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Identifying buried landslide deposits using passive-source seismic (Deep ReMi) analysis, a case study from Washoe Valley, Nevada, USA

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SUMMARY

In tectonically active areas, landslide deposits may become buried by sedimentation related to ongoing tectonics. It can be important to identify these deposits to help evaluate landslide recurrence. Additionally, increased porosity and permeability can make landslide deposits attractive as targets for geothermal, hydrocarbon, and/or metal exploration. However, as landslide deposits are buried it becomes difficult to identify them. Well penetrations can be used, but are expensive. In this study, we tested the Deep ReMi (Refraction Microtremor) seismic method as a potential method for inexpensively and rapidly identifying landslide deposits in the subsurface.

ReMi is a method to evaluate the subsurface shear wave velocity profile by utilizing data collected by and geophone array with passive sources. We evaluated the efficacy of Deep ReMi in identifying landslide deposits by deploying two 2-km, 99-geophone arrays in Washoe Valley, Nevada, USA. One array was deployed across the toe of the Slide Mountain landslide complex and a second array away from known landslide deposits. The landslide complex array showed lateral heterogeneity in Vs velocity inversions in the upper 50-100 m not observed in the second array. The heterogeneity is interpreted to represent landslide deposits with faster velocities from areas with larger average clast size.

Introduction

Rangefront-bounding normal faults generate steep topography that is eroded by several processes including landslides. However, our understanding of the relative importance of landslides in both denudation of footwalls and filling of hanging-wall basins remains limited in part because landslide deposits can become buried by subsequent sedimentation. The presence of buried landslide deposits can be confirmed by boreholes, but drilling them is expensive and time consuming. Less expensive geophysical techniques may provide a way to identify buried landslide deposits. In addition to answering landscape evolution questions, evaluating presence and extent of buried landslide deposits can help improve risk assessments for future landslides. Buried landslide deposits may also be a resource target, as their generally high porosity and permeability can house hydrocarbons, metallic deposits, or could allow for geothermal fluid flow.

The goal of this study was to test whether buried landslide deposits can be differentiated using the passive-source seismic method Deep ReMi (Refraction Microtremor). This method generates shear-wave velocity (Vs) profiles modeled at several points along a seismic node array. The expectation here is that buried landslide deposits will generally have higher Vs values and more lateral variability in Vs than areas without buried landslide deposits. This hypothesis was tested by deploying two seismic node arrays in Washoe Valley, Nevada, USA, with one array deployed across an area with known buried landslide deposits and the second array deployed in an area with no expectation of buried landslide deposits.

Study area and characterization of landslide deposits

The Slide Mountain landslide complex is located on the northwestern side of Washoe Valley in west-central Nevada, USA. Washoe Valley sits between the Carson and Virginia Ranges to the west and east, respectively. The Carson Range is the easternmost portion of the Sierra Nevada. The Sierra Nevada frontal fault system, which is a large normal fault, marks the boundary between the Carson Range and Washoe Valley. The Carson Range near Washoe Valley dominantly comprised of Cretaceous granitic rocks with lesser Miocene intermediate volcanic flows.

The Slide Mountain landslide complex is comprised of ~10 Quaternary landslides, with the most recent occurring in 1983 (Glancy and Bell, 2000). The landslides originated atop Slide Mountain and flowed down the Ophir Creek drainage to be deposited in a landslide-dominated fan (Fig. 1). A large area of sheared and brecciated granite exposed high in the Carson Range is the source for landslides within the Slide Mountain landslide complex.

Method and/or Theory

Refraction Microtremor (ReMi) is a method that allows for evaluation of the shear-wave velocity profile in the subsurface (e.g., Louie, 2001; Louie et al., 2022). ReMi has dominantly been used for seismic hazard analysis in the upper 30 m of the subsurface (e.g., Coccia et al., 2010; Carvalho et al., 2016; Pancha et al., 2017a), but recent work (e.g., Pancha et al., 2017b) has shown the utility of the method for evaluating velocity structure down to >1 km depth. The method uses ambient noise as a source, including vibrations from passive traffic, trains, and wind. The depth of investigation is around half of the array length and resolution is a function of nodal spacing.

Seismic data were collected using 99 Fairfield 3-component seismic nodes that were borrowed from the IRIS PASSCAL (now called EPIC) geophysical instrument consortium. The nodes were deployed in two 2.2 km-long arrays with an average nodal spacing of 22 m (Figs. 1 and 2). The nodes collected noise data for 4 hours for each array. The data were processed and modeled using the VsSurf 2dS® software from Terēan. The data were gathered into 30 minute records which were stacked for ReMi inversion. The inversions were done on thirty 30-node, 638-m long subarrays for each array. The inversions result in plots in frequency-slowness space, which are then picked along the lower envelope of coherent data representing the fundamental-mode Rayleigh phase velocity dispersion curve (Fig. 3). These picks are then used to model shear-wave velocity profile at the center point of the subarray. The velocity profiles were then stitched together into 2D Vs profiles (Fig. 4).

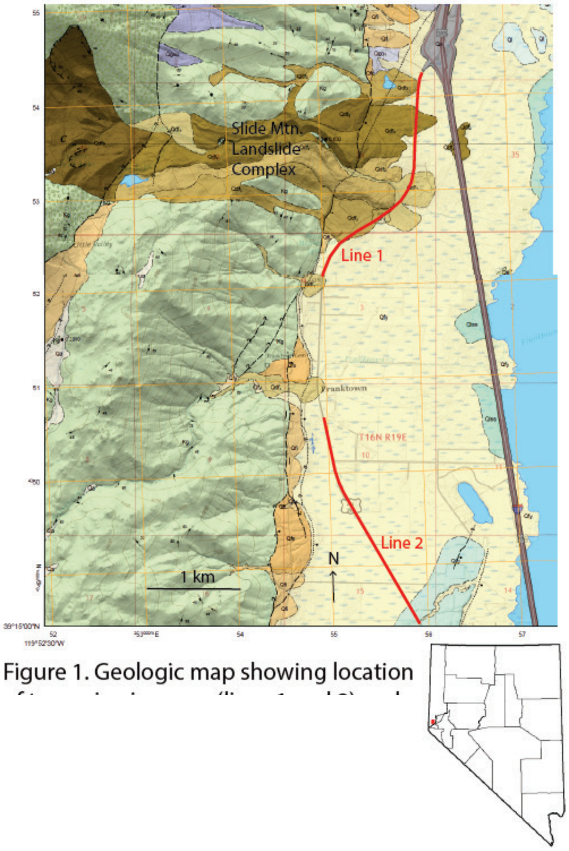

Figure 1 *Geologic map showing location of two seismic arrays (lines 1 and 2) and the Slide Mountain landslide complex. Map from Carlson et al. (2019). Map in lower right shows approximate location of map within Nevada, USA.*

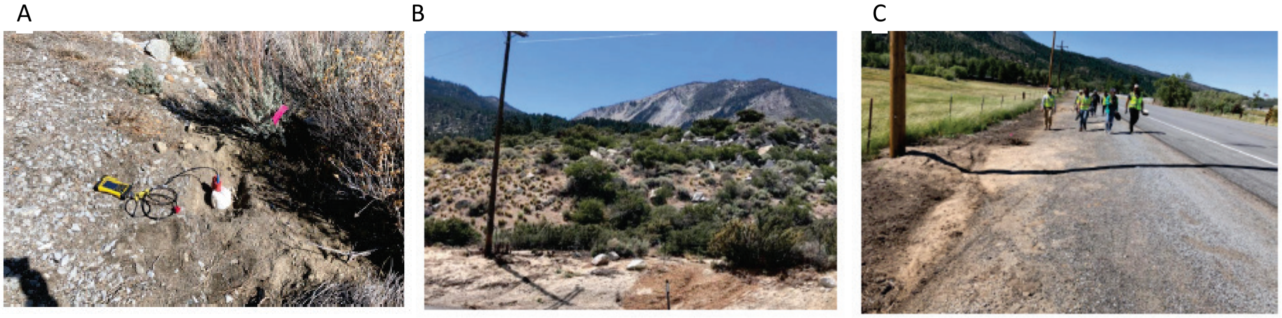

Figure 2. *Field photos from deployment. A. Seismic node being deployed. B. Slide mountain (background) with the Slide Mountain landslide complex (foreground). C. Deployment team measuring out array 2.*

Results

Line 1 across the toe of the Slide Mountain landslide complex has abundant lateral heterogeneity, and local velocity inversions (velocity decreases with increasing depth) (Figure 4a). The lateral heterogeneity is interpreted to represent clast heterogeneity within the landslide complex, with faster velocities resulting from the dominantly larger clast sizes within the portions of landslide deposits. The jump to high velocities at the base of the 2D profile are interpreted as fault contact with granitic basement.

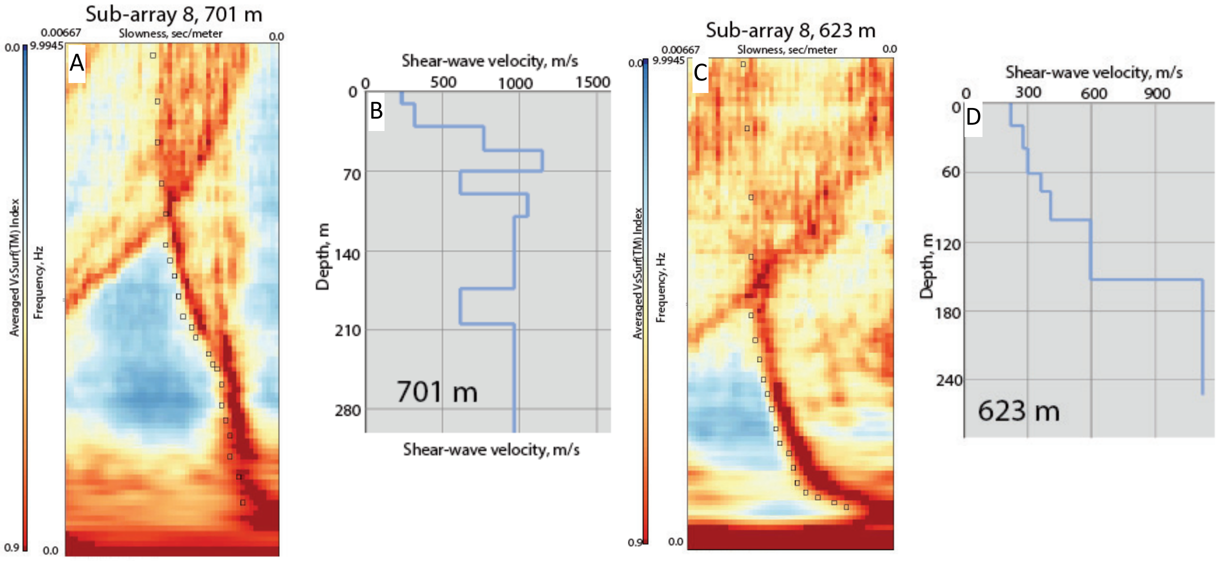

Figure 3. *Picks (boxes) on sub-array frequency-slowness plots and resulting shear-wave velocity models for sub-array 8 for array 1 (A and B) and sub-array 8 for array 2 (C and D).*

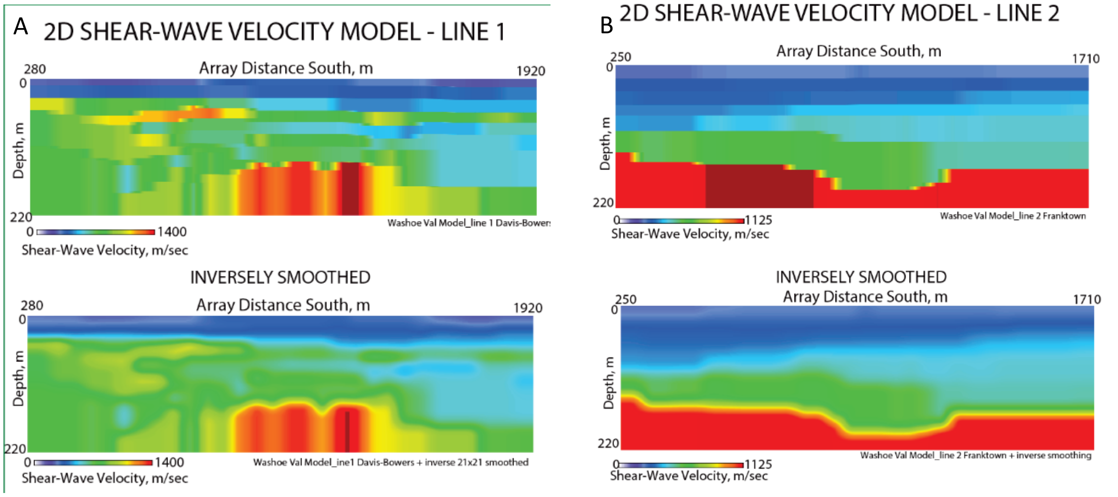

Figure 4. *2D shear-wave velocity-depth profiles for this study. Lower models have been inversely smoothed. A. depth profiles for array 1 across the toe of the Slide Mountain landslide complex. Right, depth profiles for array 2 in an area of west-central Washoe Valley with no suspected landslide deposits.*

In contrast, line 2 in west-central Washoe Valley is more laterally homogeneous than the profile from line 1 (Figure 4b). The homogeneity is interpreted to represent a more uniform clast size with depth and a more uniform depositional environment (distal alluvial fan) throughout the filling of this portion of the basin. As with line 1, the high velocities at the base of the 2D profile represent granitic basement, with the boundary representing the basin-bounding normal fault.

Conclusions

The Slide Mountain landslide complex contains at least 10 deposits from Quaternary landslide events. In this study we tested whether the buried portion of this landslide complex could be identified based on shear wave velocity profile. Deep ReMi analysis across the toe of the landslide complex showed a heterogeneous Vs profile, with lateral variability and velocity inversions. However, vertical and horizontal resolution was limited due to the relatively large nodal spacing. In contrast, a second array in an area with no suspected landslide showed a Vs structure that was laterally homogeneous with velocities increasing with depth. This initial study shows that Deep ReMi has the potential to identify buried landslide deposits, which could be a useful tool to understanding geomorphic evolution of rangefronts and as potential resource targets.

Acknowledgments

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