# PS Using Landscape Evolution Modeling to Evaluate Potential for Buried Mega-Landslide Reservoir Units Within the Basin and Range, Western U.S.A.*

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## Abstract

Mega-landslides reside on the surface and in the subsurface throughout the Basin and Range province of the western USA. Buried mega-landslide blocks locally are excellent hydrocarbon reservoirs, accounting for approximately half of the produced hydrocarbons in Nevada. These basins are bounded on one or both sides by Miocene to recent normal and/or strike-slip faults. Basins within the province are filled with several km of poorly consolidated and unconsolidated clastic material shed from the ranges, lacustrine sediments, and volcanic ash and flows, making seismic imaging in this region very difficult and expensive. Therefore, the purpose of this study is to use clues in rangefront morphology to help identify mega-landslides in the subsurface.

We used the LandLab software to develop numerical landscape models of a developing horst range affected by mega-landslides. LandLab is a Python-based open source landscape evolution modeling software that is designed to quantify surface processes and evolution of landscapes through time. Idealized modeling exercises were run to evaluate the scope of potential rangefront morphologies resulting from mega-landslide processes. The baseline modeling exercise used a deep-seated dip-slope landslide process to simulate the evolution of a range during regional extension. From these baseline results, landslides were imposed according to a size-frequency distribution and conditioned for the range of local lithologies and structures within the Basin and Range. Model stratigraphy was tracked to evaluate how different distributions of landslide sizes impact the alluvial architecture with a range of fault slip rates and climatic parameters.

This idealized landscape modeling has provided information on (i) the general evolution of rangefront stratigraphy as it relates to landsliding and landslide deposits; (ii) estimating the time scale for relaxation of landslide source areas following an event, and what lingering impacts on the fluvial network may remain to be extracted from the topography; and (iii) disruptions to the pattern of alluviation on the fans and other basin fill by emplacement of a mega-landslide. These results will be compared to exposed mega-landslides throughout the province. Key geomorphic features from these models will be used to guide analysis of rangefronts for potential buried mega-landslide reservoirs in the Basin and Range.

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## Research Question

Can we develop and use an idealized landscape evolution model to evaluate how a distribution of mega-landslide sizes impact the alluvial architecture with varying climatic and tectonic parameters?

## Study Location

The Basin & Range Province is a large-scale zone of continental extension which has been actively deforming since Miocene time (~17 Ma). Range strata are dominated by sedimentary and volcanic rocks (Stewart and Carlson, 1978). Basins are bounded by normal and/or strike-slip faults (dePolo, 2008). Basin fill is mostly shed from the ranges, lacustrine sediments, and volcanic deposits.

*Figure 1. Map illustrating the general location of the province and the area it covers (USGS Geomaps, 2017). Figure 2. Satellite image showing the N-W and N-S orientation of the ranges (Taken from Google Earth, 2018).*

## Mega-Landslides in the Basin & Range

Mega-landslide deposits appear on the surface and in the subsurface throughout the Basin and Range (Bertran, 1998). Many of the deposits are buried by Cenozoic alluvium which makes them difficult to identify in the subsurface. They are mid-Miocene to Holocene in age.

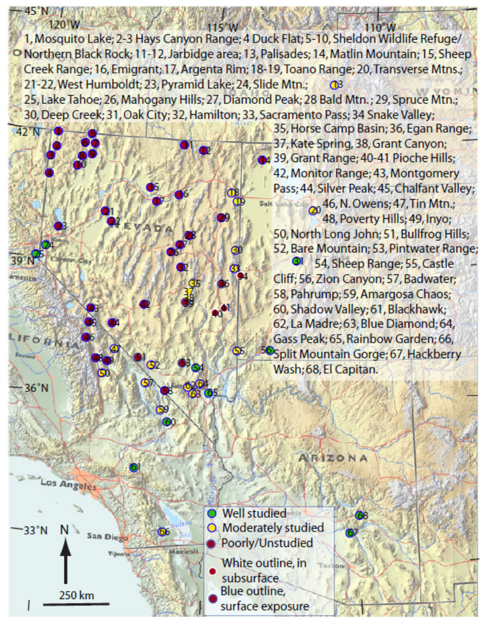


*Figure 3. Some of the known mega-landslides throughout the Basin & Range Province.*

## What is a Mega-Landslide?

Mega-landslides are rock avalanches that cover an area greater than 1-km$^2$. Deposits are classified as rock avalanche breccias, which are sedimentary breccias that form through mass wasting events caused by catastrophic slope failure (Figure 4, Friedman, 1997).

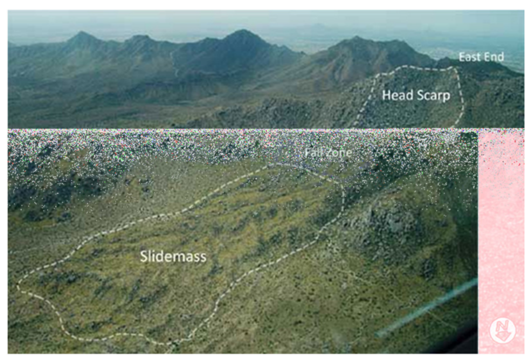


*Figure 4. Oblique view of the Marcus Landslide in the McDowell Range, Central AZ (Figure from AZGS, 2012).*

### Height Vs. Length Relationship

There is a direct relationship (H/L) between the height of the vertical drop (H) and distance traveled (L). This makes it possible to constrain the run-out distances of mega-landslides with known source areas (Figure 5, Friedman, 1997)

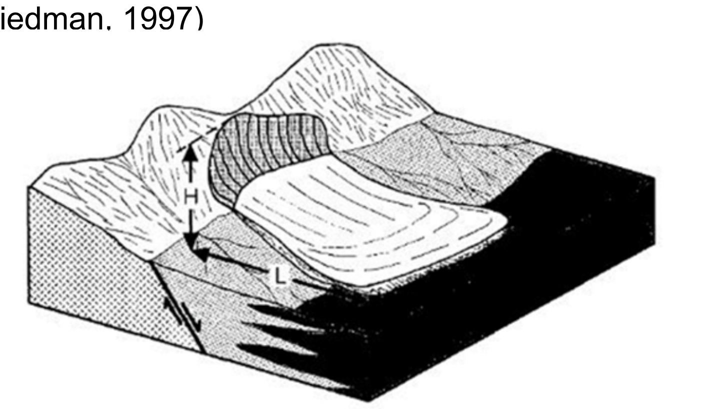


*Figure 5. Model showing the height and length (H/L) relationship of a dry climate, non-volcanic mega-landslide (Modified from Topping, 1993).*

## Importance for Hydrocarbon Systems

Buried mega-landslide blocks locally are excellent hydrocarbon reservoirs, accounting for approximately half of the produced hydrocarbons in Nevada (Figure 6; Nevada Division of Minerals, 2015).

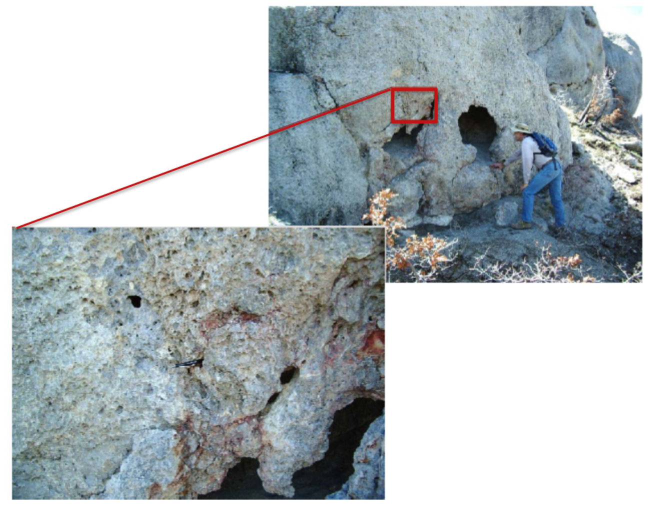

*Figure 6. Exposed Tin Mountain mega-landslides block demonstrating "6-man tent porosity" (Modified from French and Walker, 2007).*

Understanding rangefront recovery from mega-landslides will help in the identification of buried mega-landslides throughout the Basin & Range Province.

## Landscape Evolution Modeling

LandLab is a Python-based open source landscape evolution modeling software that is designed to quantify surface processes and evolution of landscapes through time (Hobley et al., 2017). Our goal is to develop numerical landscape models of a developing horst range and adjacent basin impacted by mega-landslides.

## Idealized Landscape Modeling

Baseline modeling exercises will be run in order to evaluate a range of rangefront morphologies. Model stratigraphy will be tracked. This will allow us to evaluate how a distribution of landslide sizes impact the alluvial architecture with varying climatic and tectonic parameters (Figure 7).

Basin stratigraphy example scenarios:

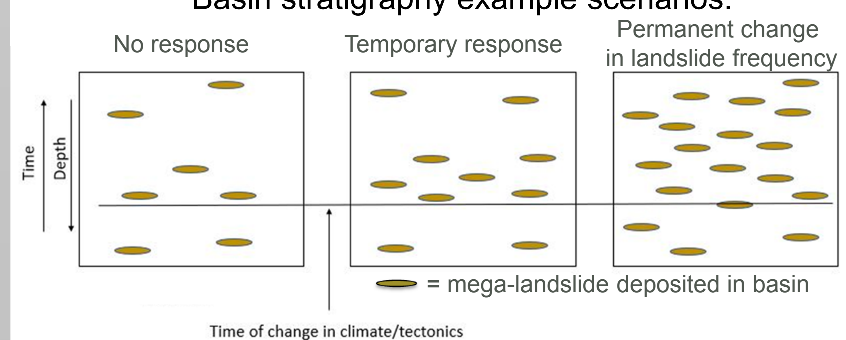


*Figure 7. Hypothetical responses to the pattern of mega-landslide deposition in a basin before and after a time of increased climatic and tectonic parameters.*

### Model Components:

- Uplift of a fault-bounded range with realistic rates within the Basin & Range and a linear tilting perpendicular to a fault (Figure 8)
- Nonlinear hillslope diffusion to handle soil creep and shallow landsliding (Figure 8)
- Fluvial erosion and deposition
- Stratigraphic layers that will track the modeled basin stratigraphic evolution

Currently, we have developed a numerical landscape model of a developing horst range:

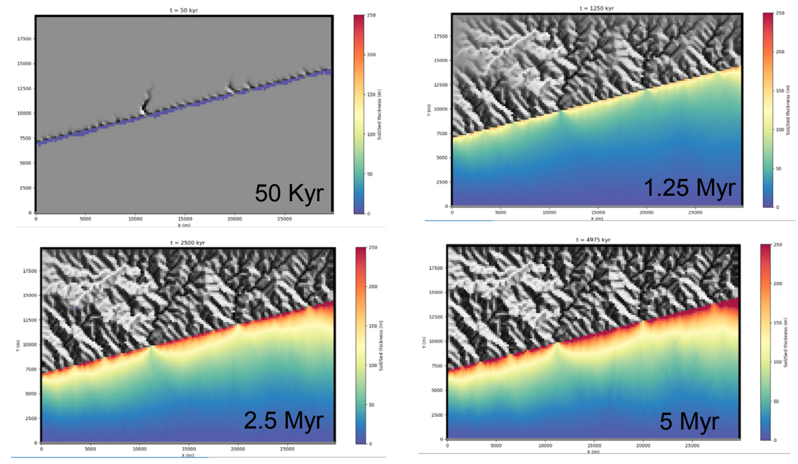


*Figure 8. Progression of a developing horst range over a period of 5 Myr*

### Modeling Large Landslides:

- Develop a criteria for potential landslide sources:
  - Topographic slope, geology, hydrology
- Develop a code for landslide removal of topography
- Landslide deposition code (Figure 9):
  - Kinetic energy/frictional loss code to create long run-out landslides
  - Will be informed by field observations

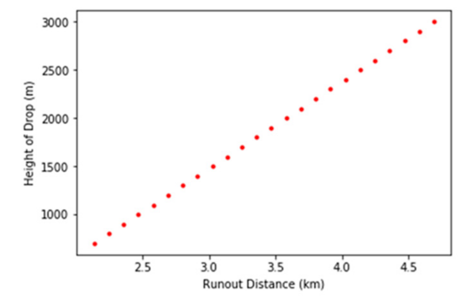


*Figure 9. Graph of model results that illustrates the direct relationship between height of vertical drop (H) and length of run-out distance (L). This 2D model was ran in Python using the conservation of energy formula to three separate inclines representing a rangefront and adjacent basin.*

## Expected Outcomes

This landscape evolution modeling will provide information on:

(1) The general evolution of rangefront stratigraphy impacted by landsliding.

(2) The timescale for relaxation of landslide source areas following an event.

(3) The relationship between occurrence of landslides and changes in climatic and tectonic parameters.


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