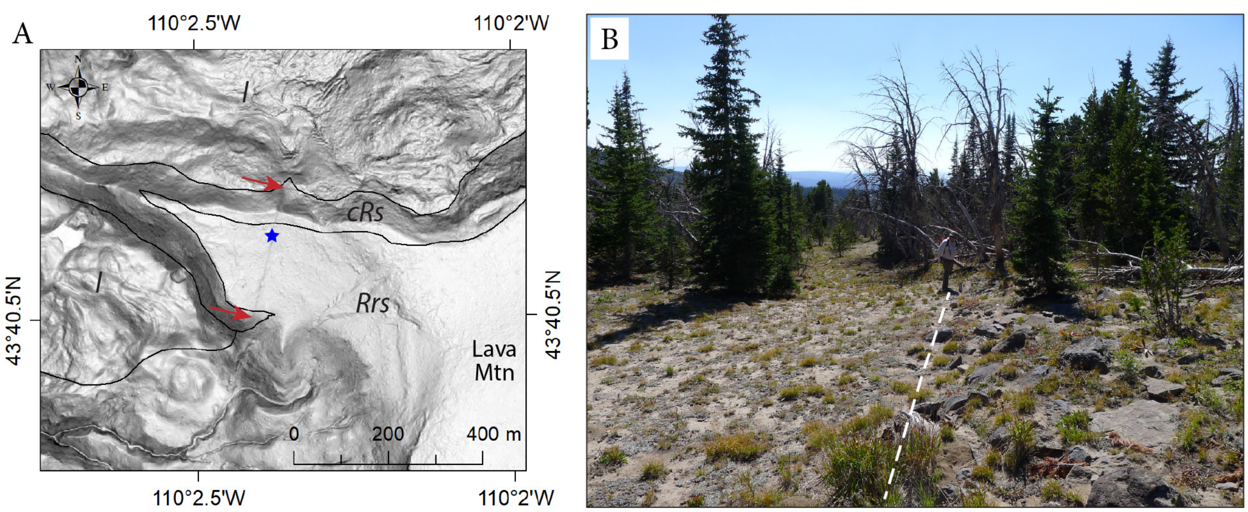

Figure 26. Lineament across the western plateau of Lava Mountain. Lidar slope map (A) shows the lineament as an east-facing slope break. Red arrows mark the northern and southern visible extents, blue star shows location of photograph (B). The lineament (white dashed line) is subtle on the ground and is recognized by a slight topographic break between andesite bedrock and residuum (right) and slopewash (left). View of photograph is to the south, geologist for scale. Units: *l* = landslide, *Rrs* and *cRs* = bedrock, colluvium, residuum, and slopewash.

more linear than the arcuate landslide headscarps in the area, but it remains possible that they are the product of mass wasting rather than tectonic processes.

Regional Tectonic Implications

The Quaternary faults mapped in this study are all expressed by 1–10-m-high scarps in Pinedale and younger deposits. However, they lack the overall topographic expression of active range-bounding structures in the region like the Teton and Grand Valley faults. Pierce and Morgan (1992) used this observation to infer that the Baldy Mountain and Togwotee Lodge faults are in a relatively early stage of development and have not yet accumulated large amounts of displacement, classifying these and other similar faults as incipient or recently reactivated. The Uhl Hill fault is the only Quaternary fault in the map area where offset of underlying bedrock can be viewed in the field (fig. 17). The lack of a significant topographic break or fault-line scarp in the juxtaposed Mesaverde Formation sandstone and Meeteetse Formation shale beneath the till cap suggests that this fault had not experienced substantial movement in the immediate period leading up to deposition of Pinedale till, and any surface trace was instead beveled to a relatively smooth topography at that time. Thus, it's hypothesized that the Uhl Hill fault is an older structure that experienced a period of quiescence before being reactivated in the late Pleistocene.

The source of new or rejuvenated activity along the four Quaternary faults in the map area may be related to uplift associated with the southwest movement of the North American plate over the Yellowstone hotspot. This recent uplift has produced the parabola-shaped "Yellowstone crescent of high terrain" and associated zone of elevated seismicity that stretches from western Wyoming through southwest Montana and eastern Idaho (Pierce and Morgan, 1992). The map area is located near the leading eastern flank of the crescent of high terrain, which may explain the recent uplift and fault activity (Pierce and Morgan, 1992). It remains to be determined if the relatively inconspicuous faults in the map area are associated and rupture in sequence with larger structures like the Teton fault or if they are independent seismic sources. Paleoseismic studies and refined lidar mapping are needed to answer unresolved questions of rupture timing, structural relations, and the resultant seismic hazard of these and other Quaternary faults in the region.

SUMMARY

The surficial geologic mapping of the east half of the Jackson Lake 30' x 60' quadrangle is intended to highlight the hazards and Quaternary geologic history of this diverse and active landscape. Outcomes from this work include updated landslide mapping, field mapping and scarp profile analysis of understudied Quaternary faults, and a synthesis of glacial geomorphic mapping in a region influenced by multiple sources, scales, and episodes of Pleistocene glaciation. The surficial geologic data presented here can be used by planners, land managers, and local governments to assist in land-use decision making and geologic hazard assessments in this rapidly developing and economically important corner of Wyoming. More broadly, this work has implications for seismic hazard modeling, landslide susceptibility analysis, and growing the understanding and appreciation of this region's dynamic Quaternary geologic history.

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APPENDIX

FAULT SCARP PROFILES

Fault scarp profiles were measured by one of two methods. All profiles from the Baldy Mountain and Togwotee Lodge faults, in addition to two profiles each from the Uhl Hill and Davis Hill faults, were surveyed in the field with a laser rangefinder. Nine profiles from the Uhl Hill fault and four profiles from the Davis Hill fault were generated by extracting distance and elevation data from a bare-earth lidar digital elevation model in ArcGIS. Profile locations along each of the four fault systems are shown in figures A-1, A-6, A-10, and A-12. The raw data for all profiles consists of points with distance (x) and elevation (z) values, measured in a straight line perpendicular to the fault scarp. Field-surveyed profiles have variable point spacing intended to capture breaks-in-slope at the fault scarp and to include as great a distance along the far-field slopes as line-of-sight allowed. Lidar-extracted profiles have a fixed point spacing that varies by profile from 0.7 to 1.2 m according to the total profile length.

Distance and elevation data from all profiles were loaded into a MATLAB script written by Christopher DuRoss of the U.S. Geological Survey. Outputs from this script include vertical surface offset (VSO), upper and lower far-field slope, and scarp slope. The script allows for multiple iterations to be run for each profile, and adjusting the chosen bounds for the upper and lower far-fields yields varying VSO values. Five iterations were run for each profile and consisted of four end-members intended to encompass the range of possible interpretations of upper and lower far-field bounding points, along with one preferred iteration that represents the best estimate of the true bounding points. From these iterations the VSO mean, minimum, maximum, and sample standard deviation were calculated. Table A-1 summarizes these data for each profile.

VSO values in the text and figures of this report are given as the mean plus or minus one sample standard deviation (1*s*). The mean VSO, rather than the preferred iteration VSO, is reported because some profiles exhibited substantial variability between iterations, and there was sometimes low confidence in the far-field bounding picks of the preferred iteration.

For display purposes, only the preferred iteration upper and lower far-field picks are included in the scarp profile plots (figs. A-2, A-3, A-4, A-5, A-7, A-8, A-9, A-11, A-13, and A-14), but the red labeled VSO values are still given as the mean ± 1*s* as calculated from all five iterations. Some lidar-derived profiles were truncated at high and low x-values in the MATLAB script in order to zoom into the scarp area and eliminate unnecessarily long far-fields; for display purposes these profiles are shown as starting at x=0. Profiles UH01 and DH6 were flipped about the z-axis from the original profile line so that all plots show the scarp as left-facing and start at x=0 for visual comparison. Finally, east and west directional labels on all plots are general; see the profile location maps (figs. A-1, A-6, A-10, and A-12) for spatial orientation.

Table A–1. Fault scarp profile data. Abbreviations: VSO = vertical surface offset, FF = far-field.

Fault	ID	Method	Offset unit	Mean VSO (m)	Sample standard dev. (m)	Coef. of variation	Preferred VSO (m)	Min VSO (m)	Max VSO (m)	Mean profile length (m)	Mean lower FF slope	Mean upper FF slope	Mean scarp slope	Num. profile iterations
Uhl Hill fault	UH01	lidar	f	1.0	0.1	15%	1.1	0.8	1.2	48.8	1.1	0.5	4.8	5
	UH02	lidar	f	1.0	0.3	25%	1.1	0.7	1.3	112.1	-0.4	-0.7	5.7	5
	UH03	lidar	g_{p1}	3.7	0.2	6%	3.9	3.3	3.9	51.5	3.6	0.1	18.8	5
	UH04	lidar	g_{p1}	1.7	0.4	25%	1.3	1.3	2.4	72.1	4.3	3.3	30.0	5
	UH05	field	g_{p1}	3.6	0.3	9%	3.5	3.3	4.0	93.6	3.0	2.9	26.5	5
	UH06	lidar	g_{p2}	1.1	0.3	26%	1.1	0.8	1.5	61.5	3.7	1.7	9.0	5
	UH07	lidar	g_{p2}	0.9	0.3	32%	1.2	0.5	1.2	41.1	-0.3	-0.8	5.9	5
	UH08	lidar	g_{p2}	1.0	0.3	33%	1.1	0.6	1.5	69.2	-0.1	-0.4	4.9	5
	UH09	lidar	g_{p1}	2.1	0.1	4%	2.1	2.1	2.2	79.2	4.6	5.4	10.5	5
	UH10	lidar	g_{p1}	1.4	0.0	1%	1.4	1.4	1.4	67.9	1.8	2.9	9.1	5
	UH11	field	g_{p1}	2.4	0.4	18%	2.2	2.0	2.9	135.9	1.5	2.3	7.7	5
Davis Hill fault	DH1	lidar	g_{p1}	2.2	0.6	29%	2.9	1.4	2.9	131.4	3.4	5.3	14.8	5
	DH2	lidar	g_{p1}	2.2	0.2	11%	2.2	1.8	2.5	94.8	5.7	7.6	17.6	5
	DH3	lidar	g_{p1}	3.4	0.5	15%	4.0	2.8	4.0	87.4	6.5	4.9	16.6	5
	DH4	field	g_{p1}	3.0	0.1	5%	3.1	2.8	3.2	56.4	5.5	6.3	15.2	5
	DH5	field	g_{p1}	3.4	0.2	7%	3.6	3.0	3.6	59.7	8.7	11.2	22.4	5
	DH6	lidar	g_{p1}	1.9	1.1	60%	1.9	0.3	3.5	52.7	31.1	26.8	10.2	5
Baldy Mtn fault	BM1	field	g_{p1}	4.3	0.3	7%	4.0	4.0	4.8	56.9	-2.1	-3.6	18.8	5
	BM2	field	g_{p1}	2.0	0.2	9%	1.9	1.8	2.2	39.9	0.1	0.3	13.4	5
Togwotee Lodge faults	TL1	field	Rsc	3.3	0.5	15%	4.1	2.8	4.1	79.4	8.3	8.5	19.0	5
	TL2	field	g_{p1}	6.9	0.7	10%	6.2	6.2	7.8	98.0	0.3	5.7	24.1	5
	TL3	field	g_{p1}	9.8	0.8	8%	8.6	8.6	10.5	75.6	3.5	1.4	31.8	5
	TL4	field	Rsc	3.7	0.9	24%	2.9	2.9	4.9	79.3	6.2	10.4	31.5	5
	TL5	field	g_{p1}	1.5	0.4	24%	1.2	1.2	2.0	33.3	-0.6	-0.6	18.3	5

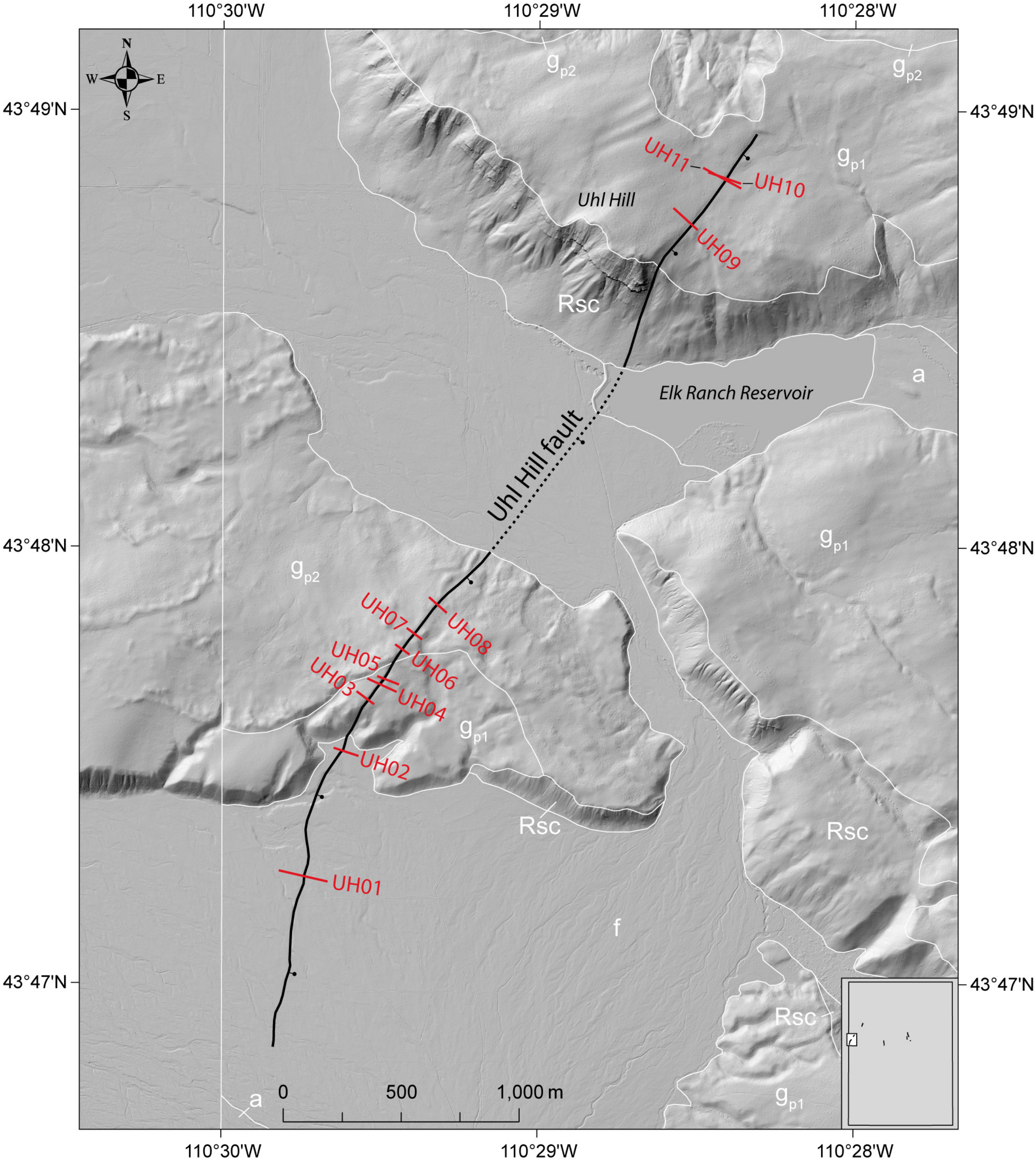


Figure A–1. Map of the Uhl Hill fault. Red lines are scarp profiles keyed to plots in figures A-2 through A-5. Base map is a 1-m lidar hillshade. Units: g_{p1} = Pinedale-1 till; g_{p2} = Pinedale-2 till; *f* = alluvial fan deposits; *l* = landslide; *a* = alluvium; *Rsc* = bedrock, slopewash, and colluvium.

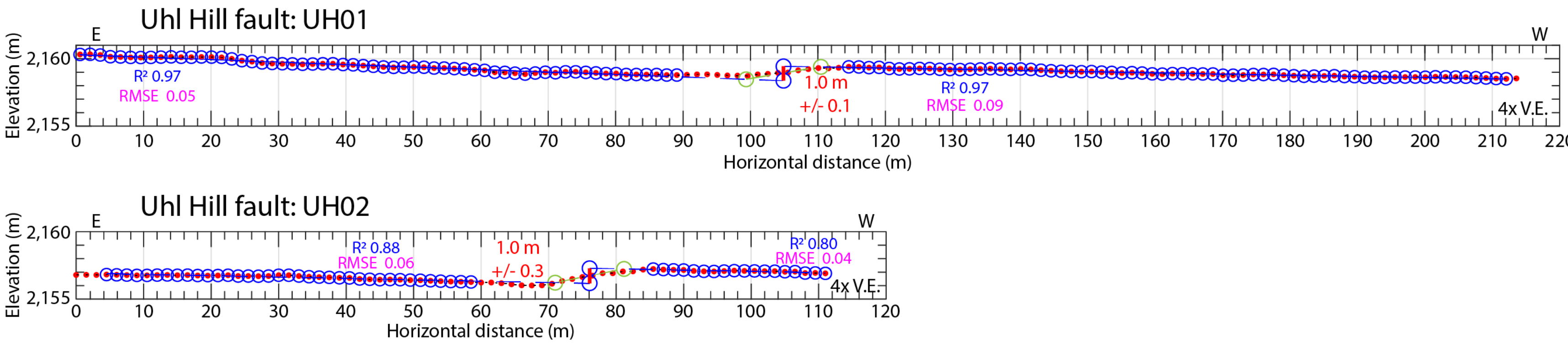


Figure A–2. Plots for fault scarp profiles UH01 and UH02 along the Uhl Hill fault.

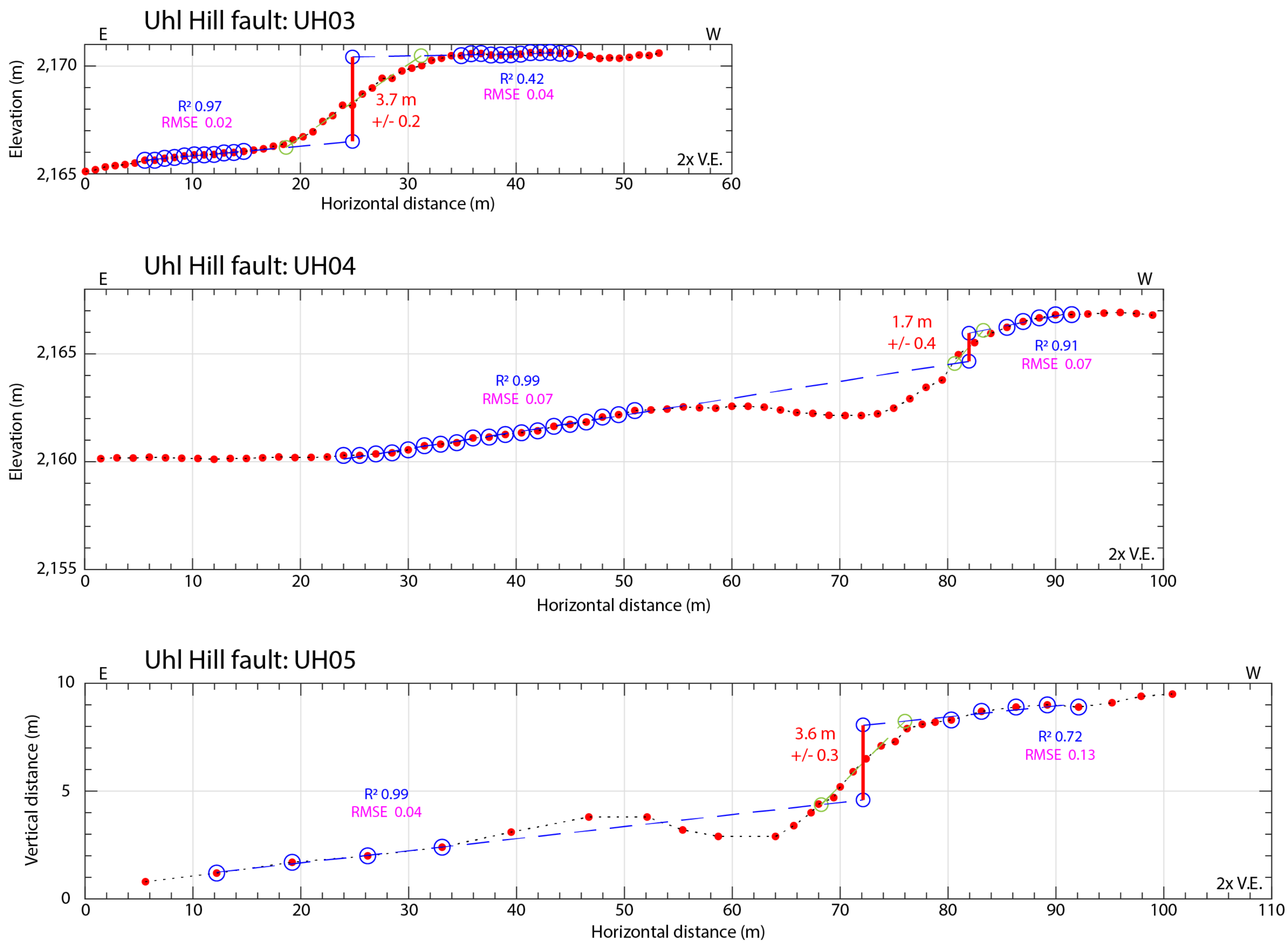


Figure A–3. Plots for fault scarp profiles UH03, UH04, and UH05 along the Uhl Hill fault.

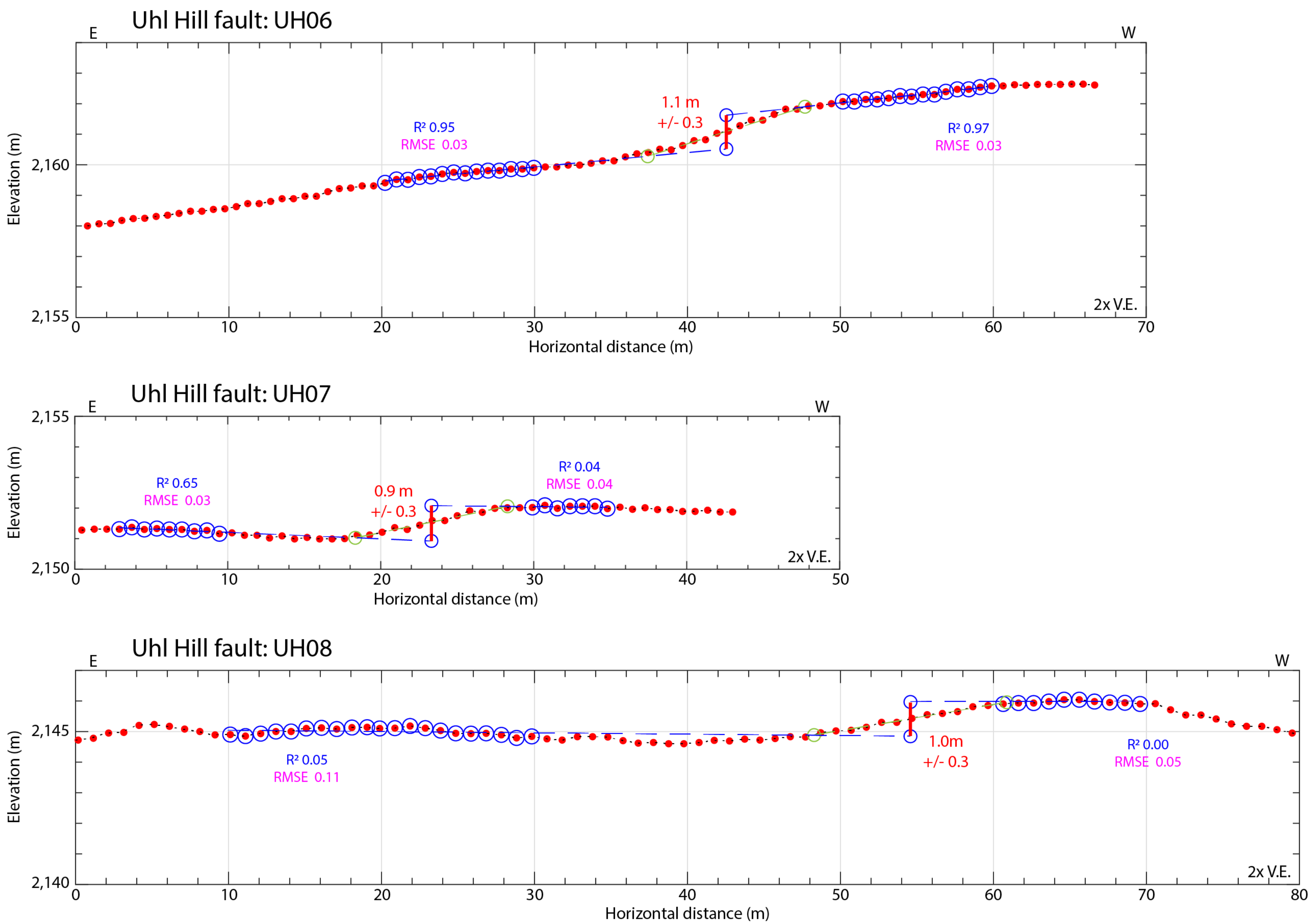


Figure A–4. Plots for fault scarp profiles UH06, UH07, and UH08 along the Uhl Hill fault.

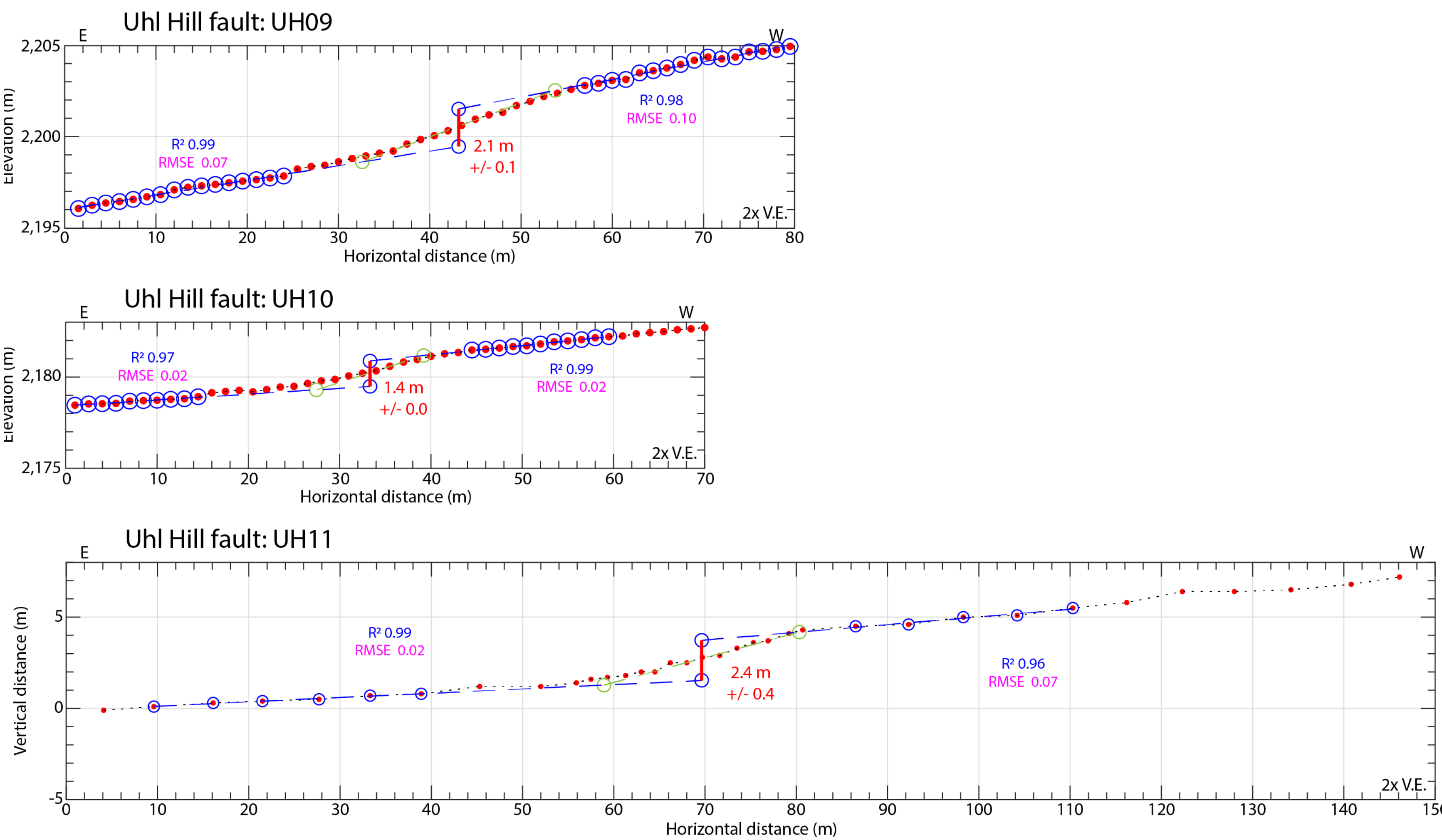


Figure A–5. Plots for fault scarp profiles UH09, UH10, and UH11 along the Uhl Hill fault.

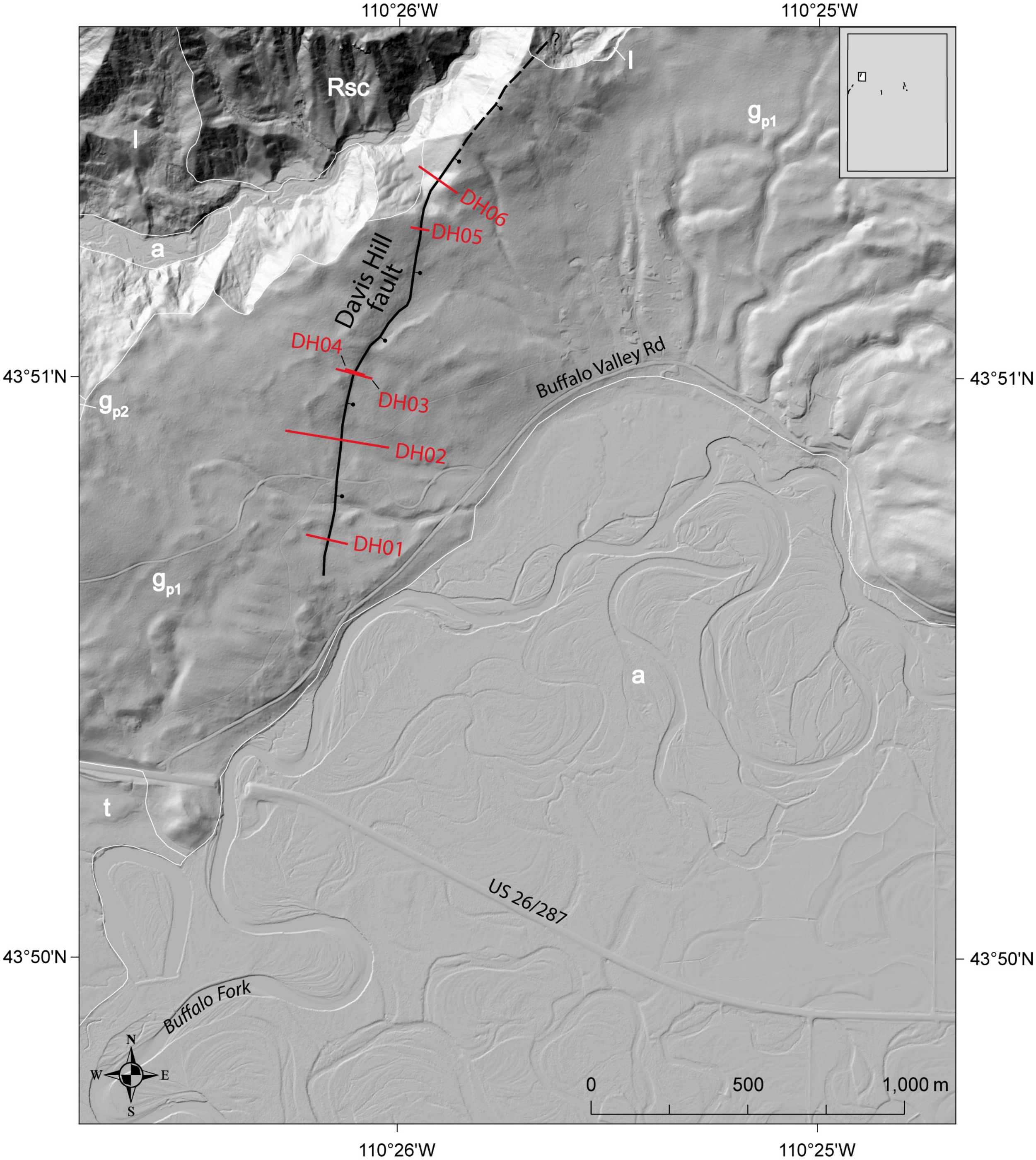


Figure A–6. Map of the Davis Hill fault. Red lines are scarp profiles keyed to plots in figures A-7 through A-9. Base map is a 1-m lidar hillshade. Units: g_{p1} = Pinedale-1 till; g_{p2} = Pinedale-2 till; *t* = terrace deposits; *l* = landslide; *a* = alluvium; *Rsc* = bedrock, slopewash, and colluvium.

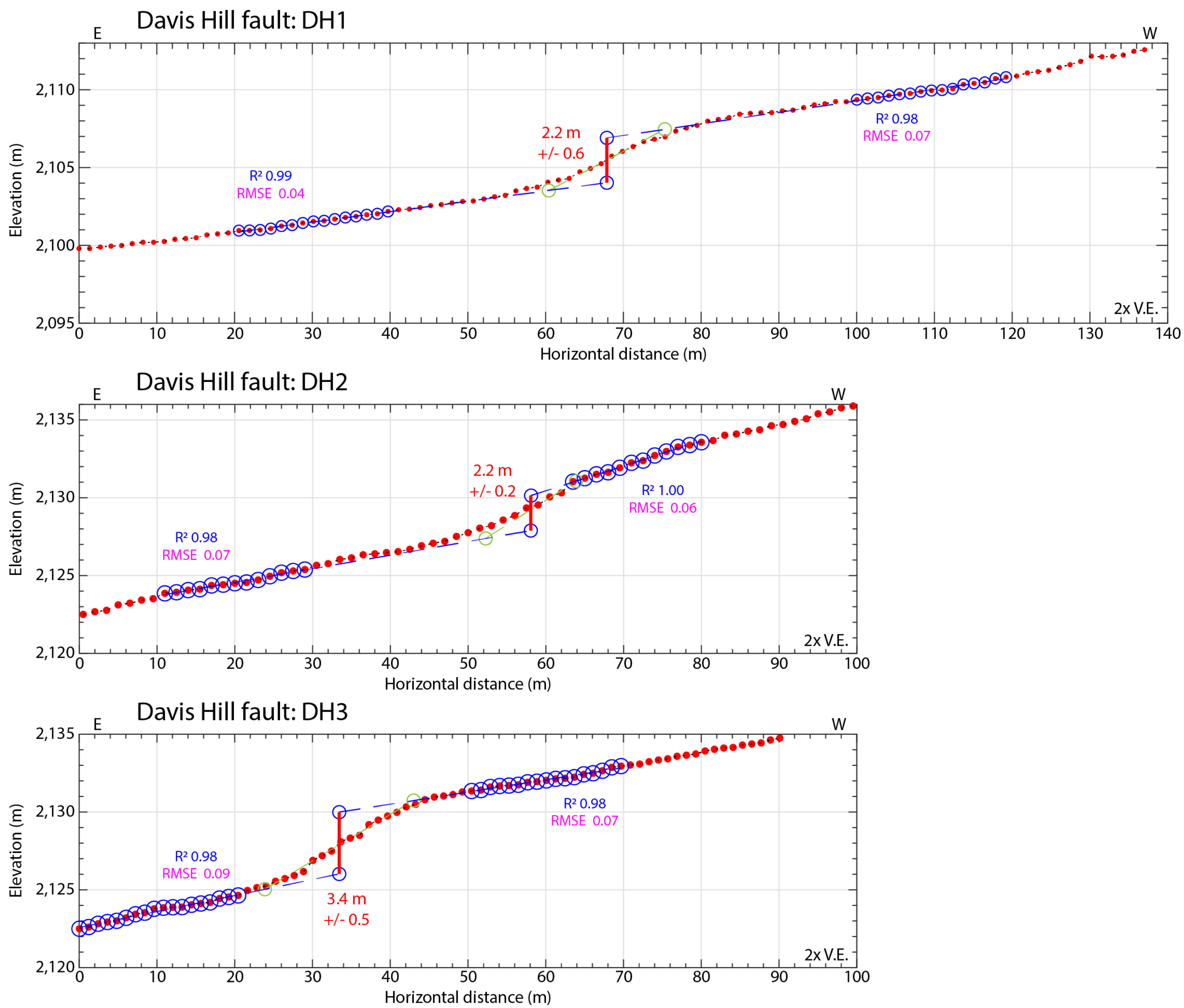


Figure A–7. Plots for fault scarp profiles DH1, DH2, and DH3 along the Davis Hill fault.

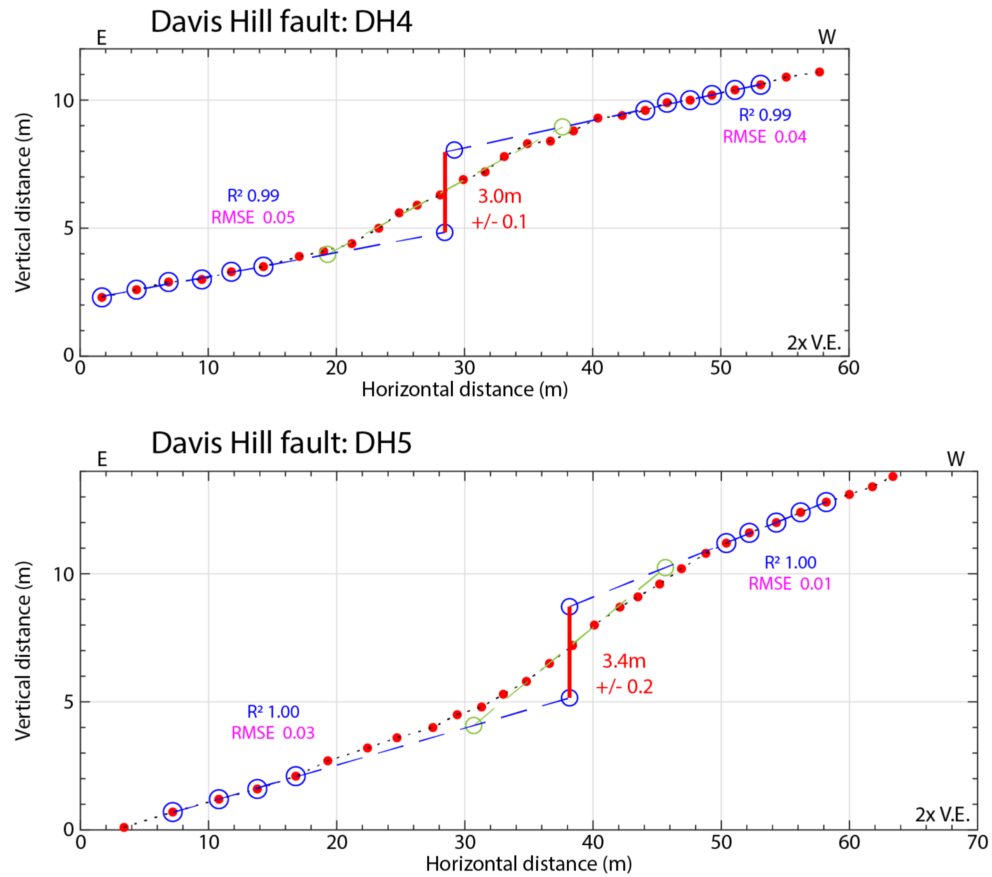


Figure A–8. Plots for fault scarp profiles DH4 and DH5 along the Davis Hill fault.

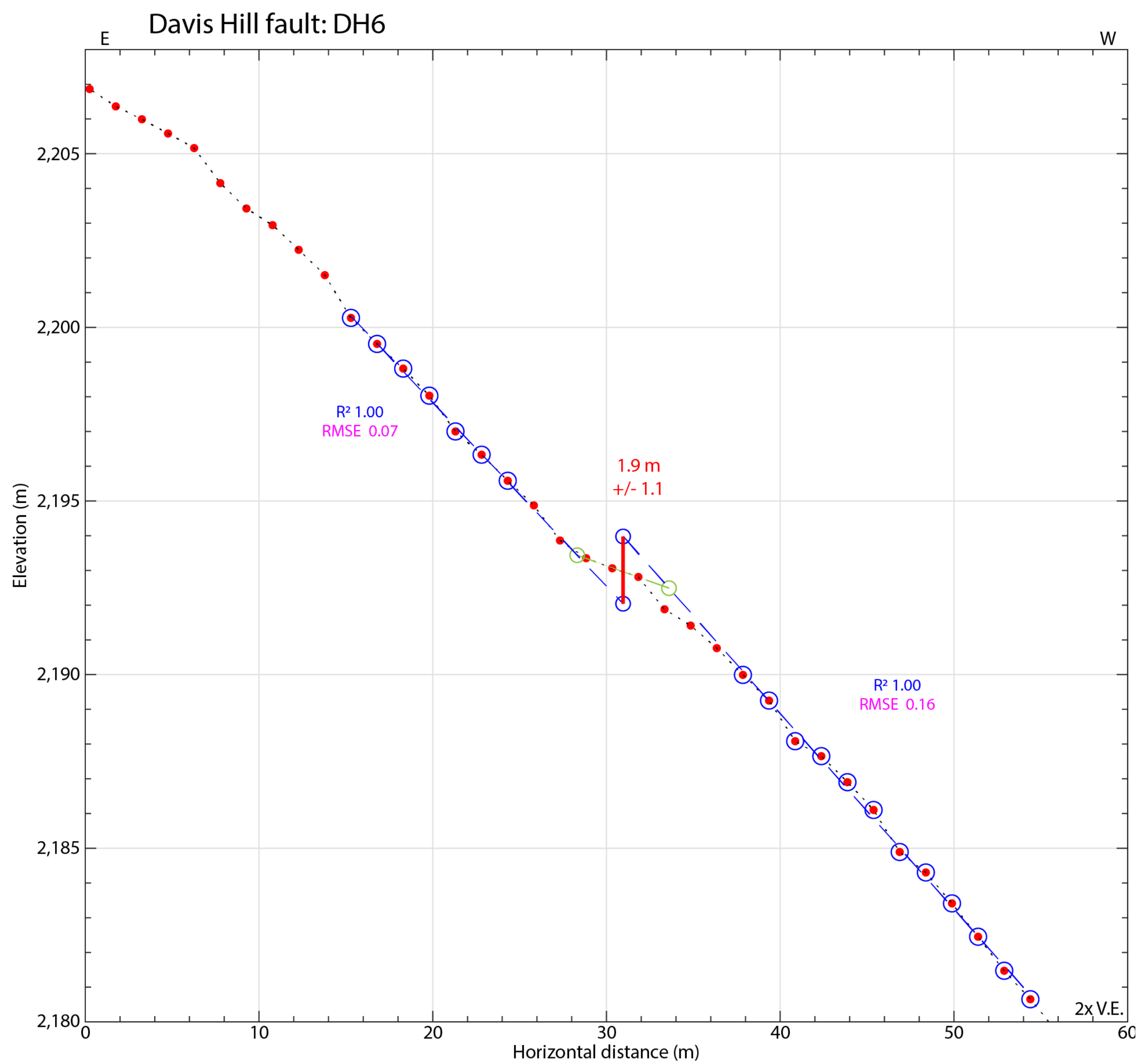


Figure A–9. Plot for fault scarp profile DH6 along the Davis Hill fault.

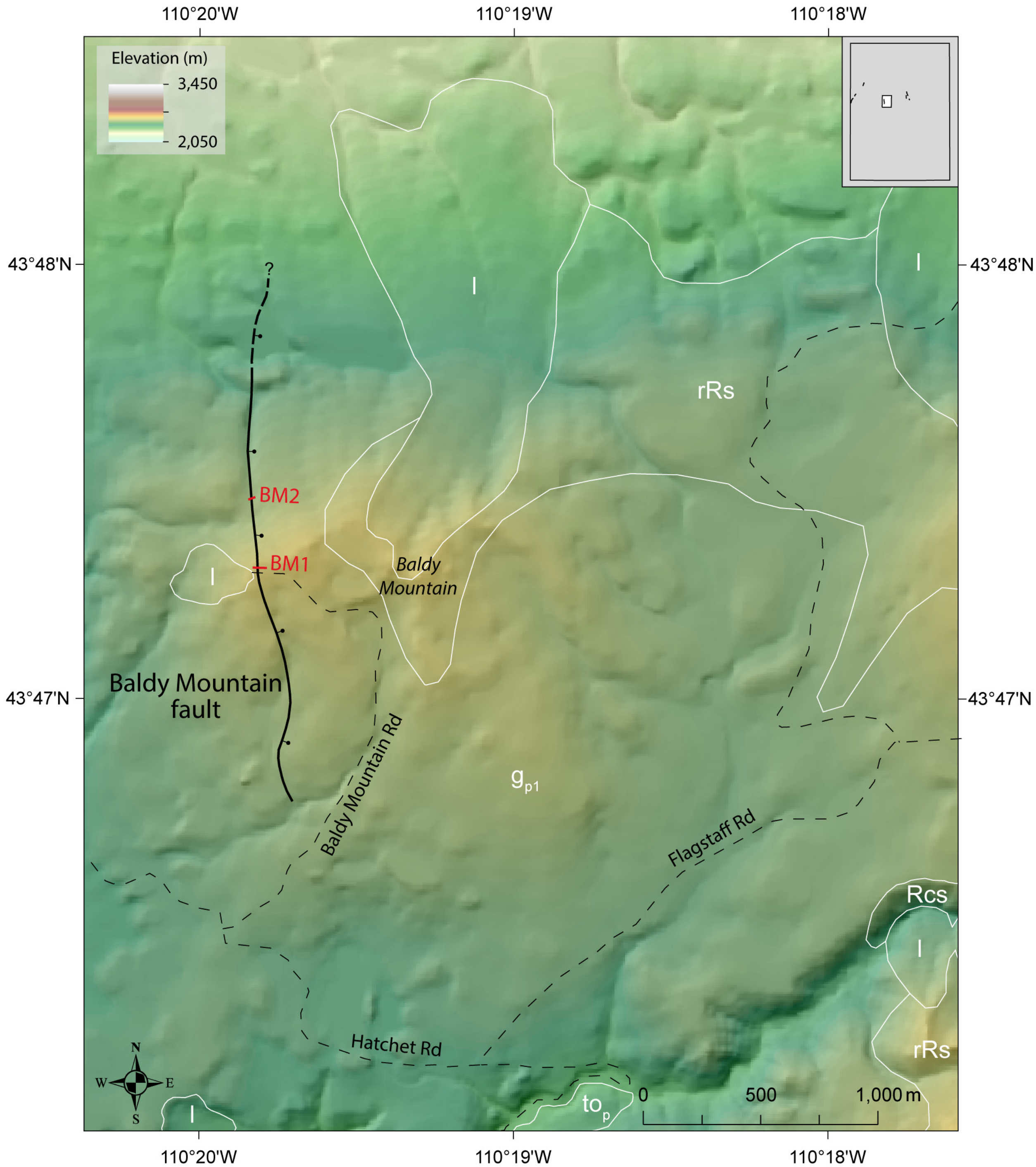


Figure A–10. Map of the Baldy Mountain fault. Red lines are scarp profiles keyed to plots in figure A-11. Base map is 10-m-resolution shaded relief. Units: g_{p1} = Pinedale-1 till; to_p = Pinedale outwash terrace; *l* = landslide; *Rcs* and *rRs* = bedrock, residuum, colluvium, and slopewash.

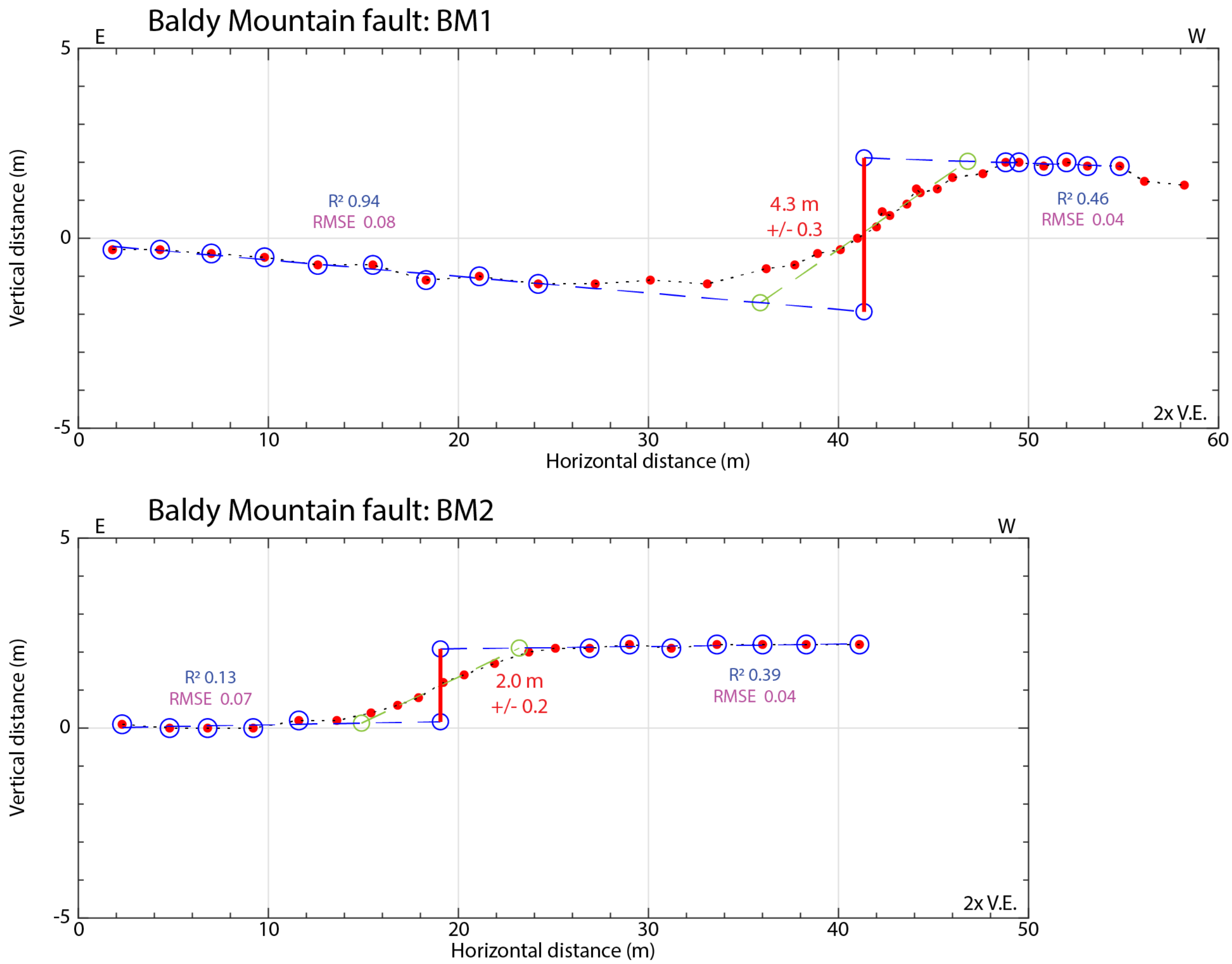


Figure A–11. Plots for fault scarp profiles BM1 and BM2 along the Baldy Mountain fault.

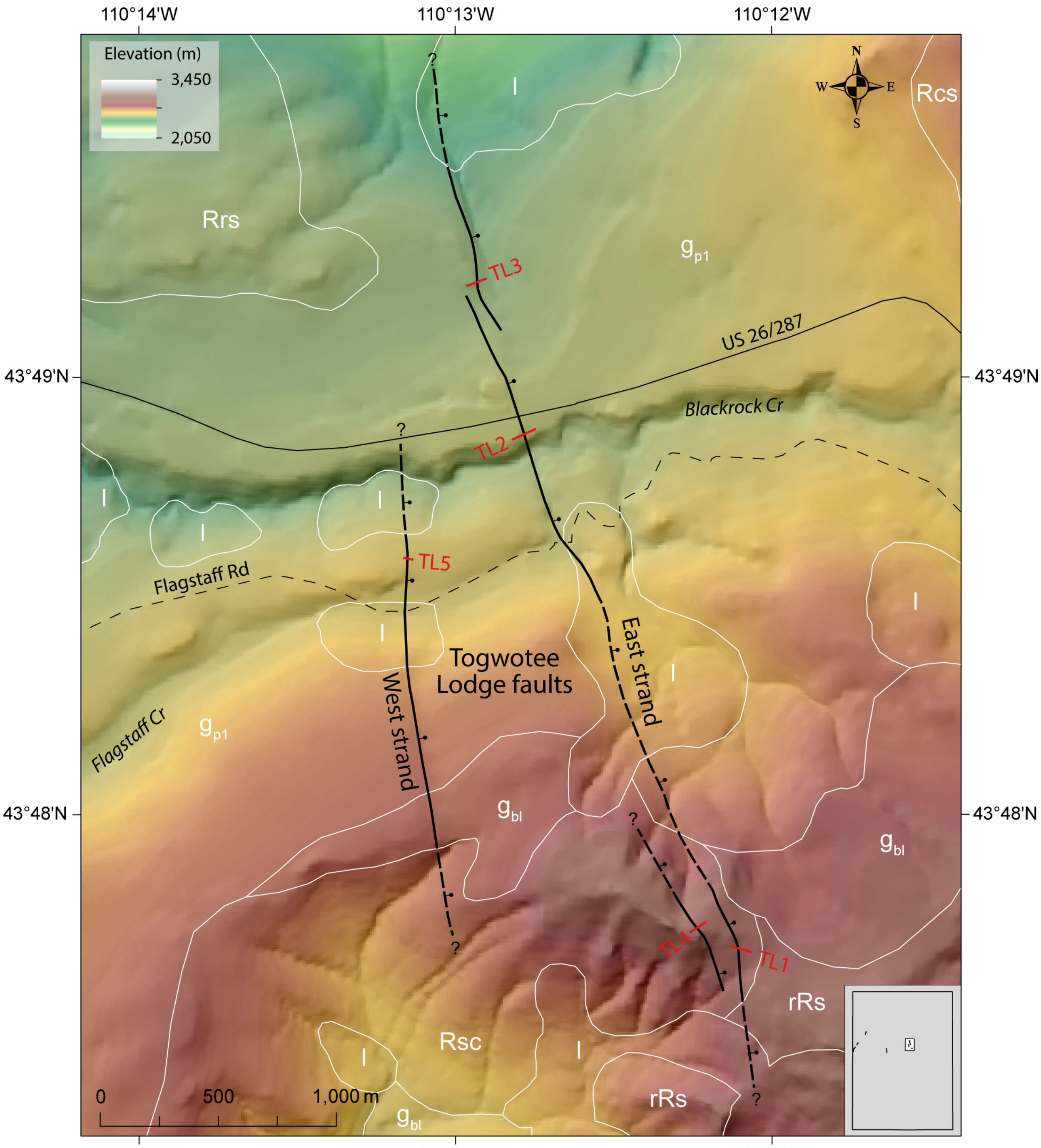


Figure A–12. Map of the Togwotee Lodge faults. Red lines are scarp profiles keyed to plots in figures A-13 and A-14. Base map is 10-m-resolution shaded relief. Units: g_{p1} = Pinedale-1 till; g_{bl} = Bull Lake till; *l* = landslide; *Rcs*, *Rrs, Rsc*, and *rRs* = bedrock, residuum, colluvium, and slopewash.

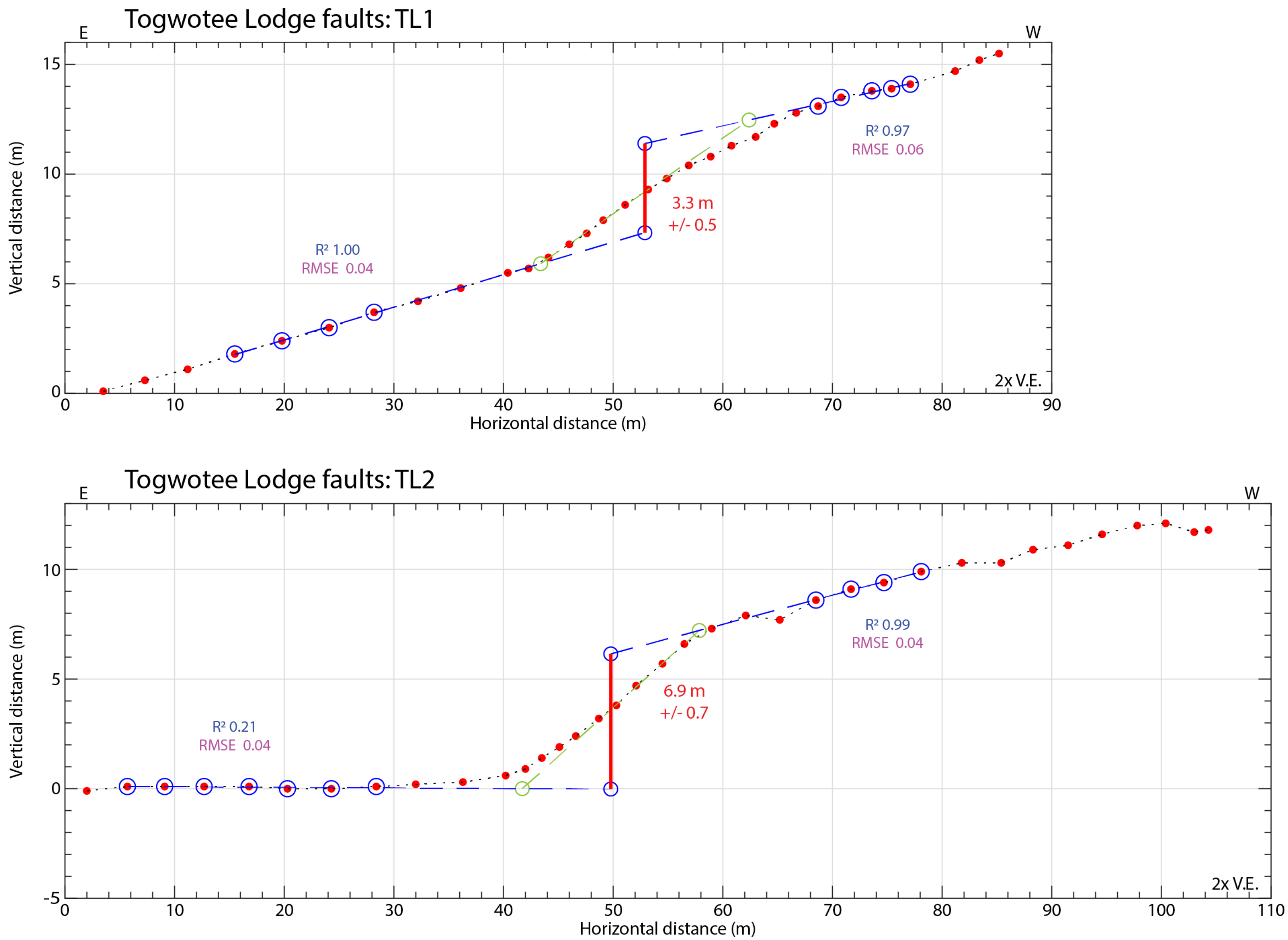
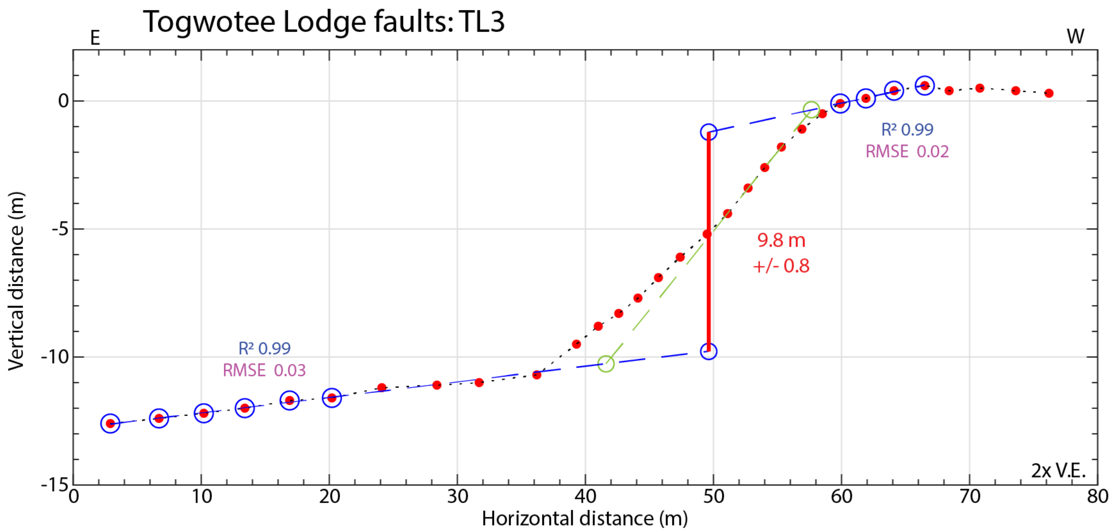
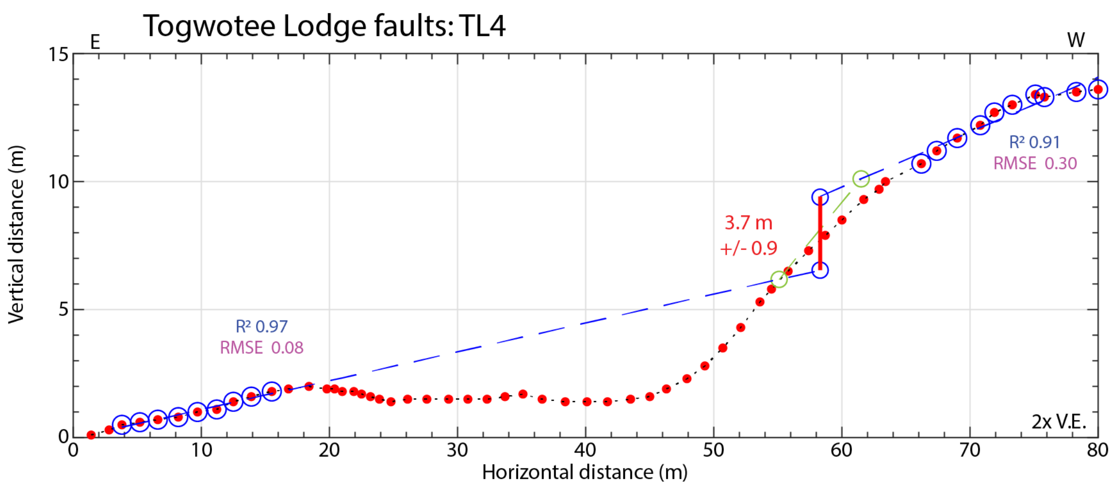


Figure A–13. Plots for fault scarp profiles TL1 and TL2 along the east strand of the Togwotee Lodge faults.





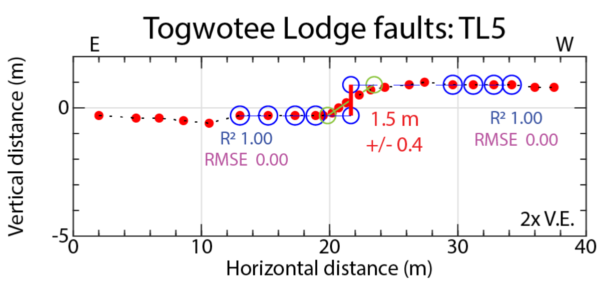


Figure A–14. Plots for fault scarp profiles TL3 and TL4 along the east strand of the Togwotee Lodge faults, and profile TL5 along the west strand of the Togwotee Lodge faults.