Geologic Map 114

Landslide Map of the Virginia City Area, Madison County, Montana

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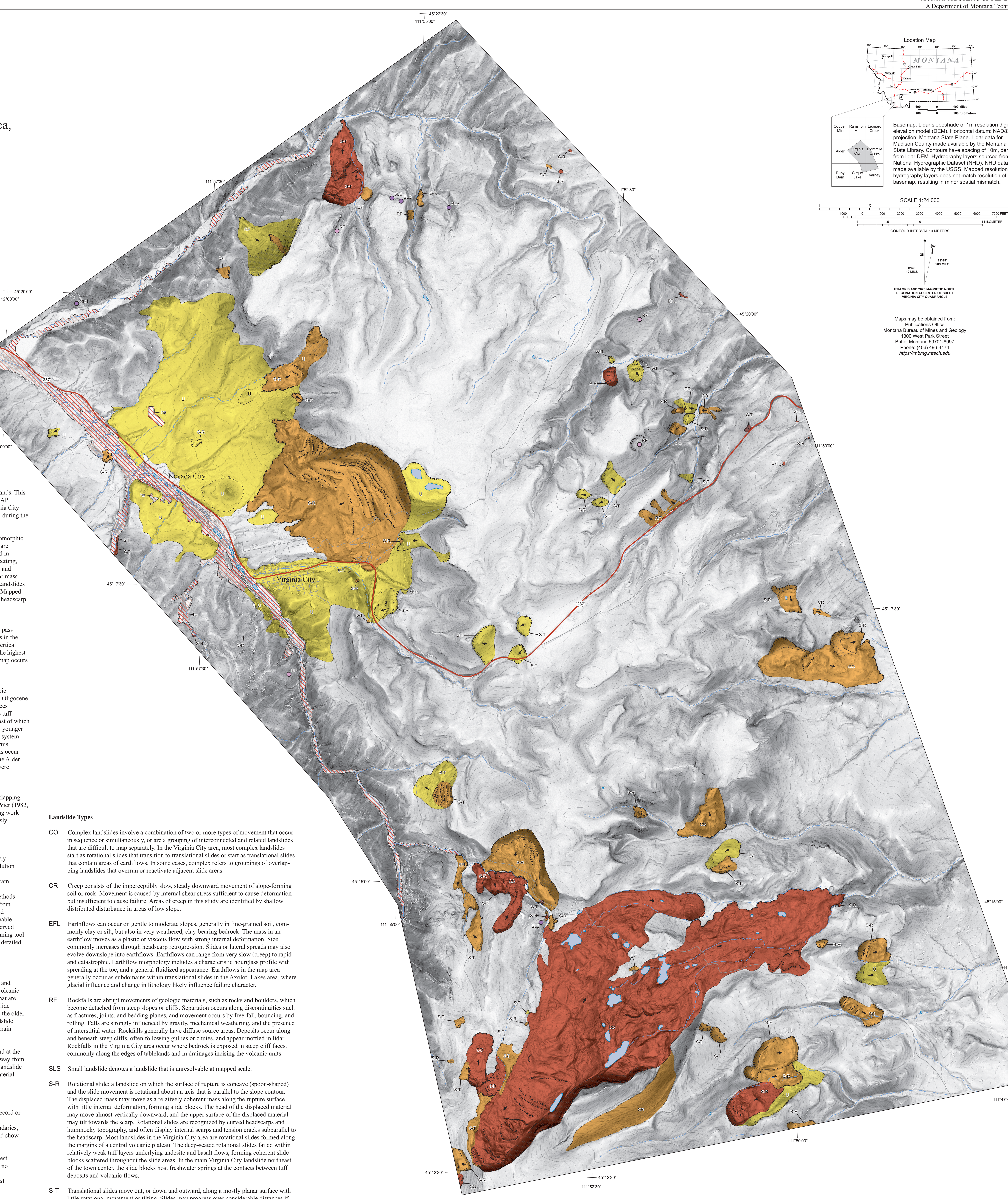

Basemap: Lidar slopeshade of 1m resolution digital elevation model (DEM). Horizontal datum: NAD83; projection: Montana State Plane. Lidar data for Madison County made available by the Montana State Library. Contours have spacing of 10m, derived from lidar DEM. Hydrography layers sourced from National Hydrographic Dataset (NHD). NHD data is made available by the USGS. Mapped resolution of hydrography layers does not match resolution of basemap, resulting in minor spatial mismatch.

Maps may be obtained from:
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INTRODUCTION

The Virginia City area hosts numerous landslides, formed in Cenozoic volcanic tablelands. This landslide map was generated as part of the United States Geological Survey STATEMAP program, as a derivative product of a previously completed geologic map of the Virginia City 7.5′ quadrangle (Mosolf, 2021), to further investigate widespread landslides identified during the geologic mapping effort.

Mass wasting deposits were mapped using light detection and ranging (lidar) data, geomorphic and topographic analyses, satellite imagery, and published geologic maps. Landslides are classified based on the relative age of surface movement, following methods described in Gavillot (2022, 2025). Controls on landslide formation include slope angle, geologic setting, stream erosion, weathering, vegetation, change in precipitation or groundwater levels, and human activities. Landslides shown on this map are gravity-driven mass movements or mass wasting deposits where soil, sediments, rock, and/or rock debris moved downslope. Landslides and mass movements include earth flows, debris flows, debris slides, and rock slides. Mapped landslides are identified from the geomorphic expression of both the source area (i.e., headscarp or scar) and transported material.

Physiographic Setting

The Virginia City map area is in Madison County, Montana, spanning a low mountain pass separating the Tobacco Root Mountains from the Greenhorn Range (fig. 1). Elevations in the map area range from 1,599 to 2,640 m (5,246 to 8,661 ft) with 1,041 m (3,415 ft) of vertical relief. A plateau northeast of Virginia City covered by mixed timber and grassland is the highest and most prominent physiographic feature in the quadrangle. The lowest point in the map occurs along Alder Gulch, which is a major tributary to the Ruby River.

Geologic Summary

Rocks in the area include Archean metamorphic basement rocks crosscut by Proterozoic pegmatite and diabase intrusions. Basement rocks are overlain by late Eocene to early Oligocene volcanogenic rocks composing the Virginia City volcanic group. The volcanic sequences generally consist of mafic to intermediate lavas intercalated with subordinate rhyolitic tuff intervals and minor gravel deposits. Scattered outcrops of Eocene dacite porphyry, most of which are entrained in landslide deposits, represent an older volcanic system unrelated to the younger bi-modal volcanism of the Virginia City group. A northwest-trending, left-lateral fault system (Virginia City Fault Zone; see Ruppel and Liu, 2004) transects the map area and deforms Archean metamorphic rocks and Cenozoic volcanic units. Large mass wasting deposits occur throughout the map area, most of which are formed in the Cenozoic volcanic units. The Alder Gulch stream drainage contains extensive dredge tailings of Quaternary gravels that were historically mined for placer gold and silver (Mosolf, 2021; Ruppel and Liu, 2004).

Previous Mapping

The Virginia City 7.5′ quadrangle was mapped by Mosolf (2021, scale 1:24,000), overlapping this map. Parts of the map area were also covered by Cordua (1973, scale 1:24,000), Wier (1982, scale 1:12,000), and Kellogg and Williams (2006; scale 1:100,000). Landslide mapping work was conducted under the STATEMAP program, as a derivative product of the previously completed geologic map of the Virginia City 7.5′ quadrangle (Mosolf, 2021; award G17AC00257).

Methods

Landslide mapping was conducted in the Virginia City map area in 2025 utilizing newly available lidar elevation data (1m resolution; Montana State Library, 2022), high-resolution satellite imagery, and geomorphic and topographic analyses. Data were digitized to a geodatabase template published by the National Cooperative Geologic Mapping Program.

Landslides are classified based on the relative age of surface movement, following methods described in Gavillot (2022, 2025). Landslide type classification scheme is modified from Cruden and Varnes (1996); landslide type descriptions are modified from Highland and Bobrowsky (2008). Landslide identification and location certainty are limited to mappable features in the lidar data at scales less than or equal to 1:5,000. Smaller or poorly preserved landslides may not have been identified. The map is designed for use as a general planning tool and is appropriate for use at a scale of 1:24,000. Site-specific investigations and more detailed geotechnical information are required for landslide hazard assessments.

MASS WASTING DEPOSITS

Tertiary volcanic rocks of the Virginia City volcanic group are prone to mass wasting, and consequentially, numerous landslides and debris flow deposits rim the high-standing volcanic tablelands. Many of the landslides appear to fail within poorly lithified tuff intervals that are saturated with groundwater and emanate spring creeks locally. Relatively young landslide deposits are easily identified in the field and in lidar digital elevation models, whereas the older dissected and eroded landslide deposits are harder to recognize. The most notable landslide complex in the map area is over 1.5 km (0.6 mi) wide and underlies the hummocky terrain northeast of the Virginia City town center.

Headscarps and flanks are identified as the steeper surface of disturbed ground at the uphill edge and perimeter of a landslide where the landslide mass has moved away from the undisturbed ground (Cruden and Varnes, 1996). Material in the associated landslide deposit moved downhill along the scarp, breaking away from the stationary material above it. Hachures are parallel to generalized direction of slip.

Landslide Deposits

Active/historic landslides represent movements that occurred in the historic record or are associated with anthropogenic activity. Landslides in this category have well-constrained locations with clear scarps or scars, cracks, well-defined boundaries, disrupted vegetation, blockage to drainages, or damaged manmade features, and show little to no erosion.

Dormant young landslides represent movements that occurred during the Latest Quaternary (within the past 15,000 years) that appear relatively fresh and have no existing historical record. Landslides in this category have well- to moderately constrained locations with clear scarps or scars, cracks, well-defined boundaries, disrupted vegetation, or blockage to a stream drainage, and show minor erosion.

Dormant mature landslides represent movements that occurred during the Late Quaternary (within the past 130,000 years) that appear smoothed and/or partly modified by erosion. Landslides in this category have well- to moderately constrained locations with some degree of headscarp rounding, diffuse scars, eroded toe area, partly smoothed boundaries and deposits, relatively uniform vegetation, and some gullies or drainages incised within the landslide features.

Dormant old landslides represent movements that likely occurred during the Quaternary (within the past 2.6 million years) that have been greatly smoothed and modified by erosion. Landslides in this category have moderately constrained to inferred locations, with a strong degree of headscarp rounding or eroded headscarp, no clear scars, toe area not preserved, smoothed boundaries and deposits, fully revegetated, and well-defined gullies or drainages incised within the landslide features.

Anthropogenic Deposits

ha **Human altered**—Artificial fill composed of excavated, transported, processed, and emplaced rock and gravel. Consists mainly of dredged placer workings and dumps from lode mines. Most extensive in Alder Gulch. Thickness generally greater than 5 m (16 ft).

Landslide Types

CO Complex landslides involve a combination of two or more types of movement that occur in sequence or simultaneously, or are a grouping of interconnected and related landslides that are difficult to map separately. In the Virginia City area, most complex landslides start as rotational slides that transition to translational slides or start as translational slides that contain areas of earthflows. In some cases, complex refers to groupings of overlapping landslides that overrun or reactivate adjacent slide areas.

CR Creep consists of the imperceptibly slow, steady downward movement of slope-forming soil or rock. Movement is caused by internal shear stress sufficient to cause deformation but insufficient to cause failure. Areas of creep in this study are identified by shallow distributed disturbance in areas of low slope.

EFL Earthflows can occur on gentle to moderate slopes, generally in fine-grained soil, commonly clay or silt, but also in very weathered, clay-bearing bedrock. The mass in an earthflow moves as a plastic or viscous flow with strong internal deformation. Size commonly increases through headscarp retrogression. Slides or lateral spreads may also evolve downslope into earthflows. Earthflows can range from very slow (creep) to rapid and catastrophic. Earthflow morphology includes a characteristic hourglass profile with spreading at the toe, and a general fluidized appearance. Earthflows in the map area generally occur as subdomains within translational slides in the Axolotl Lakes area, where glacial influence and change in lithology likely influence failure character.

RF Rockfalls are abrupt movements of geologic materials, such as rocks and boulders, which become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water. Rockfalls generally have diffuse source areas. Deposits occur along and beneath steep cliffs, often following gullies or chutes, and appear mottled in lidar. Rockfalls in the Virginia City area occur where bedrock is exposed in steep cliff faces, commonly along the edges of tablelands and in drainages incising the volcanic units.

SLS Small landslide denotes a landslide that is unresolvable at mapped scale.

S-R Rotational slide; a landslide on which the surface of rupture is concave (spoon-shaped) and the slide movement is rotational about an axis that is parallel to the slope contour. The displaced mass may move as a relatively coherent mass along the rupture surface with little internal deformation, forming slide blocks. The head of the displaced material may move almost vertically downward, and the upper surface of the displaced material may tilt towards the scarp. Rotational slides are recognized by curved headscarps and hummocky topography, and often display internal scarps and tension cracks subparallel to the headscarp. Most landslides in the Virginia City area are rotational slides formed along the margins of a central volcanic plateau. The deep-seated rotational slides failed within relatively weak tuff layers underlying andesite and basalt flows, forming coherent slide blocks scattered throughout the slide areas. In the main Virginia City landslide northeast of the town center, the slide blocks host freshwater springs at the contacts between tuff deposits and volcanic flows.

S-T Translational slides move out, or down and outward, along a mostly planar surface with little rotational movement or tilting. Slides may progress over considerable distances if the surface of rupture is sufficiently inclined. The material in the slide may range from loose, unconsolidated soils to extensive slabs of rock, or both. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil. Translational slides occur more in the southwestern portion of the map area in the Axolotl Lakes area, often with earthflows. Here, volcanic flows and tuffs of the Virginia City volcanic group overlie steeply inclined Mesozoic metasediments and Tertiary volcaniclastic deposits, which differs from the crystalline Archean basement underlying most of the map area, and likely impacts slide morphology. Slide character and morphology have also been influenced by glaciation in this area.

U Unknown denotes a landslide that cannot be defined due to complicating factors, such as small size, old age with subdued features, or complicated morphology.

Map Symbols

- Contact: dashed where approximately located, ? = Identity or existence questionable
- Rockfall
- Small landslide
- Transport direction
- Headscarp
- Internal scarp
- Main toe
- Internal toe
- Tension crack
- 287 Montana Highway 287
- Road
- Stream
- Lake/pond
- Swamp/marsh

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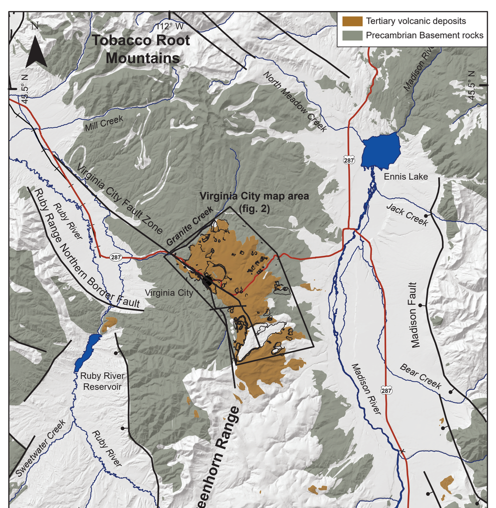

Figure 1. Simplified geologic map of the Virginia City area overlaid on a shaded digital elevation model (DEM). Geology modified from Ruppel and others (1993) and Kellogg and Williams (2006). Black polygons in map area show landslide locations.

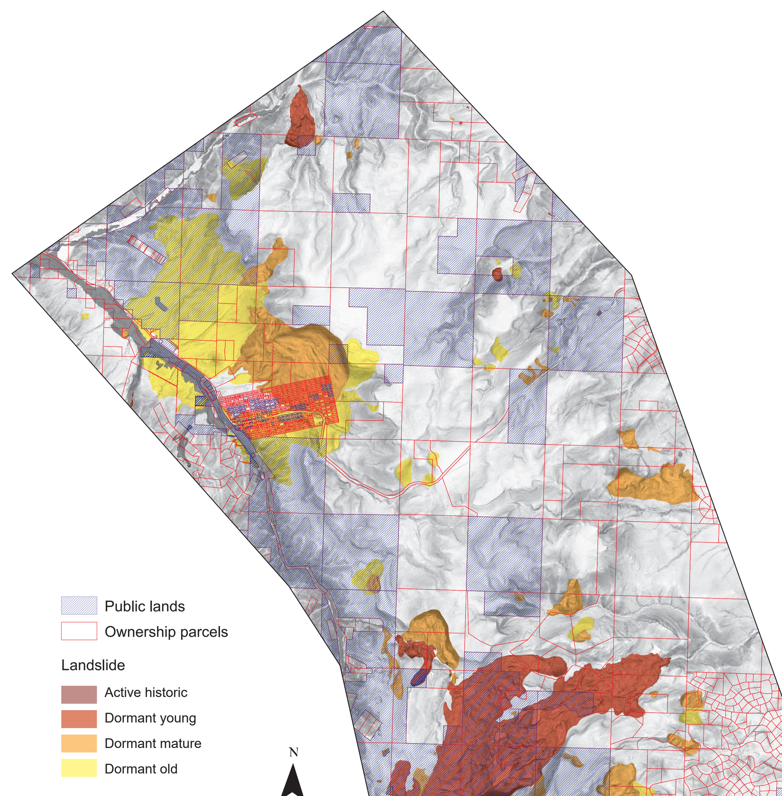

Figure 2. Map area showing outlines of ownership parcels (red) and the extent of public lands (blue hachures). For an assessment of landslide risk to an individual property or homesite, please obtain the services of a licensed geotechnical engineer or engineering geologist.

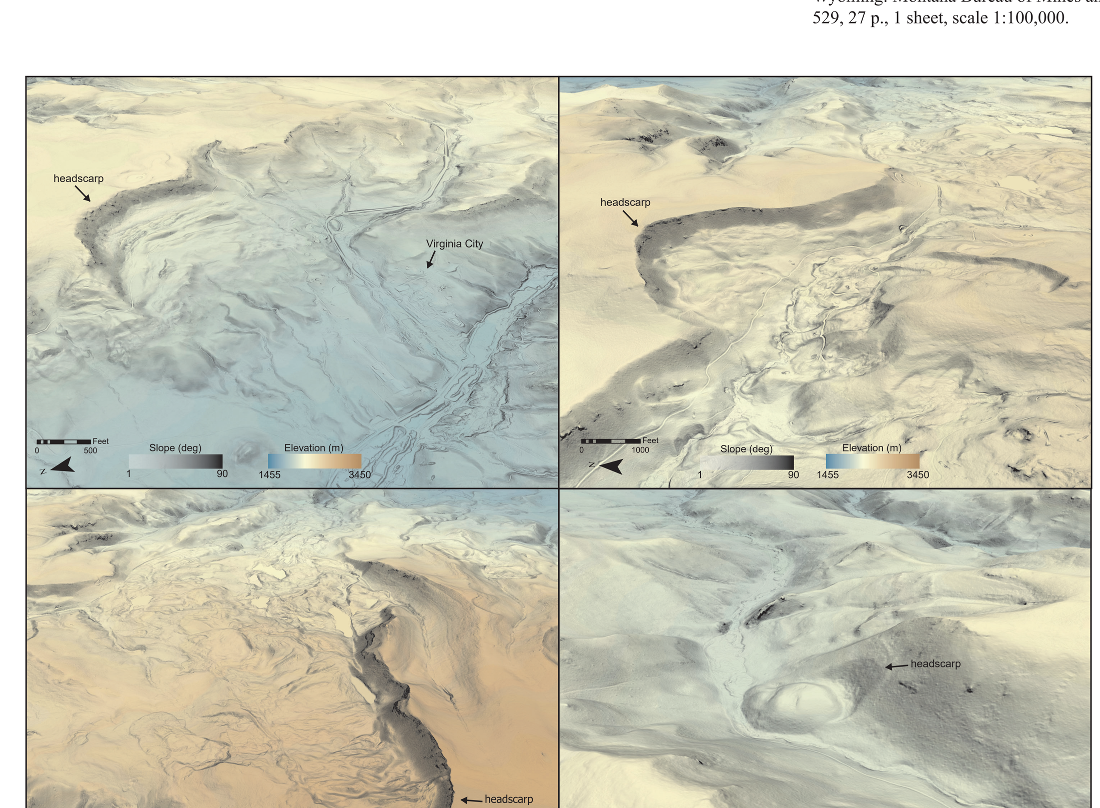

Figure 3. Varied landslide morphology present throughout the map area, as visible in lidar data (DEM color ramp reflects elevation, slope is represented in grayscale).

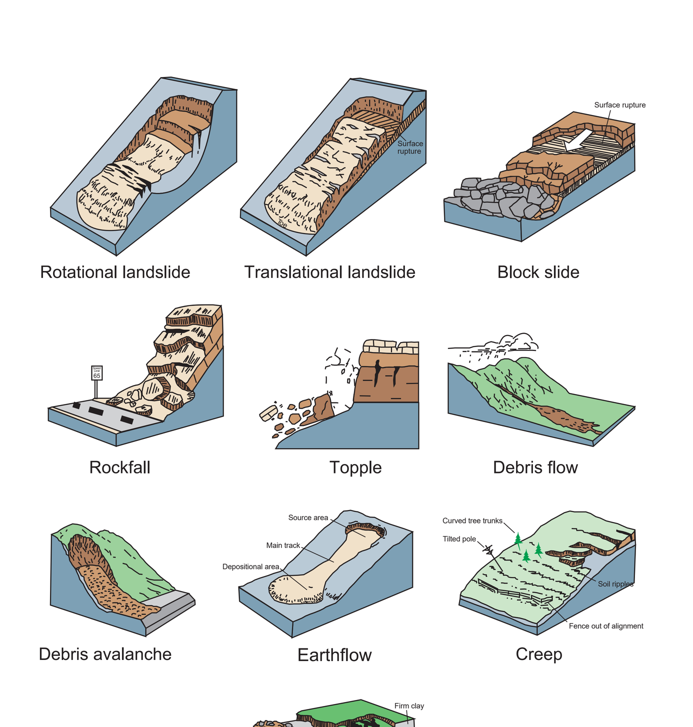

Figure 4. These schematics illustrate major types of landslide movement, some of which are present in the map area. For further information about landslide types see Cruden and Varnes (1996) and USGS (2004; Highland and Bobrowsky, 2008). Figure modified from USGS.