

Landslide25_27**Insights on source, timing, and depositional conditions of the Spruce Mountain landslide from mapping in the Spruce Well 7.5' Quadrangle, south-central Elko County, Nevada**

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SUMMARY

New geologic mapping of the Spruce Well 7.5' quadrangle in Nevada reveals new insights into the composition, source, and timing of the informally named Spruce Mountain landslide. A combination of remote sensing, field mapping, and tephrochronology and cosmogenic dating constrain the age of the deposit.

The landslide deposit was sourced from Spruce Mountain peak, which is a 3.5 km-long ridge located 3.75 km east of the study area. The landslide had a drop of ~1.4 km with a maximum runout distance of ~11.5 km. The landslide deposit is predominantly limestone breccia of the Devonian Guilmette Formation, with notable input from the Carboniferous Diamond Peak and Pennsylvanian Ely formations.

Field mapping and differentiation using topographic roughness suggest the landslide deposit extends significantly farther source-ward relative to previous mapping. In this eastern portion the landslide deposit is mantled by younger alluvium. The new extent of the landslide deposit covers up to 22 km². Tephra layers low in the section underlying the landslide deposit are tentatively correlated with the Middle Miocene, yielding a maximum emplacement age.

This study has yielded insight into the timing and extent of the Spruce Mountain landslide, and these methods will be useful in analysis of landslide deposits.

Introduction

Landslides are a common phenomenon in the state of Nevada, USA. They are characterized by different times of formation, have different genesis and are usually multi-stage in formation (Sturmer and Micander, 2020; Belair, 2019). This determines their complex nature and requires the use of an integrated approach to their study. This research aims to identify and analyze the source, timing, and depositional conditions of the Spruce Mountain landslide located south-central Elko County, Nevada. New geologic mapping of the Spruce Well 7.5' quadrangle in Nevada reveals new insights into the composition, source, and timing of the informally named Spruce Mountain landslide. A combination of remote sensing, field mapping, and geochronologic methods, including tephrochronology, $^{40}\text{Ar}/^{39}\text{Ar}$ dating, and ^{36}Cl and ^{10}Be cosmogenic dating, constrain the age of the deposit and help differentiate units within and underlying the landslide deposit.

Study area and Spruce Mountain landslide deposits

The Basin and Range province in southwestern North America is a complex, active tectonic and geologic province. Heavy extension has created extreme relief and faulting, resulting in high risk of large-scale rock avalanches in most of the region. Over 700 large rock avalanche deposits are known in Nevada, and few have had any detailed study (Page, et al., 1998; Glancy and Bell, 2000; French and Guth, 2016; Ferry et al., 2022).

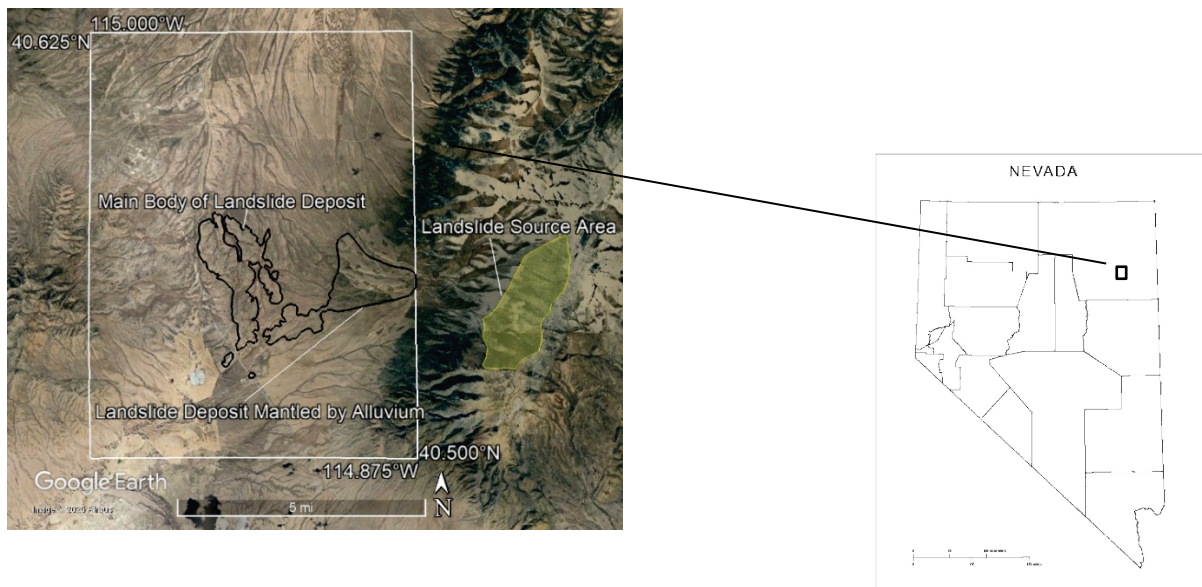


Figure 1: The map of the study area: the Spruce Well quadrangle, outlined in white. The Spruce Mountain landslide is outlined in black. The source area on Spruce Mountain is highlighted in yellow, the location of the study area in Nevada, USA is on the right

Figure 1 depicts the study area, the Spruce Well quadrangle, located in northeastern Nevada, USA. The Spruce Mountain landslide dominates the center of the field area, outlined in (color), spanning from the foot of Spruce Mountain across US Highway 93. The landslide deposit was sourced from the peak of Spruce Mountain, which is a 3.5 km-long ridge (highlighted in yellow) located 3.75 km east of the study area. Spruce Mountain is predominantly comprised of Paleozoic limestone intruded by younger igneous bodies. The landslide deposit is composed of these carbonate units, mostly limestone breccia of the Devonian Guilmette Formation, with notable input from the Ordovician Pogonip Group, Ordovician Eureka Quartzite,

and Mississippian Diamond Peak and Pennsylvanian Ely formations. (Nowaczewski et al.) The landslide had a drop of ~1.4 km with a maximum runout distance of ~11.5 km.

The remainder of the Spruce Well quadrangle is dominated by Miocene volcanic and sedimentary rocks of the Humboldt Formation and Quaternary alluvial and lacustrine units. Volcanic strata are exposed in the western portion of the area and include poorly consolidated ash-fall tuff, lapilli tuff, and tephra, locally modified by fluvio-lacustrine processes, tentatively grouped with the Blanchard member of the Humboldt Formation. The Humboldt formation covers much of northeastern Nevada and southeastern Idaho, where the Yellowstone hotspot was located in the Miocene. In the east Humboldt range north of this study area, more carbonate breccia landslides overlie the Humboldt formation. Quaternary units include several alluvial fans and beach bars and playa deposits of pluvial Lake Franklin. (Sharp, 1939; Camilleri et al., 2017)

Method and/or Theory

Remote Sensing:

The United States Geological Survey has conducted LiDAR surveys for much of Nevada, including the study area. A 1-meter resolution digital elevation model (DEM) was constructed using this data and projected in WGS 84 (Web Mercator Auxiliary Sphere), and is used in this study for analysis, including topographic maps and products and hydrological processing like active channel mapping. The topographic roughness index used in Figure 2 was calculated as standard deviation of slope as Frankel and Dolan define it:

$$m = \tan^{-1} \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} \quad (1)$$

$$\frac{\partial z}{\partial x} = \frac{[(z_{i+1,j+1} + 2z_{i+1,j} + z_{i+1,j-1}) - (z_{i-1,j+1} + 2z_{i-1,j} + z_{i-1,j-1})]}{8\partial x} \quad (2)$$

$$\frac{\partial z}{\partial y} = \frac{[(z_{i+1,j+1} + 2z_{i,j+1} + z_{i-1,j+1}) - (z_{i+1,j-1} + 2z_{i,j-1} + z_{i-1,j-1})]}{8\partial y} \quad (3).$$

Viewing the study area with this method reveals new insights into mapping, like revealing landslide deposit where it was not mapped. The eastern portion of the mapping area was previously mapped as alluvial fan, but morphometrically appears more similar to landslide deposit than a smoother fan. Field truthing is required to confirm this.

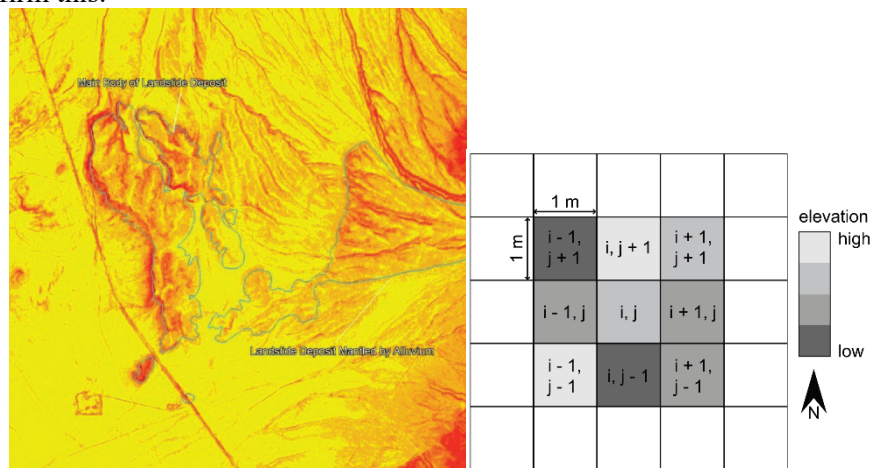


Figure 2: The topographic roughness index map of the study area: Left: A portion of the study area displaying the topographic roughness index and the landslide deposit outline. Right: The topographic roughness index moving window referred to by equations 2 and 3.

Field Mapping:

Field mapping took place in November 2024 and June 2025. Field reconnaissance and sample collection was the focus of the earlier field session, in which several samples of tephros, tuffs, and breccias were returned to the University of Cincinnati and sent for analysis to determine an emplacement age for the landslide deposit using tephrochronology, $^{40}\text{Ar}/^{39}\text{Ar}$ dating, and ^{36}Cl and ^{10}Be cosmogenic dating respectively.

The second field season in June 2025 was field mapping in the landslide deposit, the alluvial fans, and volcanic units of the study area. Unit description and differentiation were the primary goals, as well as a preliminary gravity survey along US Highway 93 and Spruce Mountain Road using a SCINTREX CG-6 and a Trimble differential GPS.

Results

Exploration of the main body of the landslide deposit confirms that the majority is carbonate breccia. The northern portion of the deposit is more cherty than the carbonate breccia of the southernmost deposit, possibly due to post-depositional chemical processes or from a difference in the source unit. These two different suites of carbonate are separated by a breccia composed mostly of the Serpukhovian Diamond Peak conglomerate and a dark, fine-grained quartz breccia. The basal contact of the landslide deposit is exposed in a few places, most notably near the center of the deposit where a secondary landslide has occurred on the eastern edge of the deposit, exposing the contact pictured in Figure 3. The rock here contains fossiliferous limestone, deformed calcite crystal, and overlies soft lacustrine silt and unconsolidated pebble sand.

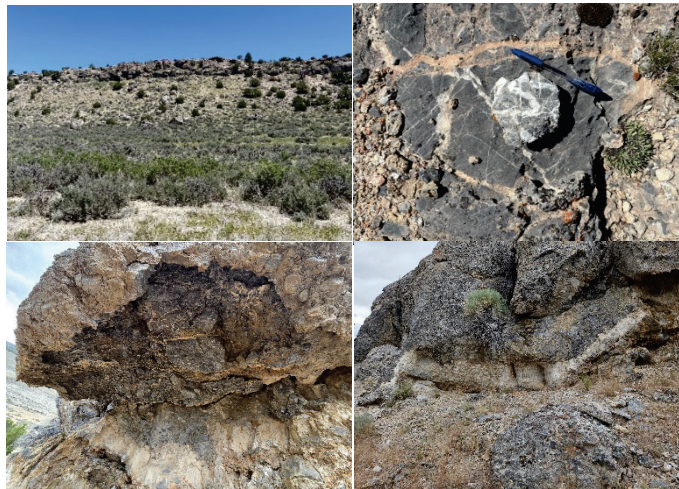


Figure 3: *Spruce Mountain landslide site, Nevada: Top left: The landslide in profile viewed from US Highway 93. Top right: Carbonate breccia on top of the landslide deposit. Bottom left: Underside of the landslide deposit exposed by a secondary landslide on the western edge of the deposit. Bottom right: Basal contact of the landslide with shear zone exposed.*

Field mapping and differentiation using topographic roughness suggest the landslide deposit extends significantly farther east (source-ward) relative to previous mapping by Hope, 1972 (Hope, 1972). The basis for this hypothesis is Frankel and Dolan's topographic roughness index based on standard deviation of slope from the 1-meter LiDAR-derived DEM. Topographic roughness as depicted in Figure 2 indicates that the landslide deposit is extremely rough compared to the smooth alluvial fans. Near the foot of Spruce Mountain, the alluvial fan (informally and henceforth referred to as the Sprucemont fan, for the old mining town present in the area) is uncharacteristically rough compared to the other fans, and instead appears more

similar to the landslide deposit. This prompted a hypothesis that this Spruce Mountain fan is actually landslide deposited onto an alluvial fan. Field mapping discovered landslide carbonate breccia in the side of the channels in this fan, confirming this hypothesis. In this eastern portion the landslide deposit is dominantly mantled by younger alluvium. Based on the new mapping the landslide deposit covers up to 22 km².

Tephra layers low in the section underlying the landslide deposit are tentatively correlated with the 11.93±0.03 Ma Ibex Hollow and 11.80±0.04 Ibex Peak 8 ashes, thus providing a Middle Miocene maximum emplacement age. These tephras were correlated using glass chemistry tephrochronology. ⁴⁰Ar/³⁹Ar dating of tuffs below the deposit, and ³⁶Cl and ¹⁰Be cosmogenic samples exposed on top of the slide, will be used to constrain the emplacement age with more confidence, but they are still being analyzed.

Conclusions

This study has revealed a significantly expanded extent of the Spruce Mountain landslide and its interaction with alluvial processes. These methods will be used to study large-scale landslide deposits in the Basin and Range and hazard assessment.

Acknowledgements

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