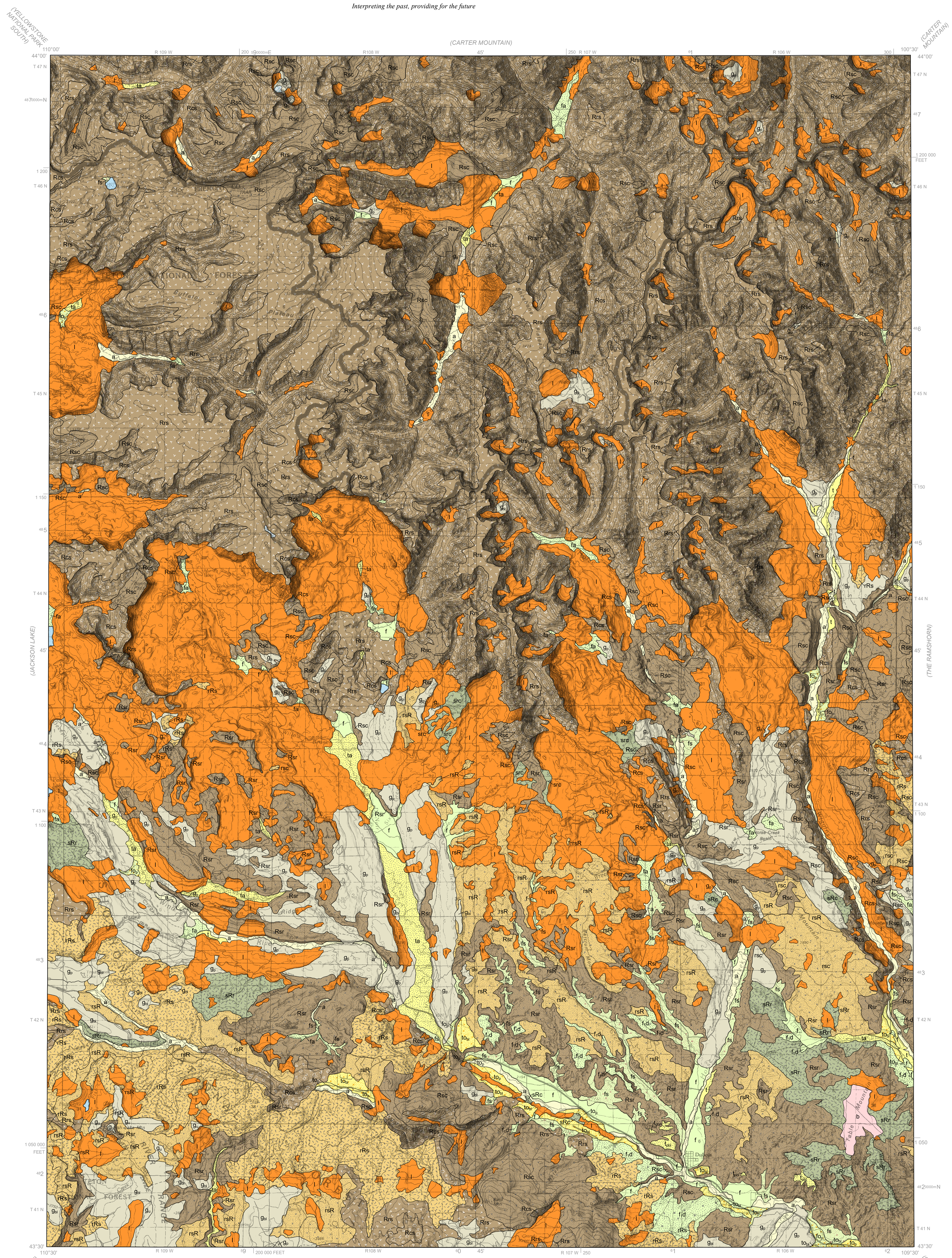
**WYOMING STATE GEOLOGICAL SURVEY**
**Erin A. Campbell, Director and State Geologist**
**Laramie, Wyoming**

*Interpreting the past, providing for the future*

**OPEN FILE REPORT 2023-1**
**West Half of**
**The Ramshorn 1:100,000-scale**
**Surficial Geologic Map**



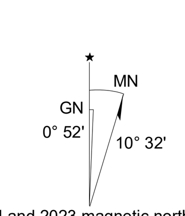
Base map from U.S. Geological Survey 1:100,000-scale metric topographic map of The Ramshorn, Wyoming Quadrangle, 1978

Base hillshade derived from U.S. Geological Survey 3D Elevation Program 1/3 Arc Second (~10-meter) Digital Elevation Model n44w110, 2021-11-16; multidirectional hillshade, no vertical exaggeration

Projection: Universal Transverse Mercator (UTM), zone 12
North American Datum of 1927 (NAD 27)
10,000-meter grid ticks: UTM, zone 12
50,000-foot grid ticks: Wyoming State Plane Coordinate System, west central zone

National Geodetic Vertical Datum of 1929

Wyoming State Geological Survey
P.O. Box 1347 - Laramie, WY 82073-1347
Phone: 307-766-2286 - Fax: 307-766-2605
Email: wsgs.sales@wyo.gov



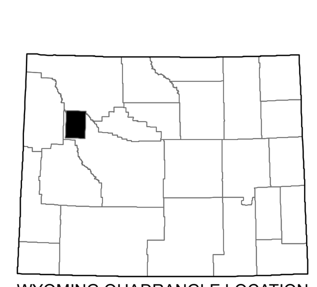

UTM grid and 2023 magnetic north declination at center of map, from www.ngdc.noaa.gov (diagram is approximate)

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 Jon M. Krupnick

Map edited by James A. Amato

Prepared in cooperation with and research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G22AC00306. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Suggested citation: Mauch, J.P., Wittke, S.J., and Krupnick, J.M., 2023, Preliminary surficial geologic map of the west half of The Ramshorn 30' x 60' quadrangle, Fremont and Park counties, Wyoming: Wyoming State Geological Survey Open File Report 2023-1, 34 p., scale 1:100,000, https://doi.org/10.15786/22770890.

# PRELIMINARY SURFICIAL GEOLOGIC MAP OF THE WEST HALF OF THE RAMSHORN 30' x 60' QUADRANGLE, FREMONT AND PARK COUNTIES, WYOMING

mapped by

James P. Mauch, Seth J. Wittke, and Jon M. Krupnick

2023

## 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 bounded by steeper erosional scarps on their flanks

Terrace deposits (**t**). Unit assigned to terrace deposits along the Wind River, Wiggins Fork, and Horse Creek with indeterminate age and uncertain correlation with glacial outwash deposits; terrace treads are typically less than 9 m above the active channel along the Wind River and in the upper Wiggins Fork; a subset of terraces along Horse Creek and the lower Wiggins Fork are 26–40 m above the active channel

Terrace deposits and active alluvium (**ta**). Mapped primarily along perennial tributaries in confined valleys where alluvium and terrace deposits could not be separated at the map scale; terrace treads are typically less than 5 m above the active channel; may locally include glacial outwash deposits

Terraces composed of glacial outwash deposits from the Bull Lake (**$to_{bl}$**) and Pinedale (**$to_p$**) glacial episodes. Outwash terraces are downstream of their respective glacial termini in the Wind River valley, and are identified by their position relative to terminal moraines and height above the active channel. Bull Lake outwash terrace treads are 55 to 90 m above grade; Pinedale outwash terrace treads are 3 to 14 m above grade

High terrace deposits of the Wind River (**$t_{pbl}$**). Discontinuous gravel deposits that form two levels of high terraces near and downstream from Dubois. Tread heights are 170–180 m and 85–100 m above grade; deposits are up to 15 m thick on straths beveled in the Wind River Formation. Deposits are inferred to predate the Bull Lake glaciation based on landscape position above the Bull Lake outwash terrace

**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**). Most alluvial fans grade to the active valley floodplain or are incised less than 7 m by modern drainages

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 (**$fo_p$**). Includes deposits distal to Pinedale terminal moraines as well as fan deposits up-valley of Pinedale glacial termini that are highly dissected; alluvial fans in the latter setting are incised 13 to 20 m by the active channel and are hypothesized to be composed of outwash from glacial recession

Piedmont gravel deposits (**$f_1d$**). Gravels cap landforms that slope toward valley axes and grade to multiple levels above the modern floodplain. Most piedmonts grade to, or are incised up to 15 m at their toes by, the Bull Lake outwash terrace. Mapped along the Wind River, Horse Creek, and the lower Wiggins Fork

**Bench deposits**—Gravel deposits that form a thin cap atop an elevated, relatively level surface

Bench deposits (**b**). Mapped exclusively on Table Mountain in the southeast map area

**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 (**$g_{bl}$**), Pinedale age (**$g_p$**), and post-Pinedale age (**$g_h$**). High, undifferentiated glacial deposits (**$g_u$**) are mapped in the southwest map area at elevations above 2,900 m where cobbles and boulders of exotic lithology form a featureless surface veneer; age and origin uncertain

**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 residuum with minor components of colluvium (**src**)

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

**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 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**)

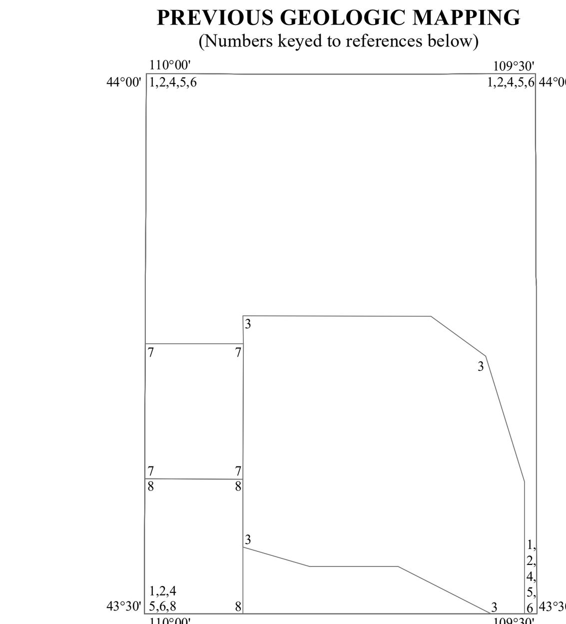
**Water**—Areas covered perennially by standing water, snow, or ice

Water in lakes, ponds, and reservoirs

Ice in perennial snowfields or glaciers of the Absaroka Range

### PREVIOUS GEOLOGIC MAPPING

(Numbers keyed to references below)




1. Case, J.C., 2001, Preliminary landslide maps in The Ramshorn quadrangle, Fremont and Park counties, Wyoming (unpublished): Wyoming State Geological Survey, scale 1:24,000.
2. Case, J.C., Arneson, C.S., and Hallberg, L.L., 1998, Surficial geologic map of Wyoming: Wyoming State Geological Survey Hazards Section Digital Map 98-1a, scale 1:500,000.
3. Keefer, W.R., 1957, Geology of the Du Noir area, Fremont County, Wyoming: U.S. Geological Survey Professional Paper 294-E, Plate 26, scale 1:48,000.
4. 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.)
5. Love, J.D., Christiansen, A.C., Brown, T.M., and Earle, J.L., 1979, Preliminary geologic map of the Thermopolis 1 degree x 2 degree quadrangle, central Wyoming: U.S. Geological Survey Open-File Report 79-962, 6 p., 1 pl., scale 1:250,000.
6. 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.
7. Rohrer, W.L., 1966, Geologic map of the Kissinger Lakes quadrangle, Fremont County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map 527, scale 1:24,000.
8. Rohrer, W.L., 1968, Geologic map of the Fish Lake quadrangle, Fremont County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map 724, scale 1:24:000.

### NOTICE TO USERS



### NOTICE FOR OPEN FILE REPORTS

Open File Reports are preliminary and usually require additional fieldwork and/or compilation and analysis; they are meant to be a first release of information for public comment and review. The Wyoming State Geological Survey welcomes any comments, suggestions, and contributions from users of the information.

### DISCLAIMERS

*Interpreting the past, providing for the future*

# Preliminary Surficial Geologic Map of the West Half of The Ramshorn 30' x 60' Quadrangle, Fremont and Park Counties, Wyoming

James P. Mauch, Seth J. Wittke, and Jon M. Krupnick

Open File Report 2023-1
June 2023

# Wyoming State Geological Survey

Erin A. Campbell, Director and State Geologist

# Preliminary Surficial Geologic Map of the West Half of The Ramshorn 30' x 60' Quadrangle, Fremont and Park Counties, Wyoming

James P. Mauch, Seth J. Wittke, and Jon M. Krupnick

Layout by Christina D. George

Open File Report 2023-1
Wyoming State Geological Survey
Laramie, Wyoming: 2023

Open File Reports are preliminary and usually require additional fieldwork and/or compilation and analysis; they are meant to be a first release of information for public comment and review. The Wyoming State Geological Survey welcomes any comments, suggestions, and contributions from users of the information.

Citation: Mauch, J.P., Wittke, S.J., and Krupnick, J.M., 2023, Preliminary surficial geologic map of the west half of The Ramshorn 30' x 60' quadrangle, Fremont and Park counties, Wyoming: Wyoming State Geological Survey Open File Report 2023-1, 34 p., scale 1:100,000, https://doi.org/10.15786/22770890.

## Table of Contents

## List of Figures

## INTRODUCTION

The Ramshorn 30' x 60' quadrangle is in Fremont, Park, and Hot Springs counties, Wyoming. The quadrangle encompasses the southern Absaroka Range, northwestern Wind River Basin, and northwestern Wind River Range. This study mapped the surficial geology of the west half of The Ramshorn quadrangle at a scale of 1:100,000 in an effort to better understand the region's geologic hazards and Quaternary geology.

This work is part of a broader effort by the Wyoming State Geological Survey (WSGS) to map the surficial geology of Wyoming at 1:100,000 scale. In particular, surficial geologic mapping on The Ramshorn quadrangle is motivated by a need for updated landslide mapping in one of the most landslide-prone regions of the state. Landslides have historically impacted U.S. Highway 26/287, an important transportation corridor in the southwest quadrant of the map, yet the only prior landslide inventories in the area were completed 20 years ago without field verification and before the availability of lidar data. This mapping leverages recently released lidar data for Fremont County along with select ground truthing to characterize the distribution of landslides and other surficial deposits in the study area. In the process, this work provides additional insights into the recent geologic history of the region through the mapping and documentation of Quaternary glacial and alluvial deposits. The data presented here are intended to improve geologic hazard assessments and to help land managers, local governments, and the public make informed land-use decisions in this unique landscape.

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 G22AC00306.

### Previous Mapping

Rohrer (1966, 1968) completed the only prior 1:24,000-scale bedrock mapping within the study area on the Kissinger Lakes and Fish Lake 7.5' quadrangles. Keefer (1957) mapped the bedrock geology of the DuNoir Creek and Horse Creek drainages south of the Absaroka Range front at a scale of 1:48,000. Bedrock mapping by Love and others (1979) at 1:250,000 scale and Love and Christiansen (1985) at 1:500,000 scale provide coverage of the entire study area.

The only previously published surficial geologic mapping within The Ramshorn quadrangle was completed by Case and others (1998) as part of a 1:500,000-scale statewide compilation. Surficial geologic mapping by Mauch and others (2022) at 1:100,000 scale borders the map area to the west. The WSGS completed unpublished photogeologic mapping of landslides across the study area at 1:24,000 scale as part of a statewide inventory (Case, 2001). Pierce and others (2018) mapped ice extents of the Bull Lake and Pinedale glaciations in the Greater Yellowstone Region at a scale of roughly 1:2,250,000, which encompasses the entirety of the west half of The Ramshorn quadrangle.

## GEOLOGIC SETTING

The west half of The Ramshorn quadrangle encompasses the northwestern Wind River Range and Wind River Basin, and the southern Absaroka Range (fig. 1). The southern front of the Absaroka Range roughly divides the map area into north and south halves that exhibit marked differences in lithology, structural geology, and topography. The lower-relief Wind River Basin and gentle flank of the Wind River Range are juxtaposed with the high-elevation plateaus and steep, dissected valleys of the Absaroka Range—a contrast that is manifested in the surficial geology of the region.

The Wind River Range is a northwest-trending, asymmetric, basement-cored Laramide uplift bound to the southwest by the northeast-dipping Wind River thrust fault (Smithson and others, 1978; Berg, 1983; Bashum and Martin, 1985). Precambrian crystalline rocks are exposed in the core of the range and compose the glaciated peaks of the Continental Divide, which exceed elevations of 4,000 m. The northeast flank of the range within the quadrangle boundary is characterized by Paleozoic and Mesozoic sedimentary rocks that dip northeast into the Wind River

Basin. At the northwest end of the Wind River Range, these strata are onlapped by Eocene sedimentary and volcaniclastic units of the Wind River and Aycross formations (Love and Christiansen, 1985).

To the northeast of the Wind River Range in the map area is the synclinal trough of the northwestern arm of the Wind River Basin (Keefer, 1970). The Laramide structures along the axis of the basin are mostly obscured by younger Eocene strata and Quaternary sediments (Love and Christiansen, 1985). The Wind River Basin is bound to the northeast by the Washakie Range, another northwest-trending Laramide uplift expressed by faulted and asymmetrically folded Paleozoic and Mesozoic sedimentary rocks with local exposures of Precambrian basement rocks (Love, 1939; Keefer, 1970).

Within the map area, the Washakie Range is mostly concealed beneath the volcanic and volcaniclastic rocks of the Absaroka Volcanic Supergroup (AVS), which make up the high terrain of the Absaroka Range. Rocks of the AVS are Eocene in age and were derived from eruptive centers that were primarily northwest, north, and east of the map area (Love, 1939; Smedes and Postka, 1972; Prostka and others, 1979). Several dispersed Eocene intrusions and dike complexes are found in the northern map area, but the majority of the AVS units exposed on the map are volcanic and volcaniclastic in origin. Of particular importance for the surficial geology are the Wiggins Formation—a volcanic breccia with interbedded tuff that forms the escarpments and high plateaus of the southern Absaroka Range—and the underlying Tepee Trail Formation—a recessive claystone with interbedded sandstone (Love, 1939; Smedes and Prostka, 1972). Rocks of the AVS are largely undeformed with dips of less than 5 degrees distal to vent complexes (Keefer, 1957; Smedes and Prostka, 1972). More recent volcanic activity south of the Absaroka Range is recorded in the form of Quaternary basalt and andesite flows on Lava Mountain and Spring Mountain, the latter of which is likely controlled by Laramide faults from the Washakie Range (Keefer, 1957; Downey, 2015; Brueseke and others, 2018).

The Quaternary history of the Absaroka Range is largely marked by fluvial and glacial erosion, which have dissected the Absaroka Volcanic Plateau and left behind only scarce deposits in the range's deeply incised drainages (Breckenridge, 1975). Erosional glacial landforms in the interior of the range and moraines in peripheral valleys attest to multiple periods of glaciation throughout the Pleistocene. During the last two glacial episodes, glaciers in the Absaroka Range were part of the Greater Yellowstone Glacial System (GYGS)—a large ice cap that covered much of the Absaroka Range, Yellowstone Plateau, and Beartooth Mountains. Cosmogenic radionuclide dating of moraines around the perimeter of the GYGS suggests that the penultimate (Bull Lake) glaciation occurred around 150–140 ka and that the most recent (Pinedale) glaciation occurred between approximately 22 and 13 ka, with variations in the timing of local glacial maxima dependent on topographic, orographic, and microclimatic factors (Licciardi and Pierce, 2008, 2018).

The Wind River Range also hosted a glacial system during the Pleistocene, and moraines from valley glaciers along its periphery were documented by Blackwelder (1915) as the type sections for the Bull Lake and Pinedale glaciations. Southeast of the map area at Bull Lake and Dinwoody Lakes, the nested moraine loops studied by Blackwelder (1915) were revisited by Richmond (1964), who described and named three older tills predating the Bull Lake glaciation (from youngest to oldest: Sacajawea Ridge, Cedar Ridge, and Washakie Point). A later stratigraphic and paleomagnetic study at Bull Lake demonstrated that only Sacagawea Ridge-and-younger till is present (Hall and Jaworowski, 1999), which has led to the abandonment of the terms Cedar Ridge and Washakie Point in recent studies. However, this nomenclature remains in legacy 1:24,000-scale mapping by Rohrer (1968), who mapped the three pre-Bull Lake tills of Richmond (1964) as queried in the area around Fish Lake Mountain.

The Quaternary history of the Absaroka and Wind River ranges and uppermost Wind River Basin is also recorded in a suite of well-preserved fluvial terraces that extend along the Wind River within and southeast of the map area. Blackwelder (1915) assigned the names Lenore (lower) and Circle (higher) for the two most prevalent and continuous terraces along the Wind River through the upper Wind River Basin. He hypothesized that the Lenore and Circle terraces recorded periods of broad-scale interglacial erosion that preceded the Pinedale and Bull Lake glaciations, respectively. Subsequent studies have renamed the Lenore terrace the WR-1 and the Circle terrace the WR-3

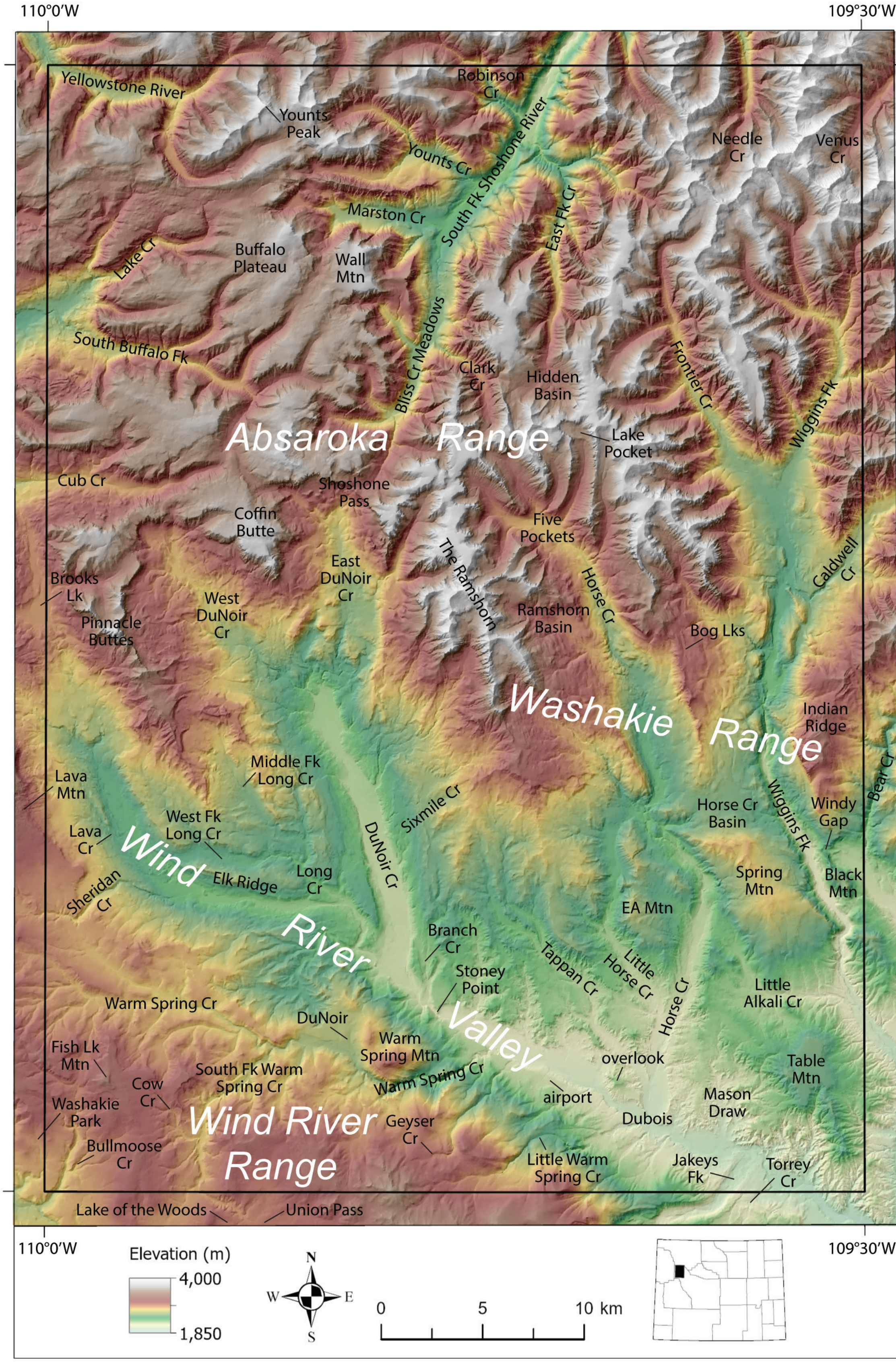



**Figure 1.** Shaded relief map showing place names referenced in this report. Map boundary is thick black line. Abbreviations: Cr = Creek, Fk = Fork, Lk(s) = Lake(s), Mtn = Mountain.

(Chadwick and others, 1994 and 1997). Mapping and numeric dating suggest that the WR-1 is contemporaneous with the Pinedale glaciation and that the WR-3 dates to, or shortly after, the Bull Lake glaciation (Chadwick and others, 1997; Phillips and others, 1997; Hancock and others, 1999; Sharp and others, 2003).

## METHODS

Mapping was completed through a combination of digital and field methods. Most of the study area was initially mapped through interpretation of 1-m-resolution lidar-derived hillshades and slope maps (U.S. Geological Survey, 2020)—supplemented with color infrared digital orthophoto quadrangles (DOQs) from 2001 and true-color National Agriculture Imagery Program (NAIP) photographs acquired in 2015, 2017, and 2019—in a geographic information system. Lidar data were not available on the Park County side of the quadrangle; DOQ and NAIP imagery and a hillshade derived from the 3D Elevation Program 1/3 arc-second digital elevation model (U.S. Geological Survey, 2021) were used for digital mapping in this area. Georeferenced images and vector data from previous maps were consulted as part of the digital mapping process, but all polygons and contacts on the map are original work. Surficial geologic map unit polygons were digitized at scales between 1:16,000 and 1:24,000 with an average node spacing of 50 m. For display at 1:100,000 scale, features smaller than 30,000 $m^2$ in area or with pinch points narrower than 70 m wide were not included on the map.

After digital mapping, select locations were visited in the field for ground verification and were given more detailed attention. Field mapping occurred over five weeks between July and September 2022. Locations with high landslide density, exposed glacial deposits, discrepancies in previous mapping, uncertain interpretation from preliminary digital mapping, and/or an absence of lidar coverage were the highest priority field targets. One week was spent mapping from a base camp in Bliss Creek Meadows, which afforded field access to the headwater drainages of the South Fork Shoshone River in an area lacking lidar coverage. This was the only opportunity to visit sites in the remote Teton and Washakie wilderness areas in the northern third of the map. The remaining four weeks of the field season were spent on public lands in the southern two-thirds of the map. Data collected in the field were used to refine digital mapping in an iterative process.

## MAP UNITS

The map unit convention used here is modified from Case and others (1998), with units built from combinations of single-letter elements that refer to basic deposit or landform types. With the exception of glacial outwash (element *o*, which is used as a modifier for fan or terrace landforms), unit elements are listed in order of relative abundance as observed at the surface and near-surface (up to 1.5 m depth) within the mapped polygon. Subscripted letters and numbers refer to sub-classifications within glacial and alluvial deposits where these units can be differentiated.

Unit elements present within the map area are bedrock, residuum, colluvium, slopewash, landslide deposits, glacial till, and multiple classes of alluvial deposits (active alluvium, terrace deposits, fan deposits, and bench deposits). The surficial geology of the northern half of the map area is dominated by bedrock and its weathering products, whereas the southern half contains a more diverse assemblage of bedrock, residuum, landslide deposits, and glacial and fluvial deposits along major drainages.

### Bedrock, Residuum, and Hillslope Deposits

By convention, units composed of bedrock (*R*), residuum (*r*), and hillslope deposits (*c* for colluvium, *s* for slopewash) are given a three-element name with the elements listed in order of relative abundance. Colluvium is defined here as an unconsolidated, coarse-grained hillslope deposit transported primarily by gravity through processes like dry ravel. Slopewash is a fine-grained hillslope deposit transported by gravity and unchannelized running water. These two hillslope deposits are characterized by slow, semi-continuous to episodic transport, distinguishing them from material transported by mass movements and acute slope failure, which are here classified as landslide deposits.

The topographic and lithologic differences between the north and south halves of the map area are apparent in the distribution of bedrock, residuum, and hillslope deposits. Unit *Rcs* dominates the northern half of the map where the volcanic breccia of the Wiggins Formation forms the steep-walled valleys of the Absaroka Range. Bedrock is the primary element exposed in this dissected topography, and clasts weathered from the breccia commonly form colluvial aprons at the base of cliffs (fig. 2). Above these steep-walled valleys are gently sloping bedrock plateaus that form high-elevation drainage divides, where unit *Rrs* is mapped. Weathering products in these areas remain in-situ for longer periods owing to shallow slope angles and poorly developed drainage networks, which allows residuum to accumulate in greater proportions. *Rrs* is present in similar low-relief settings on the shoulders of the Wind River Range and in the Washakie Range.

**Figure 2.** Photograph of cliffs in the Wiggins Formation (above) and underlying slope in the Tepee Trail formation (below) on the south ridge of Ramshorn Peak. Unit *Rcs* is mapped throughout the Absaroka Range on detachment-limited slopes similar to those pictured.

Unit *Rsc* is most commonly mapped on dip slopes of Paleozoic strata on the northern flank of the Wind River Range and where these same rocks are exposed in the unburied remnants of the Washakie Range. *Rsc* is also mapped in the Absaroka Range along the sides of broad valleys and on low-angled slopes where slopewash is more prevalent than colluvium. Unit *Rsr* is mapped exclusively in the southern half of the map area where recessive Eocene strata form low hills and weather to produce fine-grained sediment that is readily mobilized as slopewash. *Rsr* is especially prevalent in the dissected badlands of the Wind River Formation north of Dubois (fig. 3).

Map units with residuum as the primary element are present in the southern half of the map area in tributary drainages of the Wind River and on the shoulder of the Wind River Range. Unit *rRs* is mostly mapped in timbered areas along the northwest flank of the Wind River Range and near Union Pass—locations that are just beyond the Pinedale glacial limit. Unit *rsR* is commonly associated with the Wind River Formation and co-occurs with unit *Rsr* around the Dubois badlands. Whereas unit *Rsr* is mapped in heavily dissected drainages, unit *rsR* is reserved for smoother upland surfaces and interfluves where residuum is more prevalent than bedrock. Unit *rsR* is also found in the southwest corner of the map, where bedrock outcrops are rare in the recessive topography characteristic of the Aycross Formation.

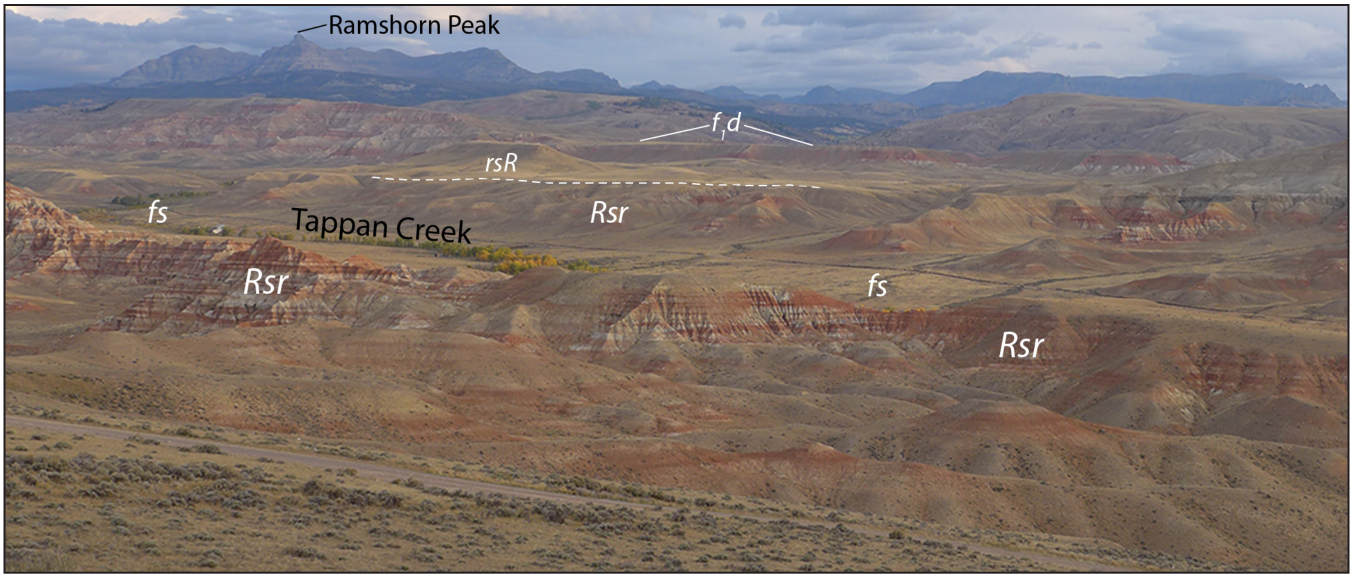



**Figure 3.** Photograph of the northward view from the Dubois Overlook. The Wind River Formation forms the variegated badlands in the foreground and middle ground, where unit *Rsr* is mapped on steep slopes, and unit *rsR* is mapped atop low-relief interfluves. Mixed fan and slopewash deposits (unit *fs*) form the valley floor along Tappan Creek; the flat surfaces in the distance are capped by piedmont gravel (unit $f_1d$).

Unit *rsc* is mapped almost exclusively in the southeastern map area near the Wiggins Fork where the surficial geology is dominated by residuum and hillslope deposits. The top and southern flank of Spring Mountain feature a veneer of angular pebbles to boulders of basalt (fig. 4), and are a special case of this unit. Unlike other nearby locations such as Table Mountain, where basalt clasts are inferred to have been transported by fluvial processes from distant sources, the basalt on Spring Mountain is derived from local vents that are associated with a network of high-angle Laramide-age faults from the Washakie Range (Keefer, 1957; Downey, 2015; Brueseke and others, 2018). Because of its nearly continuous cover across a range of landscape positions and slopes, the angular basalt rubble of Spring Mountain is interpreted to be primarily a weathered-in-place residual deposit with minor reworking by hillslope processes. Basalt outcrops are only found at and just north of the north summit of Spring Mountain, where vents and dikes cut the surrounding strata (Downey, 2015; Brueseke and others, 2018).

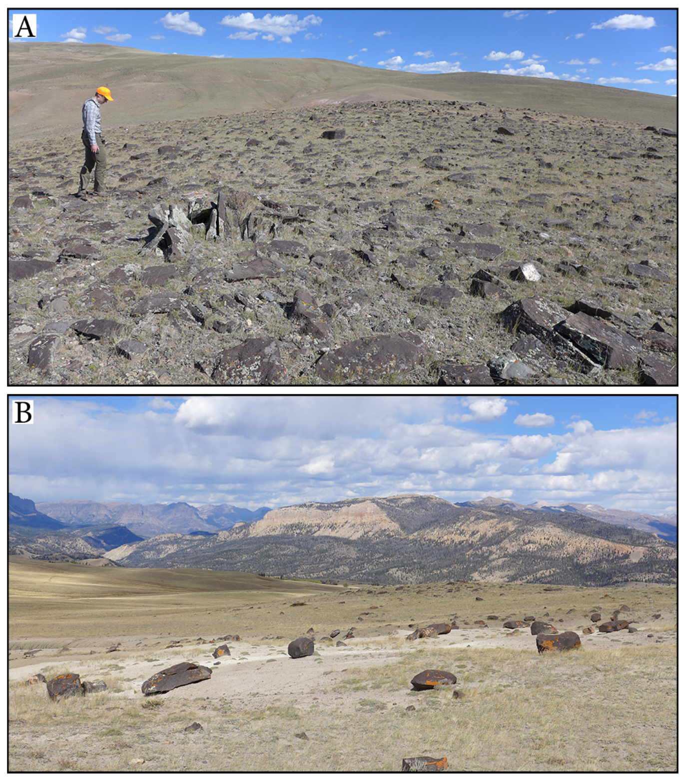



**Figure 4.** Photographs of the veneer of weathered basalt on Spring Mountain. These deposits are mapped as *rsc* and are interpreted to be residual material from basalt flows extruded from nearby vent complexes. A) Angular, shattered basalt rubble on the southern flank of Spring Mountain. B) View to the northeast from the south summit of Spring Mountain. Basalt boulders here are up to 1.5 m in diameter and rest directly on claystone of the Tepee Trail Formation.

Slopewash is mapped as the primary unit element in areas with smooth, sloping topography that are underlain by easily weathered, fine-grained sedimentary and volcaniclastic rocks in the southern half of the map. Unit *src* is found around the southern base of The Ramshorn on elevated surfaces in the Tepee Trail and lowermost Wiggins formations that have not been modified by mass wasting processes. Outcrops are rare at the surface in this area owing to the thick cover of slopewash and residuum, and the only diagnostic exposures are found in landslide headscarps. Unit *sRc* is only mapped on slopes that are beneath and mantled by unconsolidated Quaternary deposits like glacial till or alluvial terrace gravel. In these settings, slopewash—and to a lesser extent colluvium—reworked from the overlying unconsolidated deposit partially obscure the bedrock below. Most slopes like this cannot be distinguished at 1:100,000 scale, and in such cases only the overlying Quaternary unit is mapped. Unit *sRr* is mapped in areas of subdued topography with recessive bedrock. Examples include the less-heavily dissected badlands around Table Mountain in the Wind River Formation (southeastern map area) and slopes above Warm Spring Creek in the Aycross Formation (southwestern map area).

**Landslide Deposits**

Landslide mapping follows the WSGS convention of including all parts of a landslide's aerial extent in the landslide polygon, from the headscarp through the transport track to the toe of the deposit. Debris flows are the exception to this practice, where only the deposit composing the debris fan is mapped. Individual landslides or landslide complexes were first mapped as unique polygons before adjacent polygons were merged to eliminate internal contacts.

An important reference for landslide mapping on the west half of The Ramshorn quadrangle was the prior mapping of Case (2001), which is part of a 1:24,000-scale statewide landslide inventory completed by the WSGS. Through focused ground truthing and interpretation of bare-earth lidar topographic data, this study builds upon and modifies the mapping of Case (2001) by identifying previously unmapped landslides, modifying contacts to existing mapped landslides, or reinterpreting previously mapped landslides to have a different origin. Another key difference between the mapping of Case (2001) and the landslide mapping presented here are the disparate map scales, with the mapping of Case (2001) having been completed at a larger scale.

Landslides (unit *l*) are ubiquitous throughout the map area and record the important role that mass wasting processes play in the denudation of this mountainous landscape. Landslides are especially numerous and extensive in a belt along the southern escarpment of the Absaroka Range and north of the upper Wind River valley. Across the map area, landslide density and size are highest in areas that exhibit high topographic relief and steep slopes, were glaciated during the Pleistocene, and host bedrock units of contrasting competence and permeability. The geologic and topographic setting similarly influence landslide type, with unique mass movement classes characterizing different regions of the quadrangle.

Debris flows are the dominant type of mass movement in the high terrain of the Absaroka Range in the northern third of the map area. Most drainages in the Absaroka Range contain steep cirque and valley walls formed in the thick sequence of volcanic breccia and tuff of the Wiggins Formation. These rocks are friable enough to be easily undermined and detached during large storm events, and there is a high enough proportion of fine-grained particles in the breccia matrix and tuff interbeds to preferentially produce debris flows and hyperconcentrated flows when the detached material is saturated. Debris flow deposits commonly form coalesced fans (mapped as a single polygon) that choke valley bottoms and locally impound marshy bottomlands behind them (fig. 5). Rockfalls are often spatially associated with debris flows as they occur in similarly steep, high-relief terrain in the crumbly Wiggins Formation, but involve different failure and transport mechanisms (fig. 6).

Larger valleys in the Absaroka Range, such as the South Fork Shoshone River, Wiggins Fork, and Marston Creek, contain much larger block slides and rockslides that initiate high on cliffs in the Wiggins Formation. Unlike the shallow-seated point sources of debris flows, the block slides and rockslides represent complete slope failure that may be influenced by a series of west-northwest trending faults and joints in the bedrock (Love and Christiansen, 1985). One noteworthy block slide is responsible for the near-vertical, 800-m-tall north face of Wall Mountain. Two more nearby block slides coalesce to form a major knickpoint along the South Fork Shoshone River and elevate the local base level for Bliss Creek Meadows just upstream (fig. 7).

South of the Wind River on the northern flank of the Wind River Range, translational landslides and debris flows along dip slope bedding planes are common, as are smaller slump-earthflow complexes that involve clay-rich bedrock

**Figure 5.** Photograph of a debris fan in Clark Creek. The fan is visible across the valley through the burned forest, and there are recent debris flow deposits in the channel on its right flank. Note the low-gradient reach of Clark Creek upstream (left) of the constriction point formed by the debris fan.

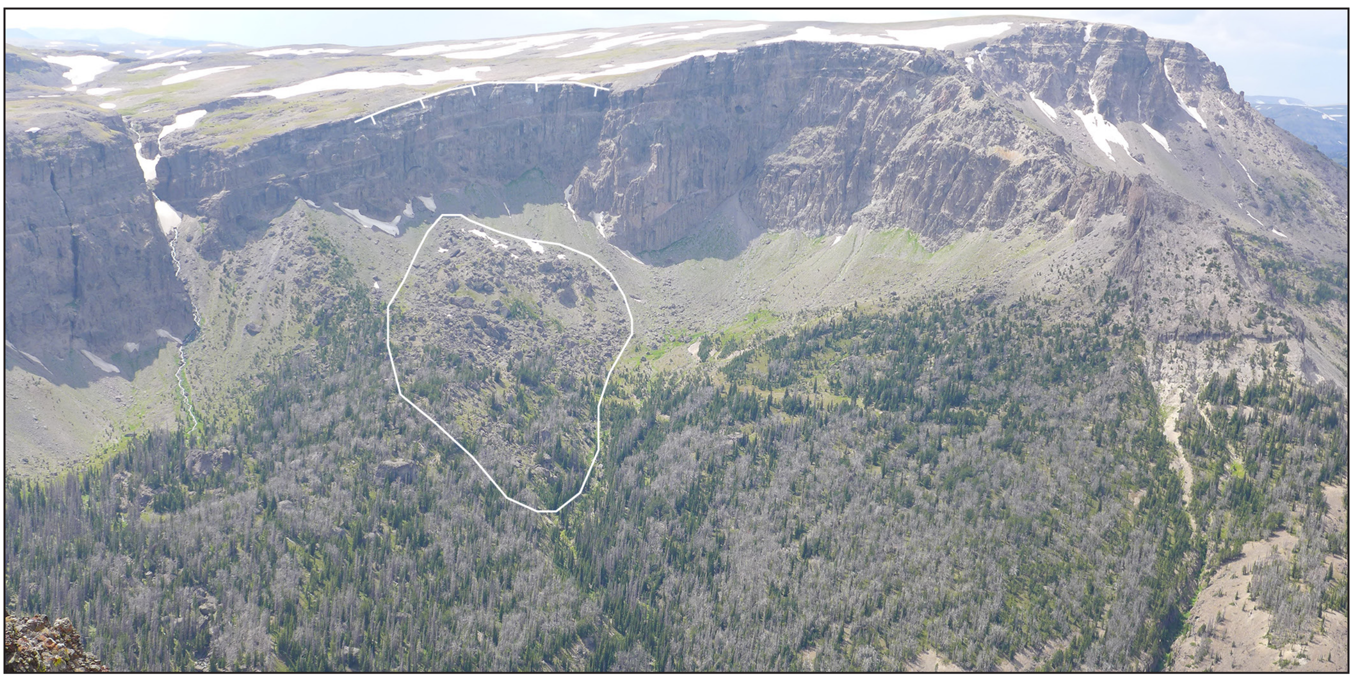


**Figure 6.** Photograph of a rockfall in the southern headwaters of Marston Creek. The approximate extent of the rockfall deposit is outlined by the white polygon, and the upper margin of the source area is marked by the hachured white line. The cliffs in the photograph are part of the Wiggins Formation, which is prone to multiple types of mass wasting along the steep valley sides and headwalls of the Absaroka Range.

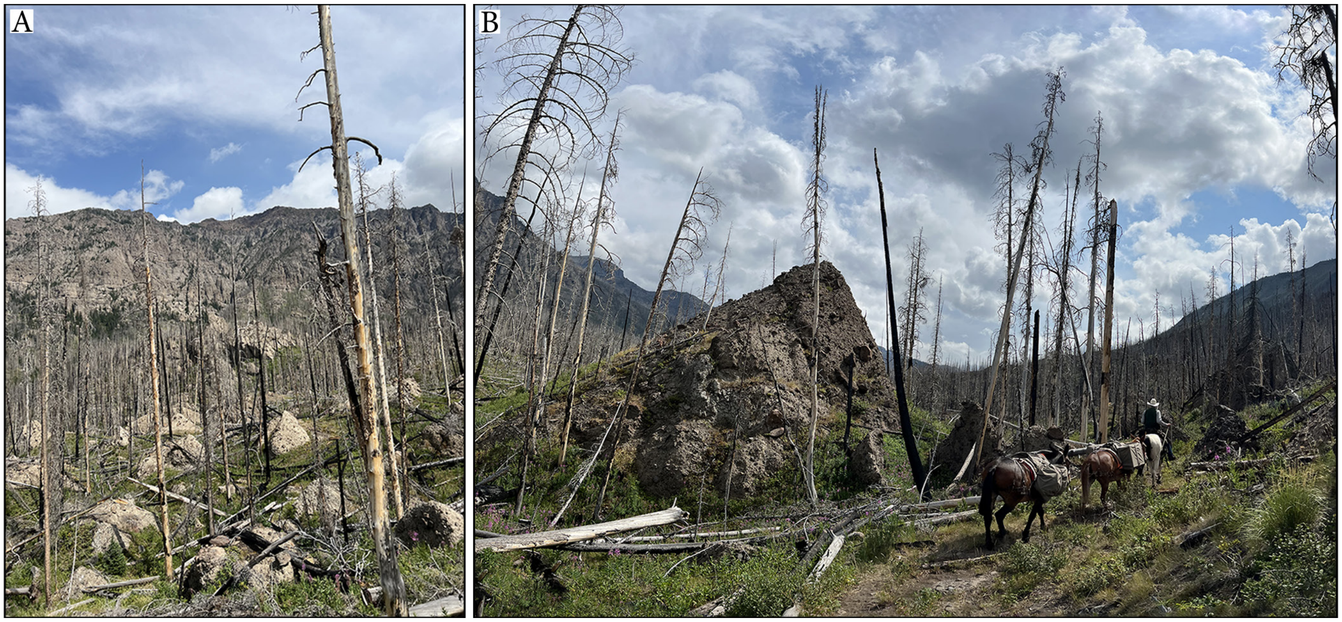



**Figure 7.** Photographs of a block slide deposit at the north end of Bliss Creek Meadows. A) View of the eastern valley wall (background) from which a portion of the slide rubble (foreground) was derived. A similar block slide occurred on the western valley wall (behind the photographer), and the deposits from these mass movements coalesce along the valley floor to constrict the channel of the South Fork Shoshone River. B) Large blocks of volcanic breccia from the Wiggins Formation are chaotically scattered throughout the slide mass. Horse and rider for scale.

units like the Wind River and Aycross formations. Farther northwest there are larger slump blocks on the east side of Lava Mountain. These blocks consist of disaggregated to semi-intact masses of basalt and andesite from Lava Mountain that maintain a rough segregation (fig. 8). The large slumps are interpreted to have formed as a result of the competent lava flows being undermined and exposed by glacial erosion, with the failure surface being the weak underlying Aycross and Wind River formations.

The most striking landslides in the map area are found in the basins along the southern escarpment of the Absaroka Range and north of the Wind River. Here, enormous slump complexes occupy entire catchments and are frequently tens of square kilometers in area. The largest complex in the West DuNoir Creek basin exceeds 100 km$^2$ in area. Due in part to their massive scale, it is difficult to identify headscarps for these slumps. However, in many cases the headscarp is interpreted to be at the clifftop hundreds of meters vertically above the deposit (fig. 9). Many of the slump complexes contain masses of relatively intact breccia from the Wiggins Formation that are back-rotated toward the headscarp and can be characterized as Toreva blocks (fig. 10). Some of the slump complexes in this area transition to earthflows at their toes—an exemplary case of this can be found north of Sixmile Creek and east of DuNoir Creek (fig. 11).

The combination of bedrock units along the southern Absaroka Range front presents a prime template for high slump susceptibility and likely played an important role in the failure of the massive Toreva blocks in this area. The thick sequence of moderately cemented volcanic breccia of the Wiggins Formation overlies the weak, impermeable, tuffaceous sandstone and claystone of the Tepee Trail Formation, which makes any steep slope prone to being undermined when saturated. Pleistocene glaciers, which carved deep U-shaped valleys as they exited the southern Absaroka Range, must also have played a role in the development of slope instability here. It is hypothesized that the largest slump complexes, like those around Brooks Lake, Horse Creek, and West DuNoir Creek, were most active in periods of deglaciation. During these times, groundwater levels were high, and the over-steepened slopes in the Wiggins Formation would have been primed for failure due to the relatively rapid exposure of a free face and loss of lateral confinement. This hypothesis is supported in part by field and lidar observations of large landslides that crosscut Pinedale glacial deposits, as seen in the DuNoir Creek valley (fig. 11). Apart from the hypothesized pulse of post-glacial slump activity, there must also be a continuum of mass movement ages along the southern front of

**Figure 8.** Photograph of a large slump block on east side of Lava Mountain. This hill is formed by a semi-intact mass of rotated and shattered basalt and andesite that slumped along the flank of Lava Mountain. There is a clear segregation between platy- versus blocky-weathering rocks in this deposit. A finger of platy-weathering rocks extends through the middle of the photograph to the left of the geologist and has a slightly lighter color than the blocky-weathering basalt to the right and left.

the Absaroka Range, with more localized background activity extending to the present day in places such as the U.S. Highway 26/287 corridor. Together, these mass wasting processes have likely been the primary driver of the northward retreat of the Absaroka Range escarpment in the latest Pleistocene and Holocene.

### Glacial Till

Glaciers covered the majority of the map area at various times throughout the Pleistocene, but their deposits are incompletely preserved. Glacial till is found mostly along and above the valley of the Wind River and its tributaries, including DuNoir Creek, Horse Creek, Wiggins Fork, and Jakeys Fork. Till is also mapped on upland surfaces north of Union Pass in the northwestern Wind River Range. The scarcity of glacial till in other parts of the map area is likely a function of post-depositional overprinting by mass movements, as interpreted along the southern Absaroka Range front, and poor preservation potential in the steep, narrow valleys that feed the Yellowstone and South Fork Shoshone rivers.

Several locations in the map area exhibit a thin, discontinuous veneer of exotic clasts on top of in-place bedrock and residuum. Though these clasts are interpreted to be glacially derived, they are only mapped as till (unit *g*) if the deposit is greater than 1 meter thick and spatially extensive enough for inclusion at the map scale; bedrock and residuum units are mapped otherwise. Accordingly, in locations such as the upland surfaces near Fish Lake Mountain and the drainage divides above West Fork Long Creek, unit *g* is confined to a relatively restricted area compared to the more widespread extent of glacial erratics, which form a veneer over much of the landscape. Deposit thicknesses were measured in the field from road, stream cut, and landslide headscarp exposures.

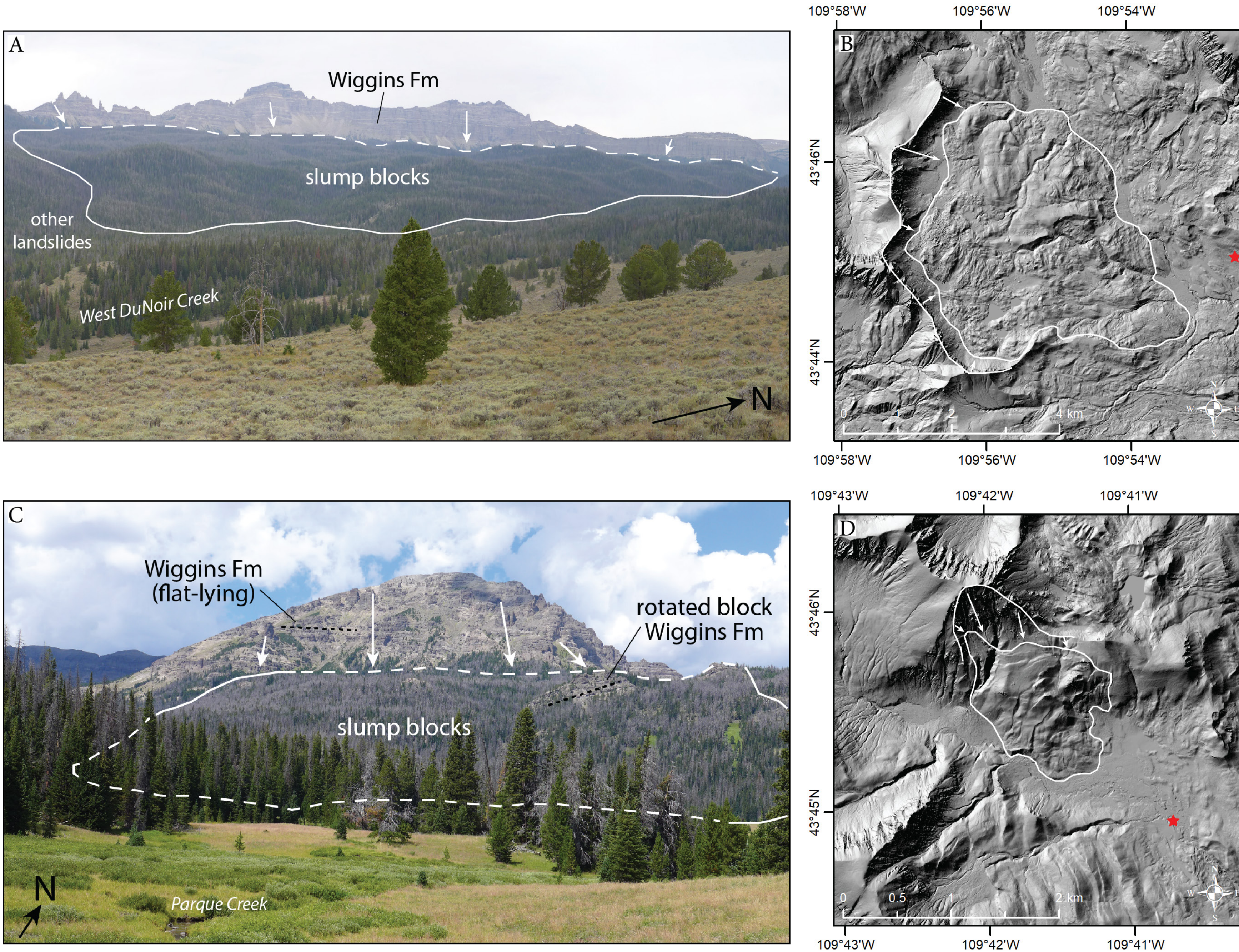



**Figure 9.** Large slump complexes along the southern flank of the Absaroka Range. Photograph (A) and corresponding lidar hillshade map (B) of a slump in the basin of West DuNoir Creek. Photograph (C) and corresponding lidar hillshade map (D) of a slump in Ramshorn Basin; note the back-rotated block of Wiggins Formation breccia in (C). Both of these examples are characteristic of the extensive slump complexes that occupy most of the southern Absaroka front. White polygons show the entent of the slump deposit, white arrows show the inferred displacement, and red stars show the location from which the accompanying photograph was taken.

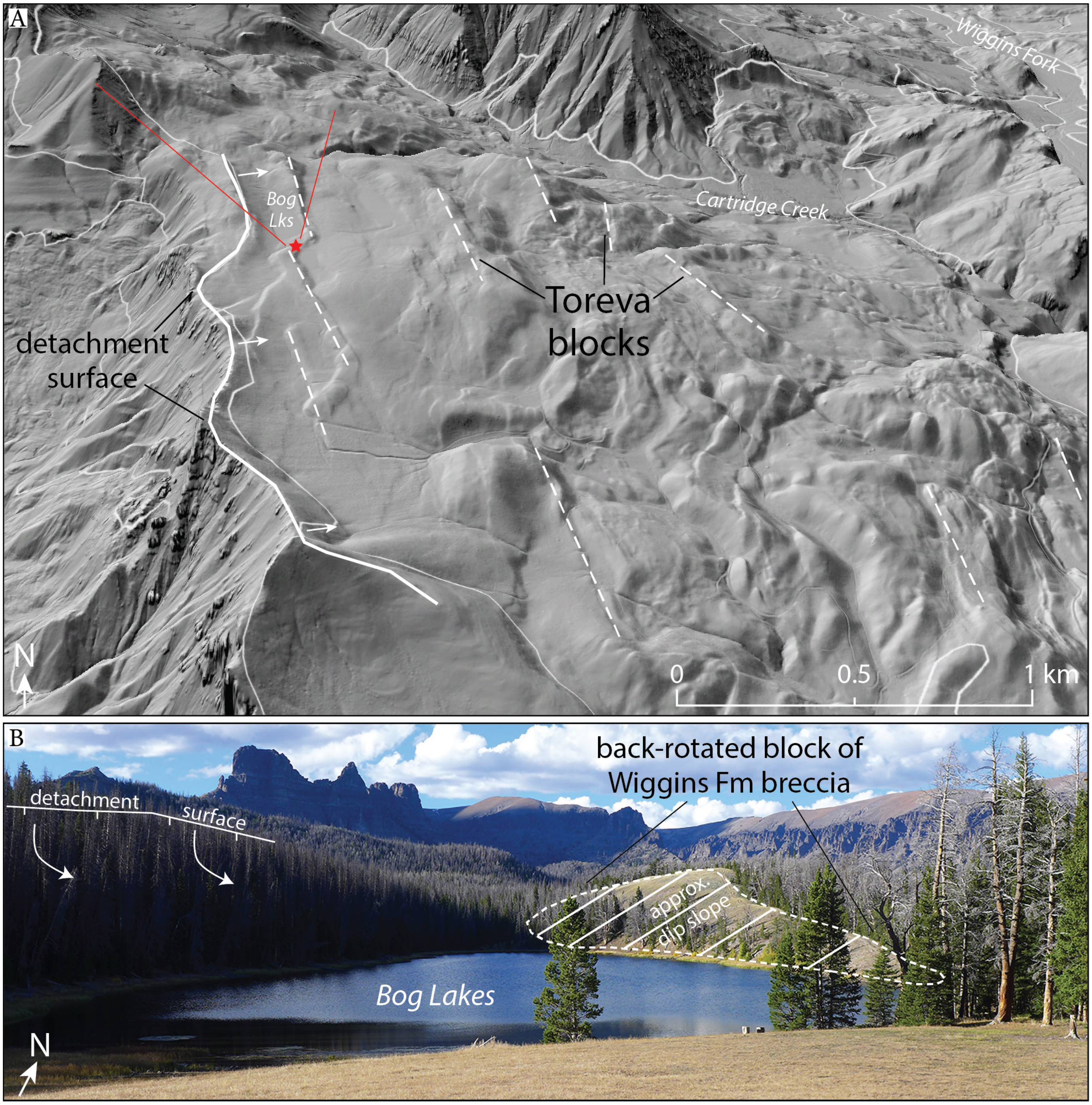



**Figure 10.** Toreva block complex near Bog Lakes. A) Oblique lidar hillshade image of the Bog Lakes and Cartridge Creek area. Intact, back-rotated blocks of Wiggins Formation volcanic breccia have slid down to the east from a detachment surface at the ridge crest (thick white line). The basal sliding surface is inferred to be incompetent, impermeable claystone beds in the underlying Tepee Trail Formation. The back-rotated masses of breccia form distinct uphill-facing slope breaks (white dashed lines) and can be classified as Toreva blocks. View is to the north with 1.5x vertical exaggeration, horizontal scale is variable due to oblique perspective. Light gray lines are contacts between map units. Red star and red lines show the photographer's location and field of view in the accompanying photograph. B) Photograph looking north across Bog Lakes. The bare slope on the northeast side of the lake roughly follows a bedding plane of a back-rotated Toreva block. The detachment surface is at the top of the treed ridge at the left side of the photograph.

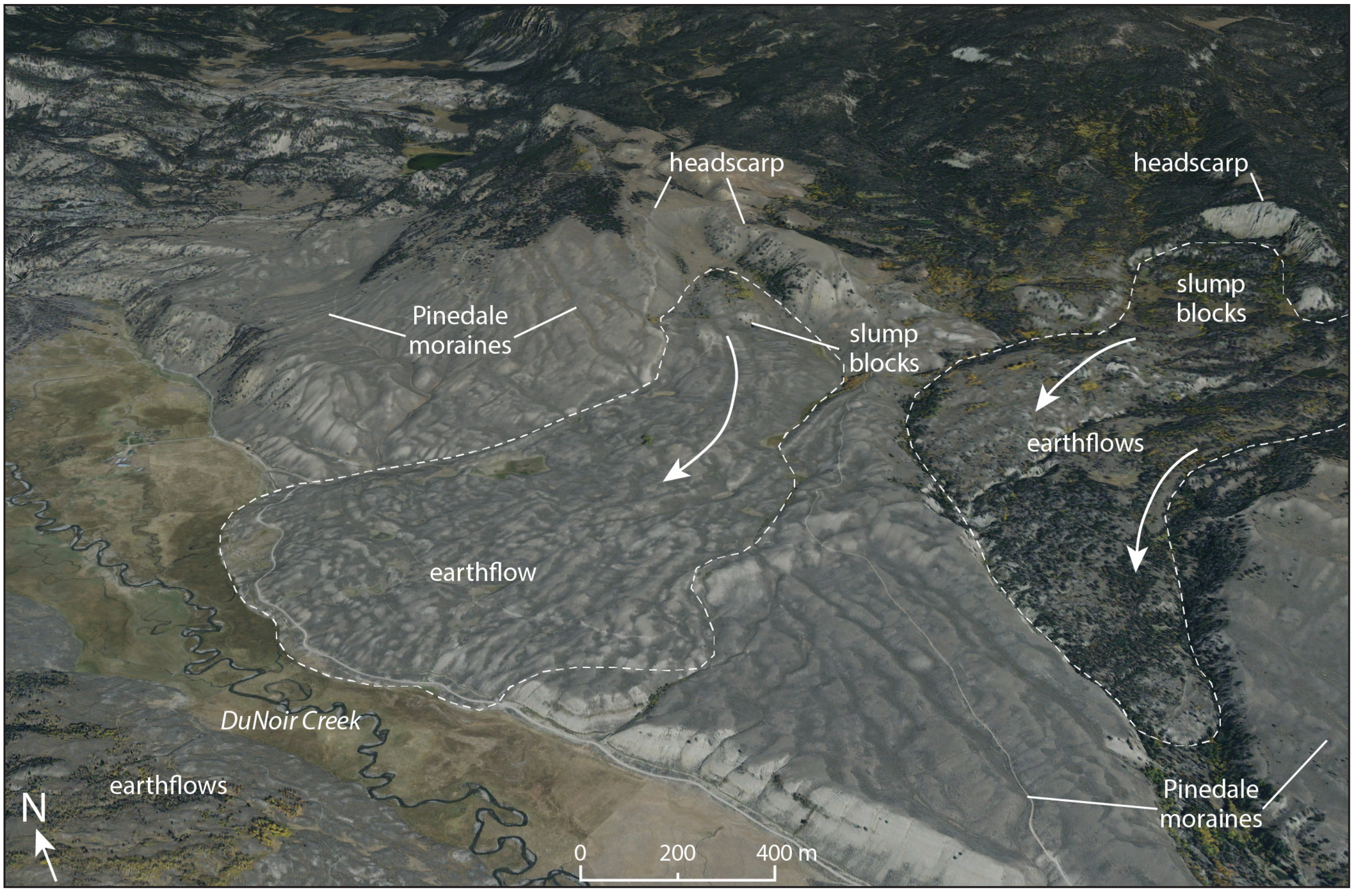



**Figure 11.** Oblique aerial photograph of slump/earthflow complexes in the DuNoir Creek valley. These mass movements are characterized by rotational slumps near their heads and distally transition into long-running earthflows. The slump/earthflow deposits are outlined in white dashed lines with the headscarp labeled; arrows show flow direction. Note how earthflows cross-cut Pinedale moraines. View is to the north-northeast with 1.25x vertical exaggeration, horizontal scale is variable due to oblique perspective.

### *Undifferentiated till*

The highest-position glacial till in the study area is found in the southwestern map quadrant at heights of 615–740 m above the modern Wind River. Because these deposits mantle multiple surfaces in different landscape positions, and because their age and origin are uncertain, they are mapped as undifferentiated till (unit $g_u$). These deposits are composed of unconsolidated pebbles, cobbles, and boulders of exotic lithology in a clayey to sandy matrix, and they form a featureless surface veneer draped atop the underlying topography. The unit is mapped in two spatial clusters—south of Pinnacle Buttes on the divide between DuNoir Creek and the Wind River, and along the Continental Divide near Fish Lake Mountain—both of which are at elevations exceeding 2,900 m. According to small-scale mapping by Pierce and others (2018), the $g_u$ south of Pinnacle Buttes is above the estimated ice surface elevation during the Pinedale glaciation, and the $g_u$ near Fish Lake Mountain sits beyond the maximum Pinedale extent of Wind River Range and GYGS glaciers, both of which suggest a pre-Pinedale age for this undifferentiated till.

Both spatial clusters of $g_u$ deposits are interpreted as being glacially derived because they are unsorted and contain a high proportion of exotic clasts. The $g_u$ south of Pinnacle Buttes has a clast composition characterized by roughly 50 percent volcanic breccia and basalt, 20 percent carbonate rocks, 20 percent rounded quartzite cobbles, and 10 percent sandstone (fig. 12). The sandstone is likely derived from the local Aycross and Tepee Trail formations, whereas the volcanic and carbonate clasts were likely transported from the Absaroka Range and Lava Mountain area. For example, the nearest outcrops of carbonate strata are 5 km to the northeast in West DuNoir Creek and 12 km to the northwest in Cub Creek, and the nearest basalt outcrop is 7 km to the east on Lava Mountain.

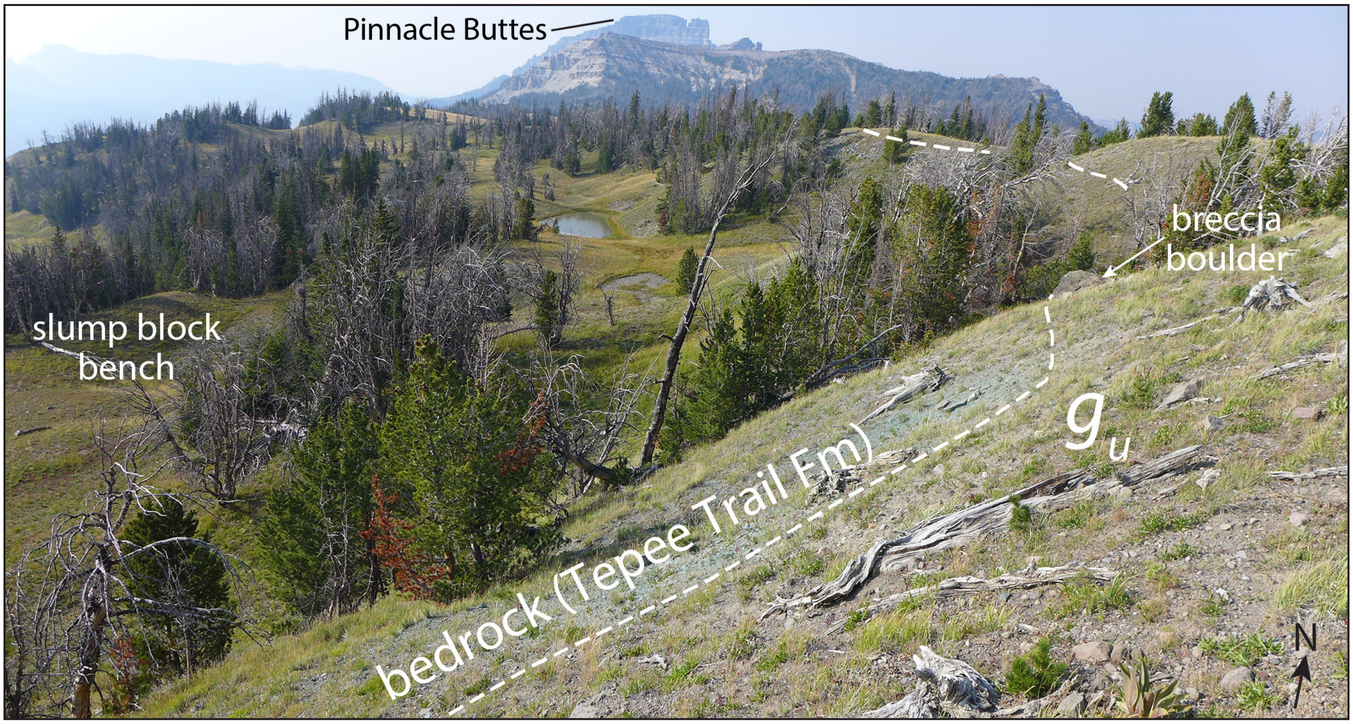



**Figure 12.** Photograph of undifferentiated, high-level glacial till (unit $g_u$) south of Pinnacle Buttes. Here $g_u$ mantles bedrock of the Tepee Trail formation, and the contact (white dashed line) is exposed in a slump headscarp. In this exposure the $g_u$ deposit is composed of exotic clasts of breccia and basalt with lesser amounts of local sandstone.

The $g_u$ near Fish Lake Mountain is composed of 60–90 percent clasts of volcanic lithology (breccia, andesite, and basalt) interpreted to have been sourced from the Absaroka Range and Lava Mountain to the north, with a lesser proportion of rounded quartzite cobbles that may be locally derived from conglomerates in the Aycross and Wind River formations. Granitic clasts from the Wind River Range are found only in the southernmost mapped polygon of $g_u$, where they make up less than 15 percent of the deposit. A slope on the east side of Fish Lake Mountain exposes a friable, white, poorly sorted quartz sandstone with interbeds of floating quartzite pebbles. This sandstone is overlain by an unconsolidated deposit with pebbles to boulders of andesite, lesser quartzite, and minor vesicular basalt and volcanic breccia. Such field relations, which demonstrate that the overlying unconsolidated material is distinct in composition from the underlying bedrock, suggest that the $g_u$ deposits were transported from their source and are not simply a residual deposit that weathered in place.

Another justification for mapping these high-level diamictons as glacial till is that they were similarly interpreted by Rohrer (1966, 1968) in 1:24,000-scale mapping. Rohrer (1966) mapped the deposit on the divide south of Pinnacle Buttes as pre-Bull Lake till due in part to its position approximately 660 m above the Wind River. Likewise, Rohrer (1968) interpreted the high-level diamicton near Fish Lake Mountain as pre-Bull Lake glacial till from the Washakie Point glaciation, the oldest of the three pre-Bull Lake glacial cycles defined by Richmond (1964). Subsequent work at the type sections for Richmond's (1964) pre-Bull Lake tills suggests that only one till—which is likely younger than 770 ka based on a normal paleomagnetic signature—is present (Hall and Jaworowski, 1999), and modern authors have largely abandoned the notion of three pre-Bull Lake tills (e.g. Pierce, 2003). Given the lack of numeric dating on these deposits and the post-1960s revision of the Rocky Mountain glacial sequence, the Washakie Point till of Rohrer (1968) is conservatively mapped here as undifferentiated till, which may be equivalent to or older than the Bull Lake till mapped elsewhere on the quadrangle.

In sum, field observations from the present study confirm that featureless high-level diamictons are present in most locations where Rohrer (1966) mapped pre-Bull Lake till and where Rohrer (1968) mapped Washakie Point till. As such, the mapping herein of unit $g_u$ follows the "Qbt" of Rohrer (1966) south of Pinnacle Buttes and the "Qw" of Rohrer (1968) near Fish Lake Mountain, except where the deposit fails to meet the 1-m thickness requirement for surficial mapping.

*Bull Lake till*

Till from the Bull Lake glaciation (unit $g_{bl}$) is preserved in two settings in the southern third of the map area. In one setting, Bull Lake till forms high lateral moraines nested outside of younger Pinedale moraines along drainages that hosted valley glaciers at the peripheries of the Greater Yellowstone and Wind River glacial systems. The $g_{bl}$ mapped east of DuNoir Creek, north of Jakeys Fork, and along the south rim of the Wind River valley at Sheridan Creek and Warm Spring Mountain are examples. Within the map area, these occurrences of Bull Lake till generally form less prominent moraines than in the valleys southeast of the map area that drain the east side of the Wind River Range, such as Bull Lake Creek (the type section for Bull Lake till) and Dinwoody Creek (Murphy and Richmond, 1965; Richmond and Murphy, 1965, 1989). This is likely due to the map area occupying a position closer to the glacial sources, its drainages being more topographically confined, and glaciers from the Absaroka Range carrying more easily weathered volcanic rocks instead of the resistant granitic rock carried by valley glaciers exiting the Wind River Range.

In a second setting, Bull Lake till is found capping gently rolling upland surfaces in the southwest corner of the map area. These deposits form a relatively featureless surface veneer that mirrors the underlying topography and lacks distinct moraine morphology. In the absence of a characteristic surface texture visible in lidar or aerial photos, Bull Lake till can only be identified in this setting through field observation. In streambank exposures, $g_{bl}$ is composed of unsorted pebbles to boulders floating in a brown clayey to sandy matrix (fig. 13A). The matrix material in $g_{bl}$ differs from residuum of the underlying Eocene bedrock, which in the southwest corner of the map area weathers to form a tan-orange sandy soil (fig. 13B). This distinction provides a means to differentiate till from residuum in areas that lack exposures, such as on the Continental Divide between Cow and Bullmoose creeks.

The mapping of Bull Lake till in the southwest corner of the quadrangle differs from that of Rohrer (1968), who mapped many of these same deposits as till from the Cedar Ridge glaciation—the middle of the three pre-Bull Lake glacial episodes defined by Richmond (1964). Rohrer (1968) mapped Bull Lake till only within and along the rim of the Wind River valley, implying that ice during this glaciation was largely confined to the existing valleys. Subsequent mapping and geochronology studies in the Greater Yellowstone region

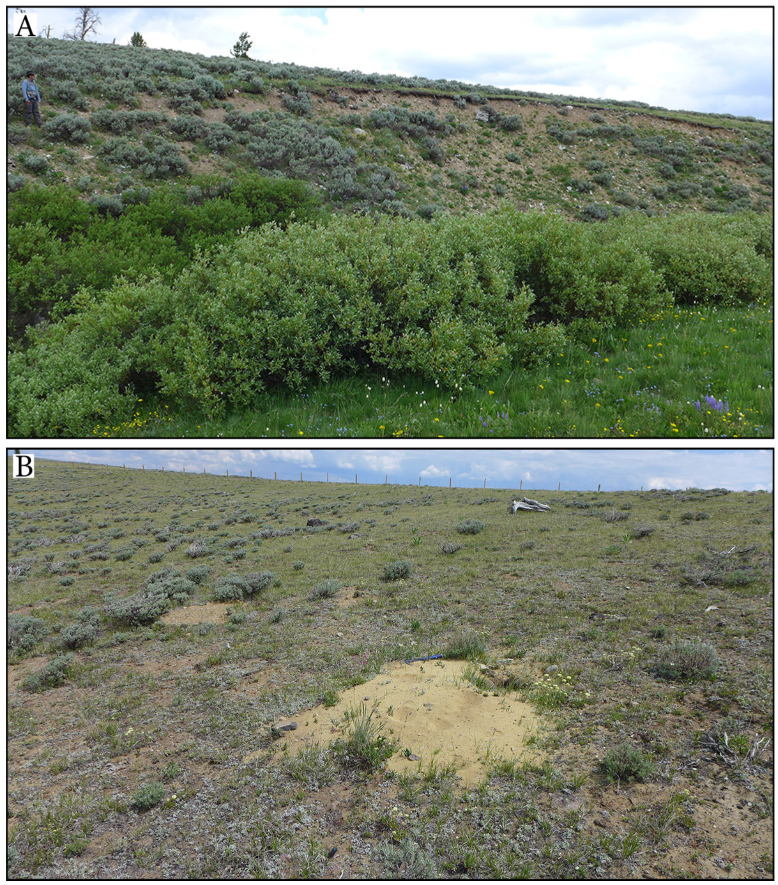



**Figure 13.** Photographs of Bull Lake till (unit $g_{bl}$) near the headwaters of Bullmoose Creek. A) A streambank exposure of $g_{bl}$. Granitic boulders are visible near the top of the exposure; note brown-colored matrix. B) Subdued topography along the Continental Divide at the head of Bullmoose Creek. Though exotic cobbles (foreground) and boulders (middle ground) of volcanic and crystalline lithology litter the surface in this location, small exposures and rodent burrows (front-center) display a distinct tan-orange sandy soil that is inferred to be residuum from the underlying sandstone bedrock. Because the overlying deposit of cobbles and boulders is less than 1 m thick, residuum, slopewash, and bedrock (unit *rsR*) are mapped here.

(e.g. Licciardi and Pierce, 2008; Pierce and others, 2018) have demonstrated that Pinedale and Bull Lake glaciers occupied larger aerial footprints than early geologists recognized and that pre-Bull Lake till is not extensively preserved in the U.S. Rocky Mountains (Pierce, 2003).

For example, 45 km west of The Ramshorn quadrangle near the mouth of the Gros Ventre River valley, Pierce and others (2018) inferred a Bull Lake age for glaciofluvial sediments that had previously been mapped as pre-Bull Lake in age by Lagas (1984) and had been mapped as a distinct formation of unknown age by Love (1994) and Love and others (1992). This reinterpretation was based on field observations and topographic analysis of moraine loops from local valley glaciers and on a revised understanding of the wide extent of Bull Lake glaciers in the Jackson Hole area (Pierce and others, 2018). In the same vein, Pierce and others (2018) interpreted sharp-crested moraines with abundant closed depressions along tributaries of the Gros Ventre River to belong to the Pinedale glaciation, whereas Lagas (1984) mapped the same moraines as Bull Lake in age. The surficial geologic mapping of Mauch and others (2021, 2022) on the Jackson Lake quadrangle largely follows these more recent interpretations of Pierce and others (2018), which are informed by region-wide cosmogenic radionuclide dating completed over the past two decades. Accordingly, deposits of both Pinedale and Bull Lake till in the Gros Ventre River valley extending east toward the Continental Divide are mapped to greater spatial extents on the surficial geologic maps of the Jackson Lake quadrangle (Mauch and others, 2021, 2022) than they are in mapping by prior workers (Lagas, 1984; Love and others, 1992; Rohrer, 1969). Mapping on the west half of The Ramshorn quadrangle follows the same precedent, with the Cedar Ridge till of Rohrer (1968) being mapped as Bull Lake till instead.

Mapping of Bull Lake till in the southwest corner of the study area is also informed by interpretation of lidar-derived hillshades and slope maps (U.S. Geological Survey, 2020)—resources that were not available to prior workers. These digital datasets show that the areas where glacial till forms a smooth veneer on upland surfaces are adjacent and distal to sharp-crested, hummocky moraines with abundant closed depressions. The morphology and landscape position of these sharper moraines suggests they are Pinedale in age, which is consistent with small-scale mapping by Pierce and others (2018). It follows that till deposits immediately distal to these Pinedale moraines are Bull Lake in age. These spatial relations are present near the western map boundary at Sheridan Creek and along the southern map boundary near Lake of the Woods and Union Pass (fig. 14).

Despite the disagreement in age designation, field observations from the present study generally support the compositional and textural differences between the Cedar Ridge and Washakie Point tills described by Rohrer (1968) on the Fish Lake quadrangle. In areas that Rohrer (1968) mapped as "Qcs" (Cedar Ridge till south of Fish Lake Mountain), boulders and cobbles of granitic lithology, along with locally derived quartzite cobbles, make up greater than 90 percent of clasts within the till. Granitic boulders in these deposits, which can be as large as 5 m in diameter, are mostly buried at the surface (fig. 15). Volcanic rocks generally compose less than 10 percent of clasts in these till deposits, though they become more numerous to the north.

In areas that Rohrer (1968) mapped as "Qw" (Washakie Point till) and "Qcw" (Cedar Ridge and Washakie Point tills, undifferentiated), the till has a finer-grained texture with predominantly cobble-and-smaller sized clasts. Approximately 60–90 percent of clasts are of volcanic lithology, 10–40 percent are locally derived quartzite cobbles, and 15 percent or less are of granitic lithology. Furthermore, upland surfaces mantled by Rohrer's (1968) Washakie Point till are at slightly higher landscape positions than those mantled by his Cedar Ridge till. These field observations support Rohrer's (1968) decision to map the Cedar Ridge and Washakie Point tills as distinct units. The mapping presented here largely follows this distinction but applies a different age interpretation, with Rohrer's (1968) Washakie Point till reclassified as $g_u$ and his Cedar Ridge till revised to $g_{bl}$. The most notable exceptions to this practice occur where tills mapped by Rohrer (1968) are observed to be too thin (less than 1 m) for inclusion on a surficial geologic map (fig. 13B).

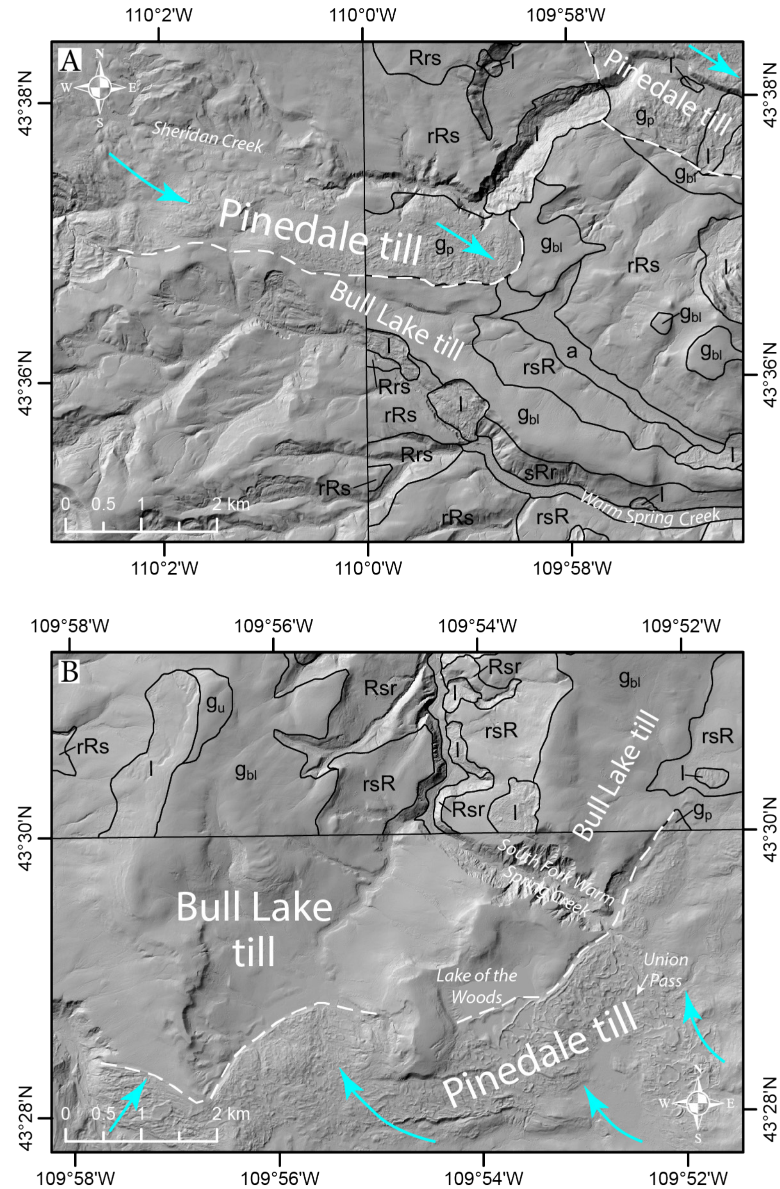



**Figure 14.** Lidar hillshade maps of the distribution of Pinedale and Bull Lake till near Sheridan Creek at the western map boundary (A) and Lake of the Woods at the southern map boundary (B). Hummocky topography and sharp-crested moraines characteristic of Pinedale till are visible in the lidar hillshade. Bull Lake till, which forms much smoother topography, is immediately distal to Pinedale till in these two areas. White dashed lines highlight the outermost Pinedale terminal and lateral moraines. Blue arrows show approximate flow directions of Pinedale ice based on moraine orientation. Black polygons and labels are map units from the west half of The Ramshorn quadrangle.

*Extent of Bull Lake glaciers*

An additional objective of mapping Bull Lake till in the southwest map quadrant was to determine the approximate extent and source of Bull Lake glaciers in this area and whether ice from the north (GYGS) and south (Wind River Range) converged during this time. Pierce and others (2018) described evidence for Bull Lake glaciers filling all of the Gros Ventre River valley and extending to uplands near the river's headwaters in the southwest corner of The Ramshorn quadrangle. The present study sought to test these hypotheses in the area roughly bound by the main and south forks of Warm Spring Creek and the southern and western map boundaries.

Observations of clast composition in till are key to determining glacial source and extent because of the contrast in bedrock lithology in the two source areas. Volcanic clast-bearing till in this region can only have come from the Yellowstone Plateau and Absaroka Range to the north, as there are no volcanic units mapped to the south in the Wind River or Gros Ventre ranges (Love and Christiansen, 1985). The most common volcanic clasts observed here are andesite and breccia, which likely originate from the Absaroka Range, and basalt, which is likely sourced from nearby Lava Mountain. Conversely, the Wind River Range provides the closest and most abundant source of granitic rocks in this area, and it's probable that these clasts were transported by glaciers that originated from the south and southeast. Rounded quartzite cobbles are another common constituent in tills from this area. These clasts likely weathered out of conglomerate beds in the Aycross and Wind River formations. Because both formations are found in the southwest map area (Rohrer, 1968; Love and Christiansen, 1985), quartzite clasts are equivocal in determining glacial provenance.

A deposit of Bull Lake till up to 8 m thick caps the ridge north of the main fork of Warm Spring Creek at the western map boundary. Several landslide headscarps above the valley of Warm Spring Creek expose the till and underlying outcrops of tan sandstone, mudstone, and interbedded conglomerate. On the ridge where the deposit is not exposed, scattered andesite boulders and rounded quartzite cobbles litter the ground surface. The till here is composed of roughly 50 percent andesite and 40 percent quartzite, with basalt, volcanic breccia, and sandstone accounting for the remaining 10 percent.

The northernmost observed $g_{bl}$ deposits that contain granitic rocks are in the headwaters of Bullmoose Creek near the Continental Divide, approximately 7 km south of Warm Spring Creek. Clast composition changes markedly across small distances in this area. An exposure on the north side of Bullmoose Creek exhibits a clast composition of 70 percent granitic cobbles and boulders, 25 percent rounded quartzite cobbles, and 5 percent andesite cobbles and boulders. Several hundred meters to the southeast, the proportion of granitic clasts increases to roughly 95 percent, and no volcanic rocks are observed. The predominance of granitic clasts in Bull Lake till continues to the southern map boundary, where large boulders are mostly buried on the ridge of the Continental Divide (fig. 15). Thus, notwithstanding the nearby, higher-elevation $g_u$ deposits, Bullmoose Creek marks the approximate southern extent of volcanic clasts in till.

Observations of multiple $g_{bl}$ exposures in Bullmoose Creek that contain both granitic and volcanic clasts suggest that glaciers from the Absaroka and Wind River ranges indeed converged, or at least overlapped in extent during different stades of the Bull Lake glaciation. The narrow belt along which these granitic- and volcanic-clast-bearing tills are found, along with the sharp spatial gradient in clast composition to the north and south, imply that this zone of convergence was relatively restricted. These observations are consistent with those documented immediately to the west in Washakie Park on the Jackson Lake quadrangle (Mauch and others, 2022). Together, this suite of observations suggests that north- and south-flowing Bull Lake glaciers coalesced along the Continental Divide, and that the collective ice mass pushed into the drainages of the Gros Ventre River and Warm Spring Creek to the west and east, respectively (fig. 16). This hypothesis is supported by multiple observations of Bull Lake till deposits in Cow Creek that contain approximately equal proportions of granitic and volcanic clasts, further indicating that ice in this area originated from two disparate sources.

**Figure 15.** Photograph of granitic boulders in Bull Lake till along the Continental Divide at the southern map boundary. Most boulders in this deposit are similarly buried with only the tops exposed, and are up to 5 m in diameter. These boulders were transported by glaciers that flowed out of the Wind River Range, the peaks of which are visible 20 km to the southeast at the horizon.

*Pinedale till*

Till from the Pinedale glaciation (unit $g_p$) is widespread in the southern map area along the valley and tributaries of the Wind River. These deposits are inset and at lower landscape positions than adjacent Bull Lake till where it is preserved. Pinedale till forms well-expressed moraines with a rougher surface texture, sharper crests, and more closed depressions than the smooth, sometimes featureless landforms characteristic of Bull Lake till. Pinedale moraines often have boulders perched at the surface. The distribution and orientation of moraines in the southern map area suggest that Pinedale glaciers here were part of several distinct valley glacier systems that formed lobes along the southern flank of the GYGS. While these valley glacier systems roughly followed the path of modern drainages, ice was not confined to valley bottoms and instead spread across several low drainage divides and topographic benches. In this regard, the present mapping differs from that of Rohrer (1966, 1968), who mapped Pinedale till only in the valley of the upper Wind River and along Brooks Lake Creek.

Valley glacier systems from the upper Wind River and DuNoir Creek formed a coalesced lobe during the Pinedale glaciation, as recorded by Pinedale till preserved along these valleys and on the adjacent valley walls and interfluves. Pinedale moraines are most clearly expressed on the surfaces above and adjacent to DuNoir Creek (both to the east and west), between the forks of Long Creek (fig. 17), near the east end of Elk Ridge, and in the bottom of the Wind River valley between the mouths of Lava and Sheridan creeks. Pinedale moraines exhibit a nested, inset spatial

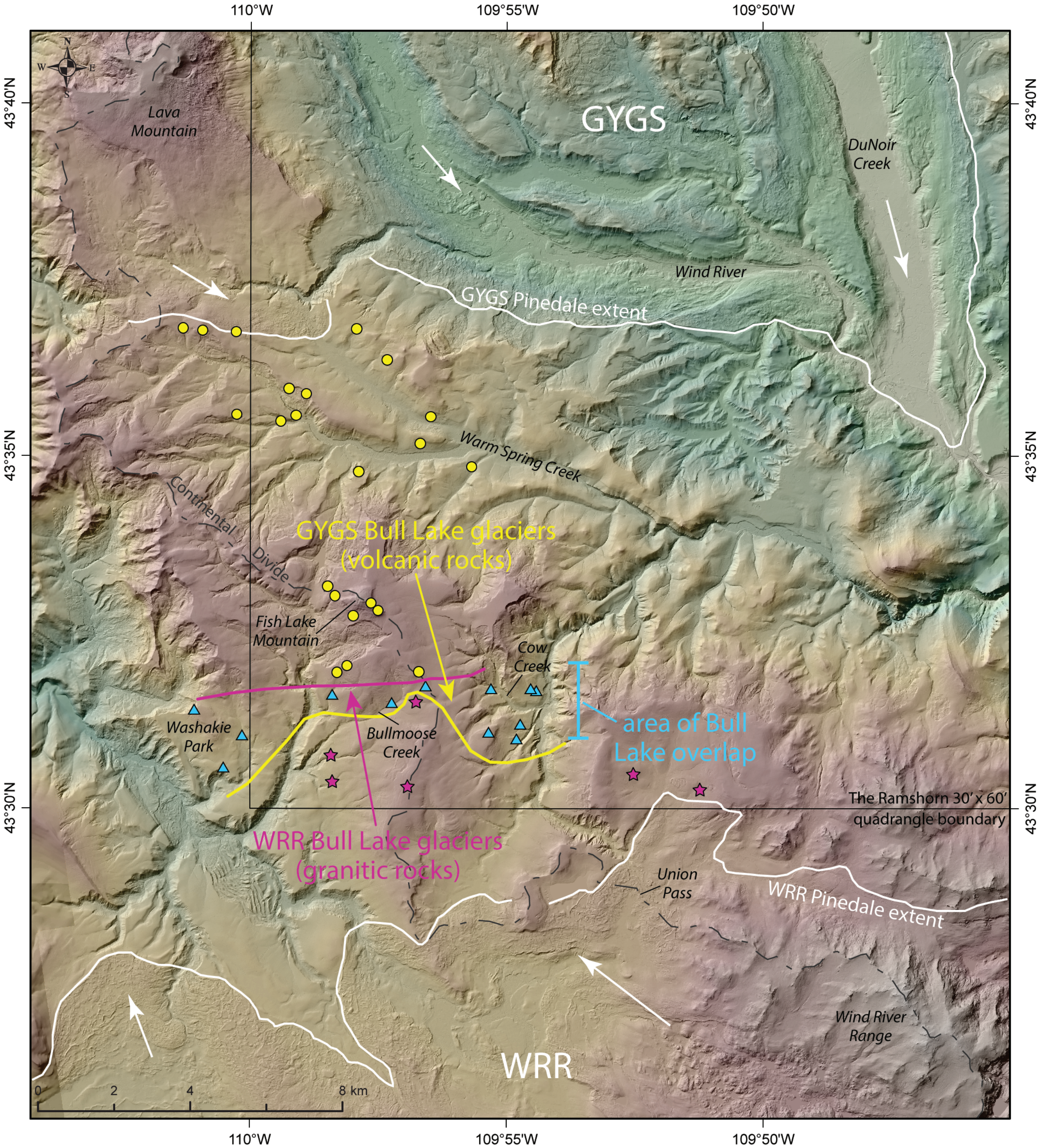



**Figure 16.** Shaded relief map of the distribution, composition, and source of Bull Lake till (unit $g_{bl}$) in the southwest corner of The Ramshorn quadrangle. Colored points are field waypoints where Bull Lake till was observed to be composed of granitic rocks (magenta stars), volcanic rocks (yellow circles), and a combination of granitic and volcanic rocks (blue triangles). The magenta and yellow lines represent the approximate northern extent of granitic rocks and southern extent of volcanic rocks in Bull Lake till, respectively. Granitic rocks were transported from the south in Wind River Range glaciers (abbreviated WRR on map) whereas volcanic rocks were transported a longer distance from the north as part of the Greater Yellowstone Glacial System (GYGS). The zone of Bull Lake till containing both lithologies supports the hypothesis that during Bull Lake time, glaciers from the Wind River Range and Greater Yellowstone converged in a narrow belt spanning the Continental Divide. White lines are the outermost Pinedale moraines from the Wind River Range and the Wind River-DuNoir Creek lobe of the GYGS; white arrows are approximate flow directions of Pinedale glaciers. The dashed black line is the Continental Divide; the solid black line is the boundary of The Ramshorn quadrangle. Waypoints outside of the quadrangle boundary are from mapping on the adjacent Jackson Lake quadrangle (Mauch and others, 2022).

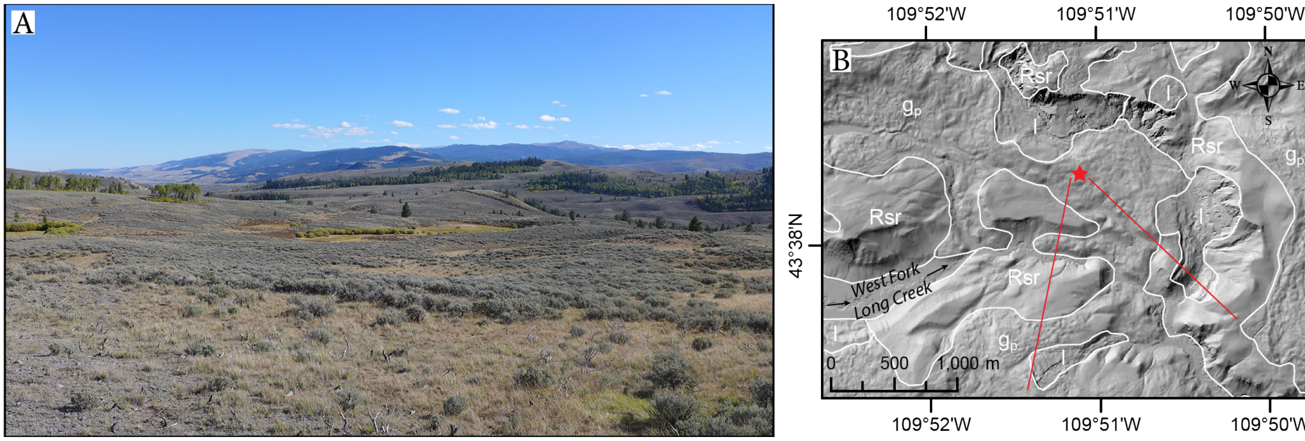



**Figure 17.** Pinedale moraines above West Fork Long Creek. A) Photograph with view to the southeast toward the east end of Elk Ridge. Note the marshy closed depressions in the middle ground. B) Lidar hillshade map, with location and field of view of the accompanying photograph displayed by the star and red lines. Note the hummocky surface topography characteristic of Pinedale till (unit $g_p$). Map units are shown in white.

relationship with Bull Lake moraines in only two locations in this area—south of Sheridan Creek (fig. 14A) and on the east side of the lower DuNoir Creek valley—which reflects the generally poor preservation of Bull Lake till. In many locations, Pinedale till is crosscut and modified by younger landslide deposits; examples are found around the upper DuNoir Creek valley (fig. 11) and along the south flank of the Wind River valley.

In the catchments of the west and middle forks of Long Creek, an extensive veneer of exotic volcanic boulders and cobbles blankets most surfaces that do not otherwise display distinct moraines. This veneer is typically less than 1 m thick, is best viewed in road cuts and stream banks, and mantles bedrock of the Wind River Formation. Well-expressed Pinedale moraines are found in both higher and lower landscape positions than the surfaces covered in this thin veneer, the two landform types grade to each other, and no notable differences in clast composition or deposit stratigraphy are apparent. These observations suggest that the veneer and moraines are different geomorphic expressions of a single deposit rather than deposits of two distinct ages. Accordingly, the thin veneer of exotic clasts is inferred to be Pinedale till, but it is mapped as *Rsr* because it is less than 1 m thick and Wind River Formation bedrock is so near to the surface. Where $g_p$ is mapped in this area, the deposit is greater than 1.5 m thick, and it forms distinct moraine landforms that are visible in the field and in lidar and aerial imagery datasets.

The $g_p$ mapped around Long Creek, the upper Wind River valley, DuNoir Creek, and Sheridan Creek is more extensive than the Pinedale till mapped by Rohrer (1966, 1968) and Miner and Delo (1943), who confined the deposit to valley bottoms. Field observations and interpretation of lidar-derived hillshades and slope maps show hummocky, sharp-crested moraines extending up the valley walls and onto drainage divides in these areas. A field transect from the bottom of the Wind River valley near the mouth of Lava Creek to the lowest landslide debris on the east flank of Lava Mountain suggests that the moraines Rohrer (1966) mapped as Bull Lake in age are as sharp and hummocky as his Pinedale moraines in the valley bottom and are mantled by a similar proportion of volcanic boulders at the surface (fig. 18). South of Sheridan Creek at the western map boundary, a deposit Rohrer (1968) mapped as Sacagawea Ridge till (the youngest of the three pre-Bull Lake tills of Richmond [1964]) forms a hummocky complex of nested moraines with abundant closed depressions (fig. 14A), many of which form perennial ponds. Consistent with mapping on the adjacent Jackson Lake quadrangle (Mauch and others, 2022) and small-scale mapping by Pierce and others (2018), this prominent deposit is reinterpreted as Pinedale till. The position of this deposit and similar Pinedale till deposits farther west (Mauch and others, 2022) suggest that Pinedale ice along the southern margin of the GYGS wrapped around the west side of, and potentially overtopped, Lava Mountain.

Farther east, a second Pinedale valley glacier system occupied the drainages of Horse Creek and the Wiggins Fork. This lobe flowed south out of the Absaroka Range, extending into what today are the arid badlands north of Dubois.

A terminal moraine from a trunk glacier that occupied Horse Creek is conspicuously preserved at the mouth of Little Horse Creek. Widespread till deposits in Horse Creek Basin (fig. 19), on the flank of EA Mountain, and at the head of Little Alkali Creek indicate that ice in this system was not confined to valleys alone. Field observations also suggest that ice from the Wiggins Fork overtopped the eastern drainage divide and flowed through Windy Gap between Indian Ridge and Black Mountain. Till in the basin immediately east of Windy Gap is composed primarily of limestone (90 percent) and Flathead Sandstone (10 percent) from the Washakie Range, and the deposit forms southeast-streamlined moraines . If the glacier depositing this material had originated from the north in Bear Creek, these moraine crests would likely have more of a southerly trend, and Bear Creek would be expected to exhibit more of a U-shaped profile than its existing narrow-bottomed gorge. Additional evidence for a glacier from the Wiggins Fork overtopping the ridge at Windy Gap comes from the high landscape position of hummocky Pinedale moraines on the northeast flank of Spring Mountain, 2 km west of Windy Gap. These moraines are perched at elevations up to 200 m higher than Windy Gap, indicating that ice would have been thick enough to overtop the divide on the east side of the Wiggins Fork (fig. 20). This interpretation of Pinedale till in the Horse Creek/Wiggins Fork glacial lobe largely agrees with the mapping of Keefer (1957) and Pierce and others (2018).

The best example of arcuate terminal moraines in the study area is at the mouth of Jakeys Fork in the southeast corner of the map. This moraine complex is marked by hummocky topography with closed depressions and subparallel, boulder-topped ridges that emanate from the confined drainage to the south (fig. 21). Just south of the map boundary, the Jakeys Fork moraines are met by terminal moraines from Torrey Creek, another south-

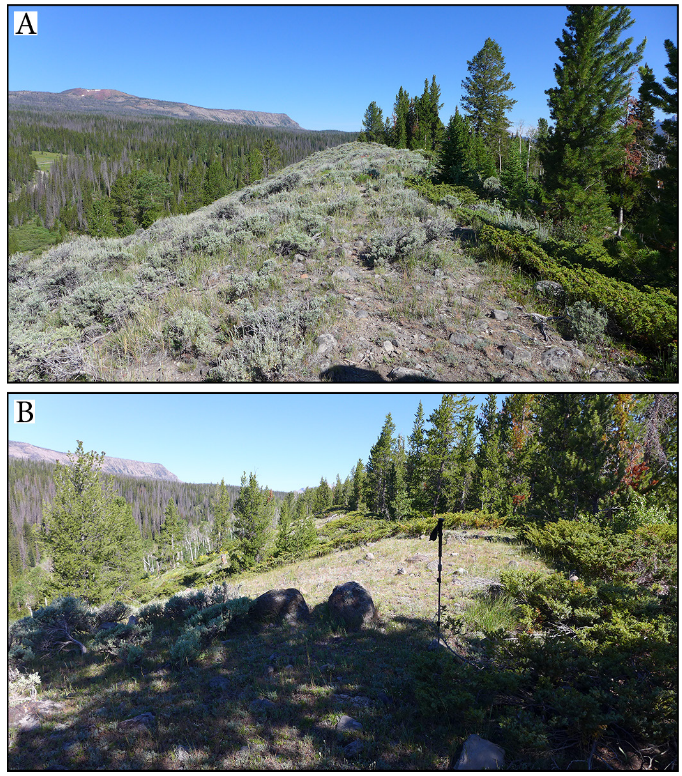



**Figure 18.** Photographs of a Pinedale moraine east of Lava Creek showing the sharp moraine crest (A) and volcanic boulders perched at the surface (B). The sharp surface topography and presence of unburied boulders suggest this moraine, and the till that composes it, are Pinedale rather than Bull Lake in age. Photographs are to the northwest with Lava Mountain in the background. Hiking pole, 1.3 m tall, for scale.

**Figure 19.** Photograph of Pinedale till in Horse Creek Basin, view to the north. Much of Horse Creek Basin is blanketed with Pinedale till, which forms the treeless, hummocky terrain visible in the photograph. Boulder in the foreground (1.2 m high) is Flathead Sandstone that was likely transported south from a source in either Horse Creek (left background) or the Wiggins Fork (right background).


**Figure 20.** Photograph of the view to the southwest from the south shoulder of Indian Ridge. Pinedale till (unit $g_p$) forms hummocky moraines that cap elevated surfaces on both sides of the Wiggins Fork, including on the flank of Spring Mountain to the southwest. Glacial erratics up to 4 m in diameter are perched on a bedrock bench at the distal end of the $g_p$ deposit on the near side of the Wiggins Fork in the photograph. The high landscape position of glacial till in this area suggests that ice during Pinedale time was thick enough to flow through Windy Gap and cross the drainage divide into the Bear Creek catchment (from right to left in photograph). White dashed lines denote the approximate extent of $g_p$.

ern tributary of the Wind River. Clasts in these Pinedale till deposits are almost exclusively granitic rocks from the Wind River Range. In fact, the Jakeys Fork deposit and a till along the southern quadrangle boundary near Union Pass are the only Pinedale till deposits in the map area that came from glaciers in the Wind River Range; all other mapped Pinedale till deposits originated from the Absaroka Range and GYGS.

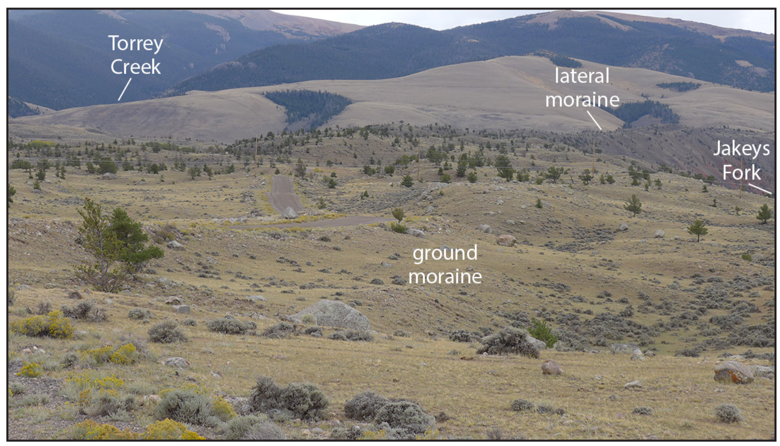



**Figure 21.** Photograph of the Pinedale moraine complex near the mouth of Jakeys Fork and Torrey Creek. Note the hummocky topography and rounded granitic boulders up to 3 m in diameter. The glaciers that built these moraines were the northernmost valley glaciers in the Wind River Range to reach the floor of the Wind River Basin during Pinedale time. View is to the south.

Pinedale till is only sparsely preserved in the steep, narrow valleys of the Absaroka Range in the northern half of the map. Settings with greater preservation potential include valley walls near tributary confluences, such as the Wiggins Fork near the confluences of Frontier and Caldwell creeks (fig. 22), and broad headwater basins, such as Hidden Basin at the head of East Fork Creek. Field observations and aerial imagery reconnaissance suggest that till is less prevalent in the valleys of Marston, Younts, Needle, and Venus creeks than previously mapped by Love and Christiansen (1985). Given the widespread nature of till deposits along its southern flank as described above, it is hypothesized that much of the Absaroka Range was indeed glaciated during both the Pinedale and Bull Lake episodes, but that most deposits in this rugged topography have since been eroded or overprinted.

*Post-Pinedale till*

Till post-dating the Pinedale glaciation (unit $g_h$) is inferred to be present in two high basins in the Absaroka Range according to aerial imagery and lidar interpretation. These deposits form sharp-crested, unvegetated, and unstable moraines in north- and east-facing cirques, and they may date to the Little Ice Age (approximately 1400 to 1850 AD). One small deposit of $g_h$ is mapped in Lake Pocket near the headwaters of Horse Creek. The other more extensive deposit is below the north face of Younts Peak at the headwaters of the North Fork Yellowstone River. The $g_h$ at Younts Peak rims a permanent snowfield that is protected in the high, north-facing cirque. The only other permanent snowfield large enough to map in the study area is on the north face of Coffin Butte and has been labeled on topographic maps as the DuNoir Glacier.

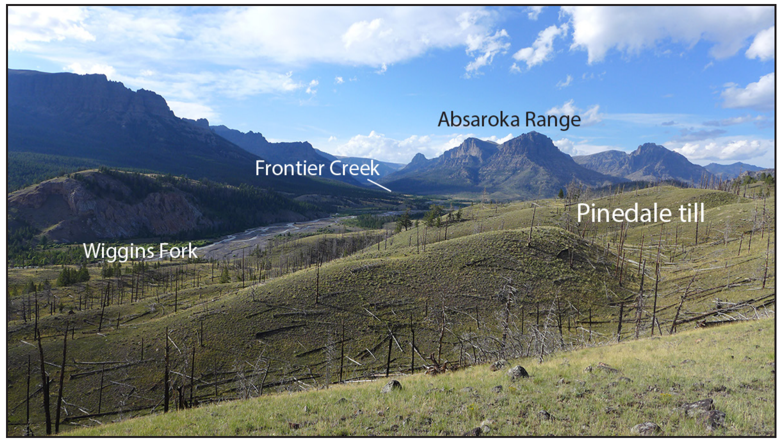



**Figure 22.** Photograph of Pinedale till near the confluence of Caldwell Creek (behind photographer) and the Wiggins Fork. Pinedale till in this area caps valley-parallel ridges that are cored by sharply folded Paleozoic and Mesozoic bedrock (visible across the river in shadow)—structures that are part of the Washakie Range. Whereas the underlying bedrock is primarily limestone and sandstone, the till here is composed of approximately 80 percent volcanic rocks derived from the Absaroka Range. View is to the north.

## Alluvial Deposits

Alluvial deposits are prevalent in the southern half of the map area along the Wind River and its tributaries. These deposits span a wide range in age and origin, and they compose a diverse suite of landforms consisting of benches, fans, and terraces.

*Bench deposits*

An alluvial gravel caps Table Mountain in the southeast corner of the map and is the only bench deposit (unit *b*) mapped in the study area. This deposit is distinguished by its high landscape position and large planform dimensions of approximately 3 km by 1.5 km. It is mapped as a bench deposit because of the landform it caps, which is consistent with prior usage of this unit in the single element classification scheme for surficial geologic mapping by the WSGS (Case and others, 1998).

The Table Mountain bench deposit is composed of cobbles to small bounders up to 0.5 m in diameter in a sandy matrix. Approximately 80 percent of clasts are andesitic, with lesser proportions of vesicular basalt, limestone, chert, quartzite, and crystalline rocks. Most clasts are rounded to subrounded, with the exception of the vesicular basalt, which can be subangular and is preferentially found as small boulders that litter the surface near the margins of Table Mountain. The deposit is approximately 10 m thick on its north end and generally thins to the south (Keefer, 1957). In a landslide headscarp exposure on the southeast side of Table Mountain, the deposit is 1.5 m thick and mantles weathered, variegated bedrock of the Wind River and Indian Meadows formations. Clasts have pedogenic carbonate rinds on their undersides up to 3 cm thick (fig. 23).

Table Mountain is 380–400 m above the active channel of the Wind River and 360–370 m above the active channel of the Wiggins Fork at similar longitudinal positions. This is higher than both the highest Wind River terrace (WR-15) documented by Chadwick and others (1997) in the Wind River Basin, which is approximately 290 m above grade, and the Black Rock gravel deposits of Blackwelder (1915), which were reported to range from 150 to 240 m above grade in western Wyoming. The surface of Table Mountain slopes gently to the south and east at a gradient of less than 1 degree, consistent with the regional flow direction of modern drainages. Accordingly, the ancient fluvial system that deposited the gravel cap likely flowed southeast from the Absaroka highlands. The presence of subangular, vesicular basalt may suggest a short transport distance for these clasts from volcanic vents on Spring Mountain, which is less than 10 km to the north. Chadwick and others (1997) extrapolated a linear incision rate anchored by younger, numerically dated terraces to estimate an age of 1.7 million years for the WR-15 terrace. The Table Mountain gravel is likely even older given its higher landscape position; however, no independent geochronology has been completed here.


**Figure 23.** Table Mountain bench deposit. A) Photograph of the view north from the top of Table Mountain. In the middle distance a landslide headscarp exposes the approximately 4-m-thick gravel cap and underlying brown-red bedrock of the Wind River and Indian Meadows formations. B) Photograph of pedogenic carbonate coating the underside of gravel clasts in the Table Mountain bench deposit. Pencil, 15 cm long, at lower left for scale.

### *Alluvial fan deposits*

A variety of deposits of diverse age are preserved in fan and piedmont landforms in the quadrangle. The oldest of these are piedmont gravel deposits (unit $f_1d$) that are clustered in the southeast map area in the valleys of the Wind River, Wiggins Fork, and Horse Creek. These deposits contain a mix of locally derived clasts and those of exotic lithology, and they likely record composite deposition from mainstem drainages, small local tributaries, and adjacent hillslopes. Clasts range in size from pebbles to small boulders and are rounded to subrounded. Deposits can be greater than 10 m thick at their toes on top of a basal bedrock strath.

A common characteristic of $f_1d$ deposits is that they compose or cap piedmont landforms that slope down toward valley axes, perpendicular to the gradient of mainstem fluvial terraces (fig. 24). Many of these landforms can be classified as piedmont alluvial fans emanating from small tributaries, but others form a continuous apron along valley walls with no defined catchment above. In other areas, such as the badlands around Tappan Creek, piedmont gravels cap low ridges but still slope perpendicular to the valley axis (fig. 3). Another defining characteristic of $f_1d$ deposits is their position well above the active channel, which suggests they are relict features. The greatest proportion of piedmonts grade to the Bull Lake outwash terrace, such as those on the south side of the Wind River near the mouth of Little Warm Spring Creek. Other piedmonts are incised up to 15 m at their toes by the Bull Lake outwash terrace, as observed along the Wiggins Fork near the mouth of Little Alkali Creek. Because $f_1d$ encompasses deposits at multiple heights and landscape positions, it's probable that these gravels trace back to multiple depositional cycles spanning a range of ages.

Alluvial fans composed of Pinedale glacial outwash are mapped as unit $fo_p$. These fans are distinguished from other alluvial fan units according to position relative to Pinedale moraines, height above grade, and degree of dissection. The fan complex at Jakeys Fork and Torrey Creek, as well as the small fan in Branch Creek, are mapped immediately distal to the Pinedale terminal moraines of the Jakeys Fork valley glacier and the Wind River/DuNoir Creek lobe of the GYGS, respectively. The position of these fans at the outer edge of Pinedale terminal moraines, the 10- to 15-m incision at their toes by the Wind River floodplain, and the presence of pebbles to boulders of lithologies that are prevalent in the glacial headwaters all suggest that these are outwash fans sourced from Pinedale glaciers. Other $fo_p$ units are mapped farther up-valley within the Pinedale glacial limit and are interpreted to be younger recessional outwash fans from when glaciers had already receded beyond these points. These fans are distinguished primarily

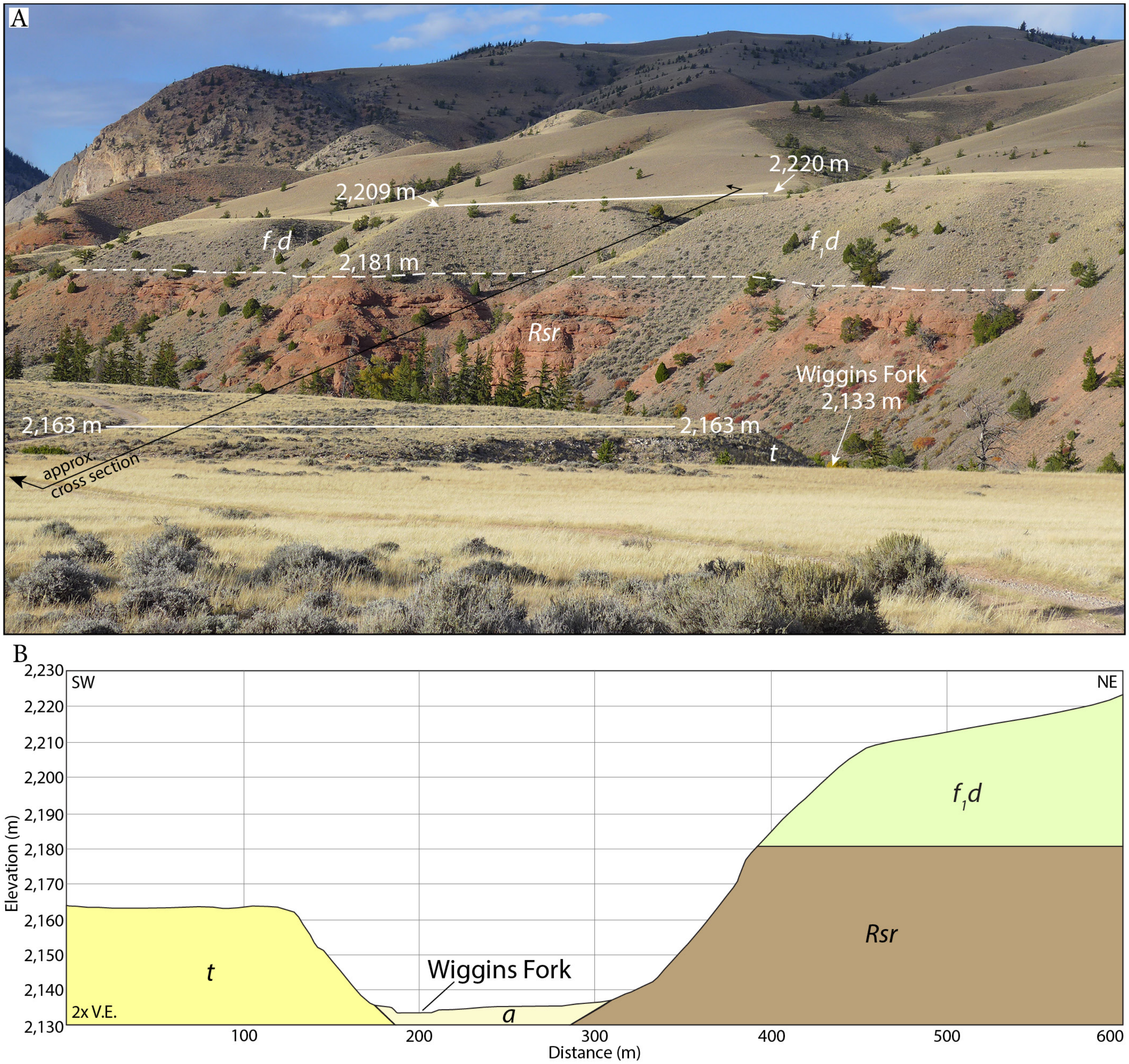



**Figure 24.** Piedmont and terrace gravel deposits along the lower Wiggins Fork. A) Photograph to the north of a piedmont (right) and terrace (left) along the lower Wiggins Fork. Piedmont gravels (unit *f₁d*) compose landforms that slope toward the valley axis whereas terrace gravels (unit *t*) compose landforms that slope parallel to the valley gradient. The piedmont gravel pictured is approximately 28 m thick at the toe of the deposit and its basal bedrock strath is 48 m above the floodplain and active alluvium (unit *a*) of the Wiggins Fork. The reddish bedrock underlying the piedmont here (unit *Rsr*) is part of the Indian Meadows Formation. White lines and labels show elevations referenced in the cross section below; thin black line shows the approximate line of cross section. B) Southwest-to-northeast cross section measured near the accompanying photograph. Cross section line is perpendicular to the valley axis and oblique to the view of the photograph. Surface elevations are extracted from lidar data; contacts between map units are simplified; 2x vertical exaggeration.

by their anomalous height above grade and their high degree of dissection compared to other alluvial fans in comparable valley positions. They are typically incised 13–20 m by active drainages and display distributary channels of small underfit streams. Recessional outwash fans are found in the middle Wiggins Fork valley, at the mouth of Lava Creek along the Wind River, and at the confluence of Lake Creek with the South Buffalo Fork.

Mixed alluvial fan and slopewash deposits (unit *fs*) are common along the margins of broad valleys in the southeast map area. These deposits reflect a combination of alluvial deposition from small, ephemeral tributaries and sheetwash deposition directly from adjacent hillslopes. They are distinguished from mainstem alluvial deposits by their fine-grained texture and the presence of local, often easily weathered, sediment that has been transported only a short distance. These deposits commonly form sweeping aprons that are the transition from eroded bedrock uplands to alluvial bottomlands (fig. 25). In the badlands around Horse and Tappan creeks, *fs* deposits form large, coalesced aprons that can occupy entire valleys where active alluvium is found only in arroyos that are too narrow for display at the map scale (fig. 3). Fan and slopewash aprons typically have a concave-up profile. Slope angles are variable, but are between those of the flat valley bottoms and the steeper upland hillslopes.

Some *fs* deposits grade to higher-position surfaces such as Bull Lake outwash terraces, as is the case south of the Wind River near Geyser Creek. It is hypothesized that these higher *fs* deposits reflect active or recent alluvial fan and slopewash deposition that is restricted in extent and graded to a higher local baselevel, and that they are not necessarily older than *fs* deposits in the valley bottoms.

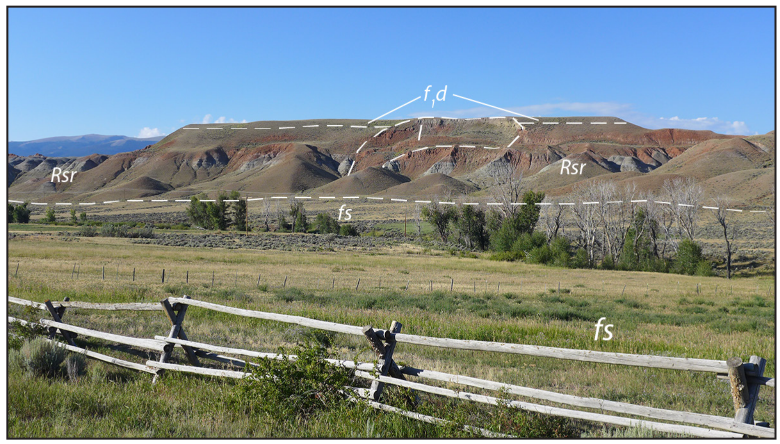



**Figure 25.** Photograph of mixed alluvial fan and slopewash deposits (unit *fs*) in the valley of Little Horse Creek. These deposits form sweeping aprons that slope down from bedrock hillsides to the valley axis in the badlands north of Dubois. Beyond the *fs* in the photograph are bedrock, slopewash, and residuum (unit *Rsr*) of the Wind River Formation, a landslide (unit *l*), and piedmont gravels (unit $f_1d$) capping a ridge. White dashed lines denote unit contacts; view to the south.

Pure alluvial fan deposits (unit *f*) are mapped where the fan landforms they compose grade to the modern valley bottom, where they are usually incised less than 7 m by the active channel. Some fan landforms display a classic radial planform shape with distributary channels, such as the Sixmile Creek fan in the DuNoir Creek valley. Others form coalesced aprons that fill openings in valleys upstream of a constriction, such as along Little Alkali Creek, or along gently sloping valley margins, such as along lower Horse Creek. Alluvial fan deposits in the latter cases are distinguished from *fs* deposits by a comparative lack of slopewash and a greater distal extent that implies alluvial deposition.

Where alluvial fan deposits grade to and are mixed with active alluvium, unit *fa* is mapped. This typically occurs in otherwise narrow valleys upstream of constrictions along perennial streams. Localized deposits of fa are common amongst the large landslide complexes on the south flank of the Absaroka Range, where there are frequent constriction points in drainages and the water table is high. These deposits are mapped as *fa* primarily because alluvial fan deposits and active alluvium cannot be spatially separated at the map scale. In a few select instances, alluvial fans that show particularly active deposition—indicated by sparse vegetation, evidence for recent channel avulsions, and no incision of the toe—were mapped as *fa*; an example is along the South Fork Shoshone River at the mouth of Robinson Creek.

*Terrace deposits*

Terrace gravel deposits are found in all major drainages in the map area, including the Wind River, Warm Spring Creek, DuNoir Creek, Horse Creek, the Wiggins Fork, and the South Fork Shoshone River. Terrace deposits are more prevalent in drainages in the southern and eastern halves of the map where there is greater accommodation space to preserve unconsolidated deposits than in the rugged, bedrock-dominated topography of the Absaroka Range. Most terrace deposits are cobble-gravels with a sandy matrix and contain rock types reflective of the upstream bedrock lithology. Quartzite, granitic rocks, limestone, and basalt are preferentially preserved in terrace deposits because of their resistance to weathering, and they are sometimes found in proportions greater than their outcroppings in the catchment would suggest. Terrace units are mapped according to their height above grade and inferred age (fig. 26). Following WSGS convention, terrace deposits that can be spatially correlated with glacial till and are inferred to have been built principally through glacial outwash are designated as outwash terraces (unit *to*), and are assigned a subscript of *p* for Pinedale and *bl* for Bull Lake. Subscript *pbl* refers to pre-Bull Lake.

The highest terrace deposits in the map area (unit $t_{pbl}$) cap hills in the Wind River Formation badlands on the north side of the Wind River valley around Dubois. There are two terrace levels within this unit, both of which are higher than the Bull Lake outwash terrace. The higher $t_{pbl}$ level is represented by a terrace 2.5 km northwest of Dubois at an elevation of 2,290 m (the Dubois Overlook) and a terrace immediately north of the Wind River from the mouth of Jakeys Fork at an elevation of 2,250 m. Both of these terraces are 170–180 m above the channel of the Wind River. The Dubois Overlook terrace deposit is approximately 17 m thick, composed almost exclusively of volcanic rocks (andesite, basalt, and breccia) with trace amounts of quartzite and granitic rocks, and displays pedogenic carbonate rinds on clasts in the top meter of the deposit (fig. 27). Basalt clasts as large as small boulders are conspicuous at the surface near the margin of the terrace, a characteristic similar to the bench deposit on Table Mountain.

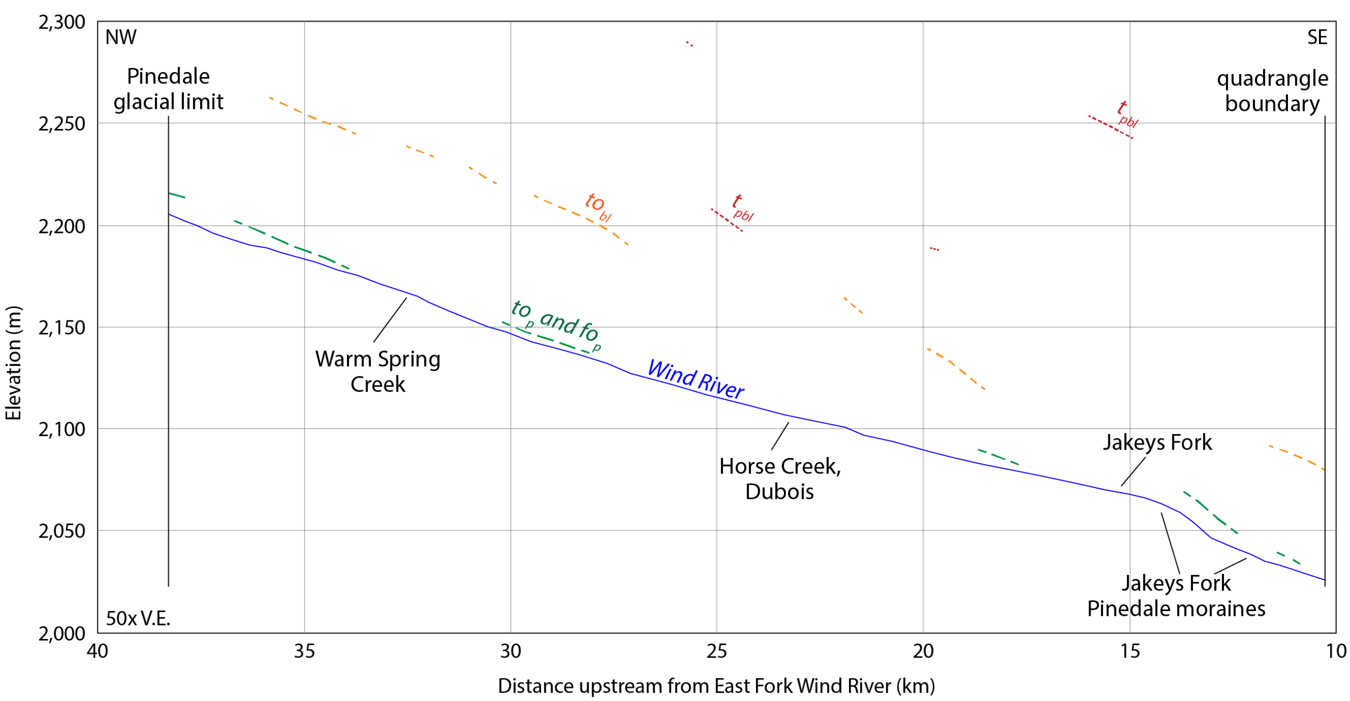



**Figure 26.** Longitudinal profile of the Wind River and its terraces between the Pinedale terminus of the Wind River/DuNoir Creek lobe of the Greater Yellowstone Glacial System and the southern boundary of The Ramshorn quadrangle. The profile of the Wind River centerline is shown as the blue solid line. The profile of the treads of adjacent mainstem terraces, where preserved, are shown in green long dashes (Pinedale outwash terrace and fans, units $to_p$ and $fo_p$), orange medium dashes (Bull Lake outwash terrace, unit $to_{bl}$), and red short dashes (high Wind River terraces, unit $t_{pbl}$). The knickpoint at the downstream end of the profile occurs where the Wind River encounters boulder-rich Pinedale till deposited in the terminal moraines of the Jakeys Fork valley glacier. Surface elevations are extracted from lidar data; 50x vertical exaggeration.

The two high $t_{pbl}$ terraces in the study area correlate in height with the WR-7 terrace that is east of the mouth of the East Fork Wind River (southeast of the quadrangle) documented by Hancock and others (1999), which is similarly around 170 m above grade. Hancock and others (1999) used a cosmogenic radionuclide depth profile to constrain the age of the East Fork Wind River WR-7 terrace to approximately 300 ka, though they acknowledge this age is likely erroneously young due to eolian deflation of the overlying loess cover. Farther downstream near Dinwoody Lakes, Chadwick and others (1997) assigned an age of 660 ± 20 ka for the WR-7 terrace based on the presence of interbedded Lava Creek Tuff, which was earlier dated by Izett and others (1992). More recent geochronology on the Lava Creek Tuff suggests it dates to around 631 ka (Matthews and others, 2015).

The lower $t_{pbl}$ level is represented by a broader, inset terrace below the Dubois Overlook at an elevation of 2,200 m, as well as a small remnant terrace west of Mason Draw at an elevation of 2,190 m. These terraces range from 85 to 100 m above grade and are higher than the nearby Bull Lake outwash terraces, which here are between 59 and 72 m above grade. On the basis of landscape position and correlation with the numerically dated WR-7 terrace downstream, both levels of $t_{pbl}$ terraces in the map area are inferred to predate the Bull Lake glaciation.

Outwash from the Bull Lake glaciation (unit $to_{bl}$) forms a prominent terrace along the Wind River in the southeast part of the map and extends downstream beyond the study area. Downstream from the mouth of DuNoir Creek at Stoney Point, a broad terrace with a tread 80–90 m above grade projects to some of the few remaining deposits of Bull Lake till in the upper Wind River valley, which sit on a bench east of DuNoir Creek. This location is inferred to be near the downstream limit of coalesced ice from the Wind River and Absaroka ranges during the Bull Lake glaciation, and it consequently represents the most ice-proximal Bull Lake outwash terrace in the Wind River valley. According to core data from the U.S. Bureau of Reclamation obtained by Keefer (1957), the depth to bedrock beneath this terrace tread is as great as 60 m, though much of the unconsolidated material may be glacial till rather than fluvial gravel.

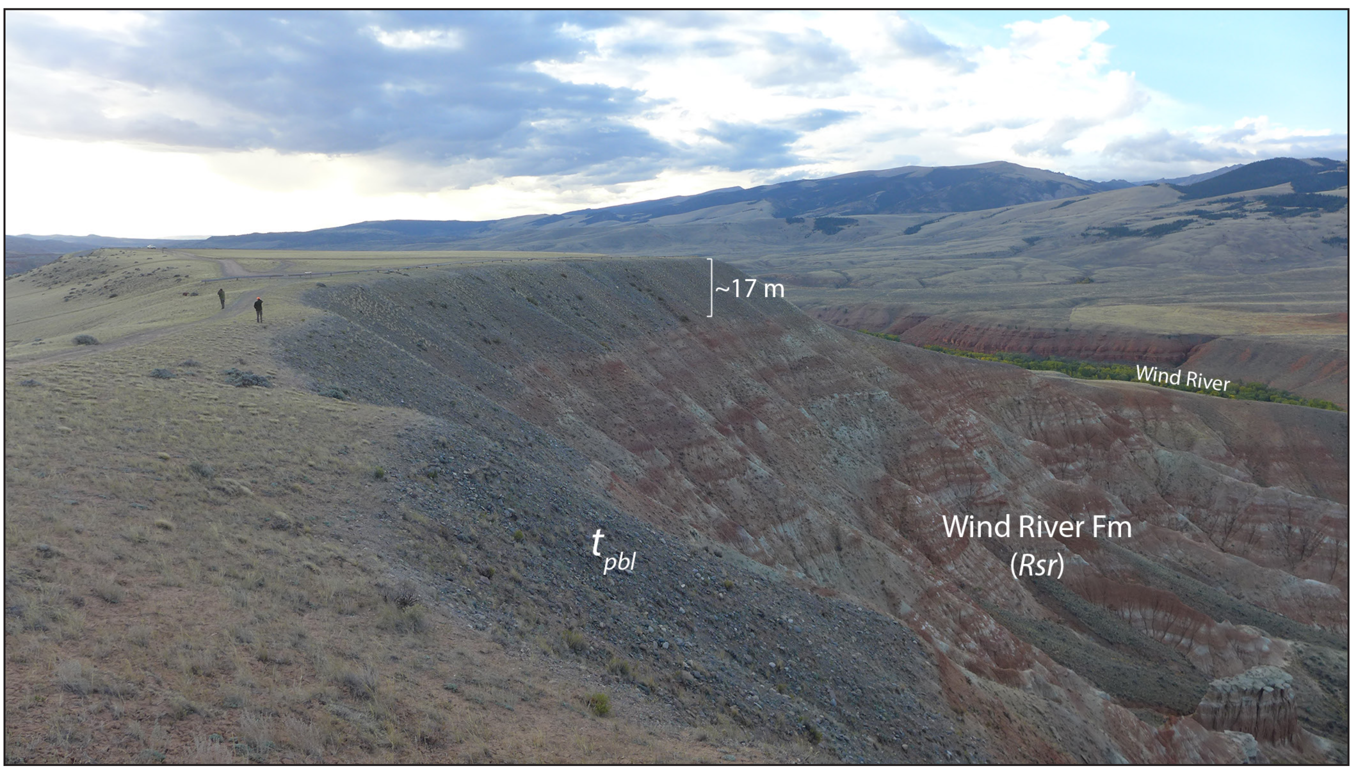



**Figure 27.** Photograph of a high terrace deposit (unit $t_{pbl}$) at the Dubois Overlook. This gravel deposit is approximately 17 m thick and composed primarily of rounded volcanic pebbles, cobbles, and small boulders. The basal contact with the underlying bedrock, slopewash, and residuum (unit *Rsr*) of the variegated Wind River Formation is visible as a distinct color change in this photograph. View is to the southeast.

Downstream from Stoney Point, the Bull Lake outwash terrace is relatively continuous on the south side of the Wind River, where it is perched on northeast-dipping strata of the Phosphoria and Chugwater formations that have been beveled to a planar strath. The tread height in this reach gradually decreases from 73 m above grade near the mouth of Warm Spring Creek to 63 m above grade at the Dubois Municipal Airport (fig. 26). Immediately east of the town of Dubois on the north side of the Wind River, the Bull Lake outwash terrace is between 59 and 63 m above grade. At the southern map boundary near Torrey Creek, the tread of the $to_{bl}$ terrace is 53–58 m above grade. This pattern of tread heights decreasing downstream along the Wind River is consistent with that documented by Chadwick and others (1997) for the stretch southeast of the map area between Dinwoody Lakes and Riverton, where the WR-3 terrace drops from 60 m to 25 m above grade. It is also consistent with the measured heights of the WR-3 terrace just downstream of the map area at the mouth of the East Fork Wind River (the type section for the Circle terrace of Blackwelder [1915]), where the terrace is 55–60 m above grade (Chadwick and others, 1997).

Given its longitudinal profile, tread heights, and spatial relations with Bull Lake moraines, it is reasonable to correlate the $to_{bl}$ terrace of the present map with the WR-3 terrace of previous workers, which itself has been traced to Bull Lake moraines in multiple drainages exiting the Wind River Range (Chadwick and others, 1994, 1997). Several previous studies have dated the WR-3 terrace in the upper Wind River Basin. Cosmogenic $^{36}Cl$ surface exposure dating of boulders that sit on the WR-3 terrace at the mouth of the East Fork Wind River yielded a depositional age of 125–100 ka (Phillips and others, 1997). A cosmogenic radionuclide depth profile in gravel of the $to_{bl}$ terrace near the Dubois Municipal Airport yielded ages of 102 ± 10 and 121 ± 13 ka for the radionuclides of $^{10}Be$ and $^{26}Al$, respectively (Hancock and others, 1999). Finally, extrapolation of incision rates anchored by $^{230}Th/U$ ages from carbonate rinds in gravel from the WR-1, 2, and 4 terraces suggests a depositional age for the WR-3 terrace of approximately 150 ± 8.3 ka (Sharp and others, 2003). These three results are consistent with the WR-3 terrace dating to the Bull Lake maximum and subsequent deglaciation, and they further support the designation of the Bull Lake outwash terrace in the present map.

Outlying $to_{bl}$ deposits are mapped along Warm Spring Creek near the community of DuNoir and along the Wiggins Fork near Little Alkali Creek. Though the Warm Spring Creek terrace tread is 37–49 m above grade—lower than other $to_{bl}$ treads along the Wind River—Keefer (1957) posited that it may be a headwater remnant of Blackwelder's (1915) Circle terrace, which along the Wind River is equivalent to the $to_{bl}$ of the present study and the WR-3 of Chadwick and others, (1994, 1997). The absence of terrace deposits downstream from this location along Warm Spring Creek makes it difficult to correlate this tributary deposit with the mainstem terraces of the Wind River, and therefore its classification as $to_{bl}$ is tentative. The Bull Lake outwash terrace along the Wiggins Fork is 59–69 m above the modern channel, and thus within the range of $to_{bl}$ tread heights documented along the Wind River.

Terraces composed of outwash from the Pinedale glaciation (unit $to_p$) are mapped locally along the Wind River and Warm Spring Creek. Tread heights range from 3–15 m above the modern channel, with the highest treads found just beyond the Pinedale terminal moraines at Torrey Creek, as well as along Warm Spring Creek near the community of DuNoir (fig. 28). This range is consistent with the 3- to 9-m tread height documented by Blackwelder (1915) along the Wind River for the Lenore terrace, and supports the correlation between these two terrace units. Contrary to the pattern documented with $to_{bl}$ treads along the Wind River, there is no systematic downstream convergence of Pinedale outwash terrace treads with the modern floodplain, even though $to_p$ treads in isolated locations have gradients steeper than the modern Wind River (fig. 26).

Near the Pinedale terminal moraines of the Jakeys Fork valley glacier and the Wind River/DuNoir Creek lobe of the GYGS at Branch Creek, Pinedale outwash fans (unit $fo_p$) grade downstream into outwash terraces ($to_p$). These two map units are distinguished by landform, with fans being radial in planform and convex-up in cross section and terraces exhibiting a planar slope that parallels the gradient of the trunk drainage. In the case of the Jakeys Fork and Branch Creek $fo_p$ deposits, the composition of the fan gravels is similar to that of the adjacent terrace gravels, since the same glacial systems were the source of sediment for both the Wind River and the tributaries that hosted these glaciers. As such, these deposits of $fo_p$ and $to_p$ are considered to be roughly contemporaneous, and their distinction as separate units is based only on landform morphology.

Pinedale outwash fans and terraces along the upper Wind River, which are equivalent to the WR-1 designation used by some authors, have been numerically dated in two published studies. Phillips and others (1997) sampled boulders at the surface of the Pinedale outwash fan near the mouth of Torrey Creek for cosmogenic $^{36}$Cl exposure dating and calculated a depositional age of between 27 and 15 ka. Sharp and others (2003) dated pedogenic carbonate rinds on gravel clasts of the WR-1 terrace near the mouth of the East Fork Wind River, which yielded an age of 21 ± 5.1 ka. These ages are within the range of Pinedale moraine depositional ages in the Wind River Range (e.g. Gosse and others, 1995; Phillips and others, 1997; Dahms and others, 2018) and Greater Yellowstone Region (e.g. Licciardi and Pierce, 2008, 2018), and they support the designation of these fans and terraces as Pinedale outwash.

**Figure 28.** Photograph of a Pinedale outwash terrace along Warm Spring Creek near the community of DuNoir. The tread of this terrace is 15 m above grade. View is to the east; geologist at center for scale.

Terrace deposits with uncertain correlation to glacial outwash episodes are mapped as unit *t*. This unit is found primarily in the Wiggins Fork, with additional deposits in Horse Creek and the upper Wind River. The treads of most of these undifferentiated terraces are less than 9 m above grade and are lower than nearby Pinedale outwash terraces and fans; this is the case in the Wind River and the upper Wiggins Fork. A subset of terraces along Horse Creek and the lower Wiggins Fork have treads 26–40 m above grade and may correlate with the WR-2 documented downstream of the map area (Chadwick and others, 1994, 1997) (fig. 24). Chadwick and others (1997) used a linear incision rate between the dated WR-3 and WR-1 terraces to assign an age of 46–28 ka for the WR-2. Sharp and others (2003) calculated the WR-2 terrace at Bull Lake to 55 ± 8.6 ka using $^{230}$Th/U dating of carbonate rinds. Because the WR-2 terrace is less continuous along the Wind River than the WR-3 and lacks the well-defined spatial relationship with adjacent glacial moraines that the WR-1 exhibits, it cannot be confidently correlated to the undifferentiated terraces (unit *t*) of the present map without more detailed investigation outside the quadrangle.

Terrace deposits and active alluvium (unit *ta*) are mapped where the two deposits cannot be distinguished at 1:100,000 scale. This occurs in confined valleys with perennial tributaries, such as upper Horse Creek and East DuNoir Creek. Unit *ta* is also mapped in broad alluvial valleys with very low terraces that are difficult to extract from the active floodplain by interpretation of digital elevation data or aerial imagery. Examples of this latter case include lower DuNoir Creek and the Wind River near the confluence of Lava Creek. In most instances, *ta* treads are only a few meters above the active channel. This unit may locally include glacial outwash deposits where outwash forms a low terrace along underfit streams or where outwash cannot be distinguished from active alluvium at the map scale.

### *Alluvium*

Active alluvium (unit *a*) is mapped along the channels and floodplains of perennial drainages. Most of the active alluvium in the map area is found in the low and wide valleys of the Wind River, the Wiggins Fork, and Horse Creek. In the Absaroka Range, most valleys are too steep and narrow to retain widespread deposits of active alluvium. Exceptions occur where large landslides constrict the valley, raise the local baselevel, and require rivers to deposit alluvium to maintain their transport grade. Examples of alluvium deposited upstream of landslide complexes are found in both the South Fork Shoshone River and South Buffalo Fork.

## SUMMARY

The surficial geologic map of the west half of The Ramshorn 30' x 60' quadrangle highlights the geologic hazards and Quaternary geology of the southern Absaroka Range, uppermost Wind River Basin, and northwestern Wind River Range. Notable outcomes from this work include updated lidar- and field-based landslide mapping, and an improved understanding of the extent and interaction of Pleistocene glaciers between the Wind River Range and Greater Yellowstone ice caps. The data are intended to provide land managers, government planners, and the public with information about surficial geologic deposits and attendant geologic hazards to inform land-use decisions. More broadly, this work brings the WSGS closer to the objective of completing surficial geologic mapping across the state at 1:100,000 scale and provides insights into the Quaternary geologic history of this dynamic landscape.

## REFERENCES


Basham, W.L., and Martin, W.F., 1985, Seismic line across the Wind River Thrust Fault, Wyoming, *in* Gries, R.R., and Dyer, R.C., eds., Seismic exploration of the Rocky Mountain Region: Rocky Mountain Association of Geologists and Denver Geophysical Society, p. 59–66.

Berg, R.R., 1983, Geometry of the Wind River thrust, Wyoming, *in*, Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists, Denver, Colorado, p. 257–262.

Blackwelder, Eliot, 1915, Post-Cretaceous history of the mountains of central western Wyoming: The Journal of Geology, v. 23, no. 2, p. 97–117, 193–217, 307–340.

Breckenridge, R.M., 1975, Quaternary geology of the Wood River area, Wyoming: Wyoming Geological Association, 27$^{th}$ annual field conference, Guidebook, p. 45–54.

Brueseke, M.E., Downey, A.C., Dodd, Z.C., Hart, W.K., Adams, D.C., and Benowitz, J.A., 2018, The leading wisps of Yellowstone—Post-ca. 5 Ma extension-related magmatism in the upper Wind River Basin, Wyoming (USA), associated with the Yellowstone hotspot tectonic parabola: Geosphere, v. 14, no. 1, p. 74–94.

Case, J.C., 2001, Preliminary landslide maps in The Ramshorn quadrangle, Fremont and Park counties, Wyoming (unpublished): Wyoming State Geological Survey, scale 1:24,000.

Case, J.C., Arneson, C.S., and Hallberg, L.L., 1998, Surficial geologic map of Wyoming: Wyoming State Geological Survey Hazards Section Digital Map 98-1a, scale 1:500,000.

Chadwick, O.A., Hall, R.D., Kelly, G., Amundson, R., Gosse, J., Phillips, F., and Jaworowski, C., 1994, Quaternary geology of the Wind River Basin, Wyoming: Friends of the Pleistocene Rocky Mountain Cell, 1994 field trip, Guidebook, 141 p.

Chadwick, O.A., Hall, R.D., and Phillips, F.M., 1997, Chronology of Pleistocene glacial advances in the central Rocky Mountains: Geological Society of America Bulletin, v. 109, no. 11, p. 1,443–1,452.

Dahms, D., Egli, M., Fabel, D., Harbor, J., Brandová, D., de Castro Portes, R., and Christl, M, 2018, Revised Quaternary glacial succession and post-LGM recession, southern Wind River Range, Wyoming, USA: Quaternary Science Reviews, v. 192, p. 167–184.

Downey, A.C., 2015, Cenozoic mafic to intermediate volcanism at Lava Mountain and Spring Mountain, upper Wind River Basin, Wyoming: Manhattan, Kansas State University, M.S. thesis, 99 p.

Gosse, J.C., Klein, J., Evenson, E.B., Lawn, B., and Middleton, R., 1995, Beryllium-10 dating of the duration and retreat of the last Pinedale glacial sequence: Science, v. 268, p. 1,329–1,333.

Hall, R.D., and Jaworowski, Cheryl, 1999, Reinterpretation of the Cedar Ridge section, Wind River Range, Wyoming—Implications for the glacial chronology of the Rocky Mountains: Geological Society of America Bulletin, v. 111, no. 8, p. 1,233–1,249.

Hancock, G.S., Anderson, R.S., Chadwick, O.A., and Finkel, R.C., 1999, Dating fluvial terraces with $^{10}$Be and $^{26}$Al profiles—Applications to the Wind River, Wyoming: Geomorphology, v. 27, p. 41–60.

Izett, G.A., Pierce, K.L., Naeser, N.D., and Jaworowski, C., 1992, Isotopic dating of Lava Creek B tephra in terrace deposits along the Wind River, Wyoming—Implications for post 0.6 Ma uplift of the Yellowstone hotspot [abs]: Geological Society of America Abstracts with Programs, v. 24, no. 7, p. 102.

Keefer, W.R., 1957, Geology of the Du Noir area, Fremont County, Wyoming: U.S. Geological Survey Professional Paper 294-E, p. 155–221, 2 pls.

Keefer, W.R., 1970, Structural geology of the Wind River Basin, Wyoming: U.S. Geological Survey Professional Paper 495-D, p. D1–35, 3 pls.

Lagas, P.J., 1984, The glacial geology of the Gros-Ventre Canyon, Teton County, Wyoming: Bethlehem, Lehigh University, M.S. thesis, 150 p., 5 pls.

Licciardi, J.M., and Pierce, K.L., 2008, Cosmogenic exposure-age chronologies of Pinedale and Bull Lake glaciations in greater Yellowstone and the Teton Range, USA: Quaternary Science Reviews, v. 27, no. 7–8, p. 814–831.

______2018, History and dynamics of the Greater Yellowstone Glacial System during the last two glaciations: Quaternary Science Reviews, v. 200, p. 1–33.

Love, J.D., 1939, Geology along the southern margin of the Absaroka Range, Wyoming: Geological Society of America Special Papers 20, 134 p.

______1994, Leidy Formation—New name for a Pleistocene glacio-fluvial-lacustrine sequence in northwestern Wyoming: U.S. Geological Survey Professional Paper 932-D, 13 p.

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.)

Love, J.D., Christiansen, A.C., Brown, T.M., and Earle, J.L., 1979, Preliminary geologic map of the Thermopolis 1 degree x 2 degree quadrangle, central Wyoming: U.S. Geological Survey Open-File Report 79-962, 6 p., 1 pl., scale 1:250,000.

Love, J.D., Reed, J.C., Jr., and Christiansen, A.C., 1992, Geologic map of Grand Teton National Park, Teton County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map 2031, scale 1:62,500.

Matthews, N.E., Vazquez, J.A., and Calvert, A.T., 2015, Age of the Lava Creek supereruption and magma chamber assembly at Yellowstone based on $^{40}Ar/^{39}Ar$ and U-Pb dating of sanidine and zircon crystals: Geochemistry, Geophysics, Geosystems, v. 16, p. 2,508–2,528.

Mauch, J.P., Alexander, K.A., and Wittke, S.J., 2021, Preliminary surficial geologic map of the west half of the Jackson Lake 30' x 60' quadrangle, Teton County, Wyoming: Wyoming State Geological Survey Open File Report 2021-3, 22 p., scale 1:100,000.

Mauch, J.P., Barrette, N.C., and Wittke, S.J., 2022, Preliminary surficial geologic map of the east half of the Jackson Lake 30' x 60' quadrangle, Teton, Fremont, and Park counties, Wyoming: Wyoming State Geological Survey Open File Report 2022-4, 52 p., scale 1:100,000.

Miner, N.A., and Delo, D.M., 1943, Glaciation of the Du Noir Valley, Fremont County, Wyoming: The Journal of Geology, v. 51, no. 2, p. 131–137.

Murphy, J.F., and Richmond, G.M., 1965, Geologic map of the Bull Lake West quadrangle, Fremont County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map 432, scale 1:24,000.

Phillips, F.M., Zreda, M.G., Gosse, J.C., Klein, J., Evenson, E.B., Hall, R.D., Chadwick, O.A., and Sharma, P., 1997, Cosmogenic $^{36}Cl$ and $^{10}Be$ ages of Quaternary glacial and fluvial deposits of the Wind River Range, Wyoming: Geological Society of America Bulletin, v. 109, no. 11, p. 1,453–1,463.

Pierce, K.L., 2003, Pleistocene glaciations of the Rocky Mountains: Developments in Quaternary Sciences, v. 1, p. 63–76.

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.

Prostka, H.J., Antweiler, J.C., Bieniewski, C.L., and Kleinkopf, M.D., 1979, Mineral resources of the Du Noir Addition, Washakie Wilderness, Fremont County, Wyoming, with a section on aeromagnetic survey: U.S. Geological Survey Bulletin 1472, 35 p.

Richmond, G.M., 1964, Three pre-Bull Lake tills in the Wind River Mountains, Wyoming—A reinterpretation: U.S. Geological Survey Professional Paper 501-D, p. D104–109.

Richmond, G.M., and Murphy, J.F., 1965, Geologic map of the Bull Lake East quadrangle, Fremont County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map 431, scale 1:24,000.

Richmond, G.M.., and Murphy, J.F., 1989, Preliminary Quaternary geologic map of the Dinwoody Lake area, Fremont County, Wyoming: U.S. Geological Survey Open-File Report 89-435, 2 p.

Rohrer, W.L., 1966, Geologic map of the Kissinger Lakes quadrangle, Fremont County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map 527, scale 1:24,000.

Rohrer, W.L., 1968, Geologic map of the Fish Lake quadrangle, Fremont County, Wyoming: U.S. Geological Survey Geologic Quadrangle Map 724, scale 1:24:000.

Rohrer, W.L., 1969, Preliminary geologic map of the Sheridan Pass quadrangle, Fremont and Teton counties, Wyoming: U.S. Geological Survey Open-File Report 69-228, scale 1:24,000.

Sharp, W.D., Ludwig, K.R., Chadwick, O.A., Amundson, R., and Glaser, L.L., 2003, Dating fluvial terraces by $^{230}$Th/U on pedogenic carbonate, Wind River Basin, Wyoming: Quaternary Research, v. 59, p 139–150.

Smedes, H.W., and Prostka, H.J., 1972, Stratigraphic framework of the Absaroka Volcanic Supergroup in the Yellowstone National Park region: U.S. Geological Survey Professional Paper 729-C, 33 p.

Smithson, S.B., Brewer, J.A., Kaufman, S., Oliver, J.E., and Hurich, C., 1978, Nature of the Wind River thrust, Wyoming, from COCORP deep-reflection data and from gravity data: Geology, v. 6, no. 11, p. 648–652.

U.S. Geological Survey, 2020, USGS Original Project Resolution WY_FEMA_East_2019_D19: U.S. Geological Survey 3D Elevation Program, accessed June 2022, at https://apps.nationalmap.gov/downloader/#/.

_____2021, USGS 1/3 Arc Second n44w110 20211116: U.S. Geological Survey 3D Elevation Program, accessed June 2022, at https://apps.nationalmap.gov/downloader/#/.