Precise dating of pre-historic plate boundary earthquakes: Dendrochronologically based age estimates for time of failure of mega debris avalanches

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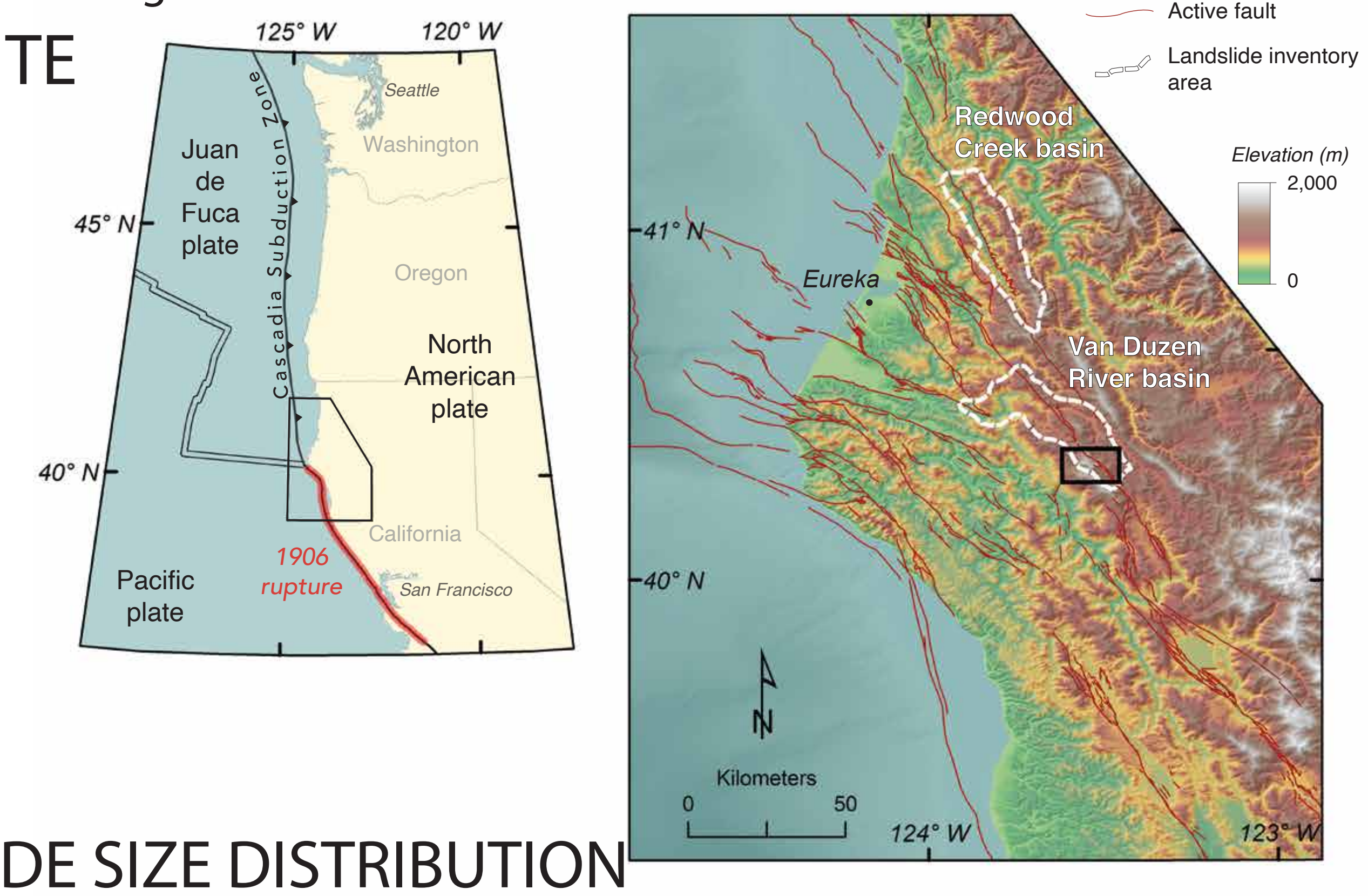
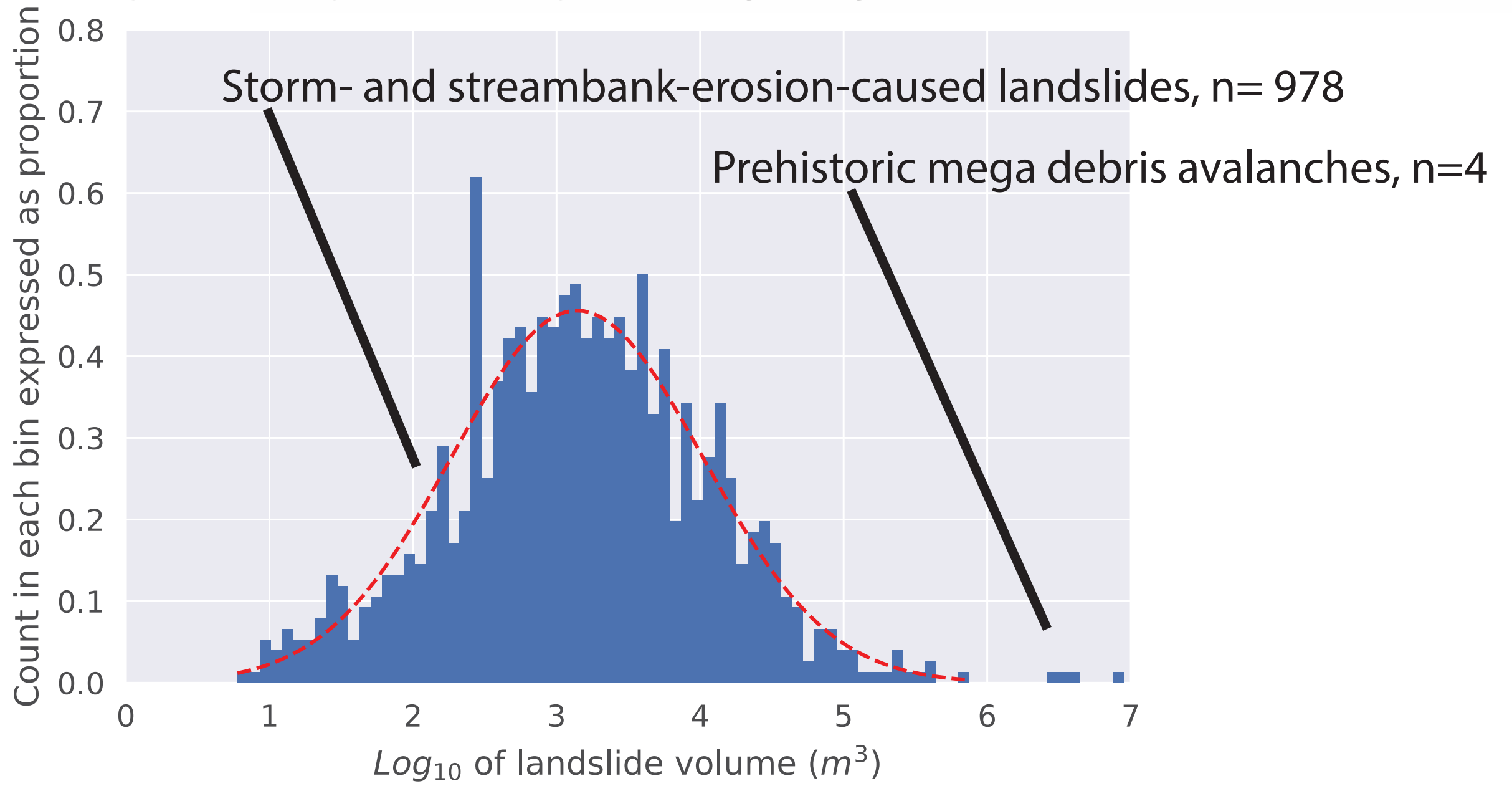
MOTIVATION

Are there prehistoric landslide scars and deposits in the Coast Ranges that were formed during plate boundary earthquakes? We address this question in the northern CA Coast Ranges by searching for mega-landslide scars (>3 x 10^6 m^3) that are not vegeated or only partially revegetated. These scars testify to head-water-to-channel-bottom, slope-clearing landslides that create straight slopes. Such landslides are candidates for seismic triggering. We discuss topographic, sedimentologic and dendrochronologic data to evalute a seismic-triggering origin for these mega-landslides.

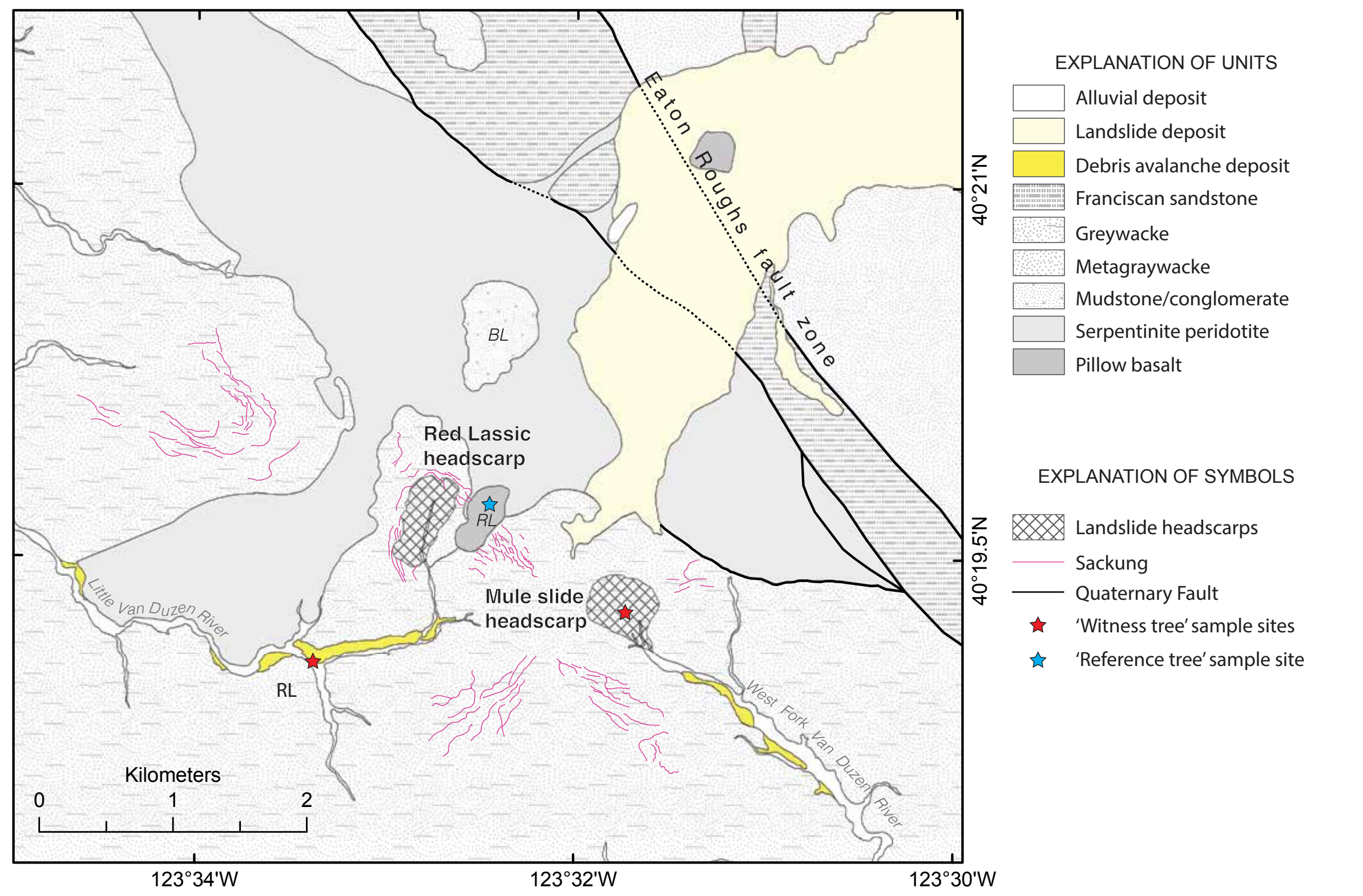
FIELD SITE



LANDSLIDE SIZE DISTRIBUTION

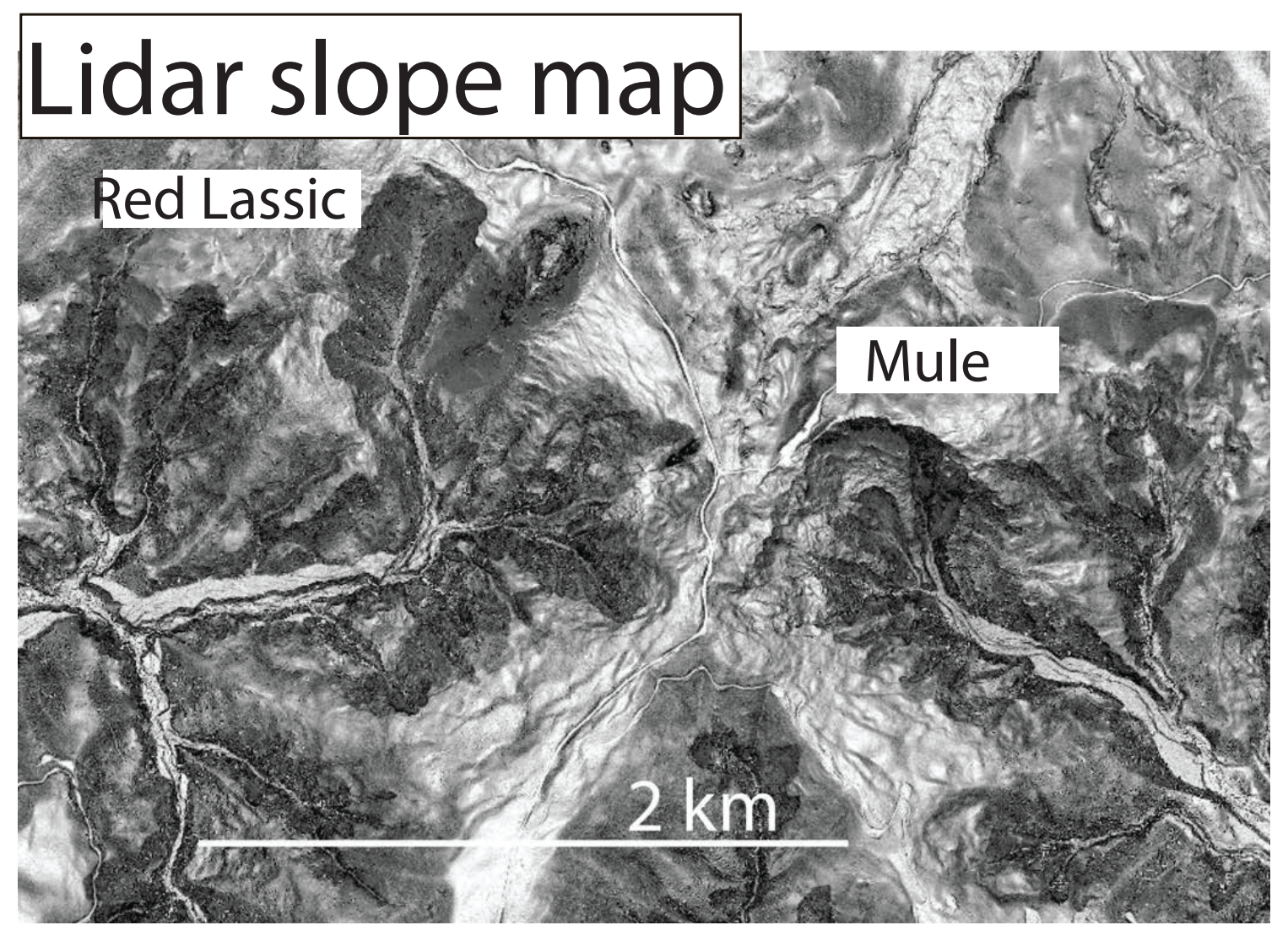


GEOLOGY AND TOPOGRAPHY



Scars are preserved in competent, massive sandstone bedrock. Scars encompass entire head-water basins; relief of the slope failures ranges from 200-300m. Sackung (extensional graben features) are developed at ridge crests adjacent to failed headscarps as well as at the top of steep ridge tops absent of headscarps.

Lidar slope map

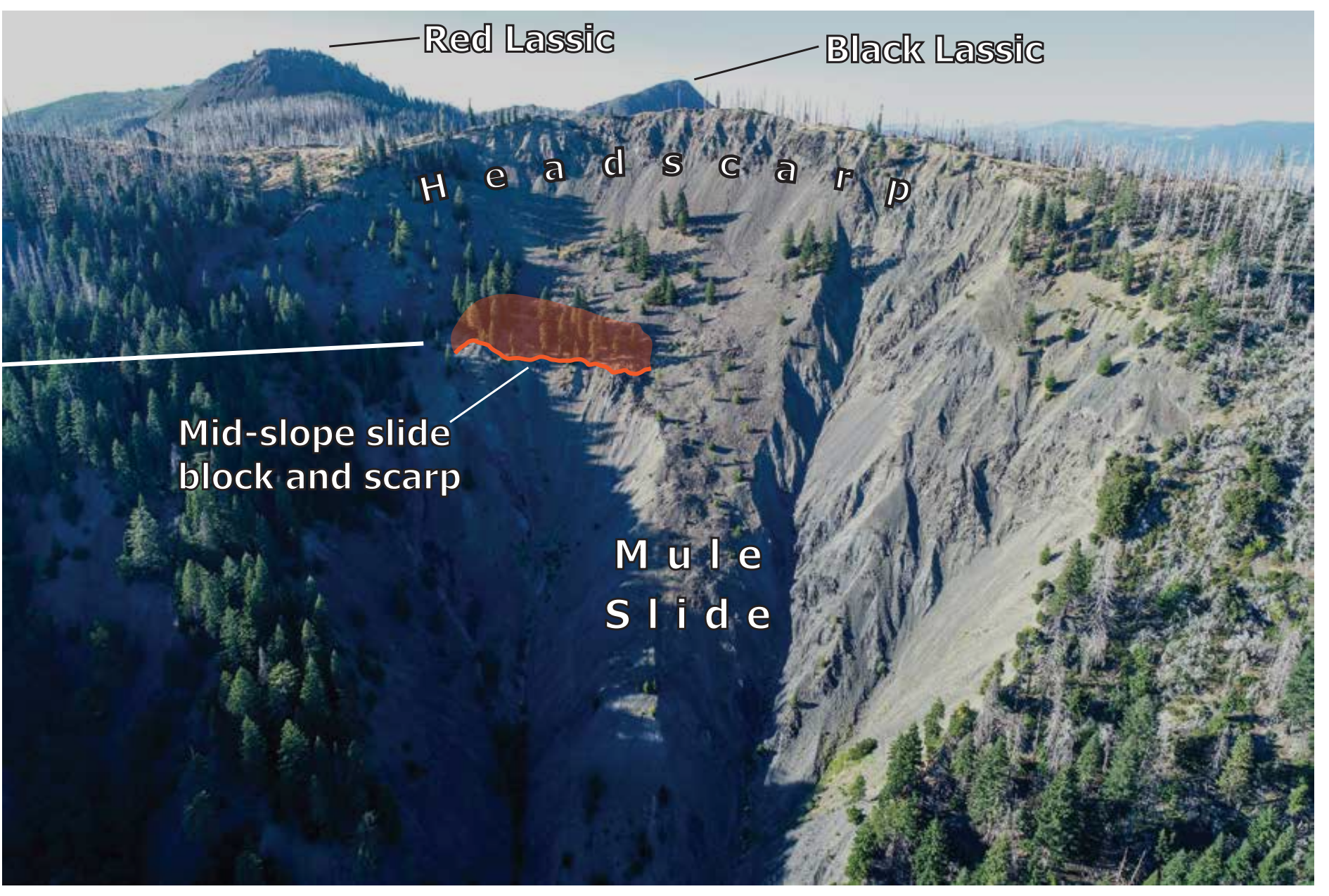


Topographic amplification of seismic shaking ?

Optimal conditions for topographic amplification of seismic shaking: convergence of three factors - high relief, steep slopes and high elevation (Dunham et al. 2022).

CATASTROPHIC FAILURE: Massive, simultaneous movement of slope material translates blocks that host trees (Mule Slide) and buries trees in a down-stream riparian corridor (Red Lassic debris avalanche)

Mule Slide: REMOTE SENSING AND STRUCTURE FROM MOTION ANALYSIS: did the mid slope slide block fail catastrophically and since then essentially has not moved? Remote sensing and structure from motion analysis investigates mobility.



2022: Aquisition of drone aerial photography

-- Unmanned aerial system (UAS) photo acquisition of Mule Slide in summer 2022.

-- GNSS RTK-surveyed ground control points (GCPs) on stable bedrock outcrops around Mule Slide

-- Structure from motion (SfM) processing in Agisoft Metashape software to produce terrain model and orthophoto

-- Pixel size: 0.04 meters: orthophoto ground sample distance (GSD) (pixel size)

-- 0.03 cm: RMSExy (positional accuracy of orthophoto based on four independent control points)

Historical Aerial Photography

-- Acquire 1944 historical aerial photographs from U.S. Forest Service, including multiple frames from adjacent flight lines.

-- Georeferencing and SfM processing in GIS and Metashape using surveyed GCPs and additional photo-identified GCPs.

-- 0.87 meters: orthophoto GSD (pixel size)

-- 2.5 meters RMSExy: approximate positional accuracy of orthophoto based on four independent control points

Geomorphic Change Analysis

--Trees and scarps recognized in each orthophoto mapped in GIS.

-- Mapped features categorized into: 1) headscarp, 2) mid-slope trees, 3) trees on slide block, and 4) block scarp.

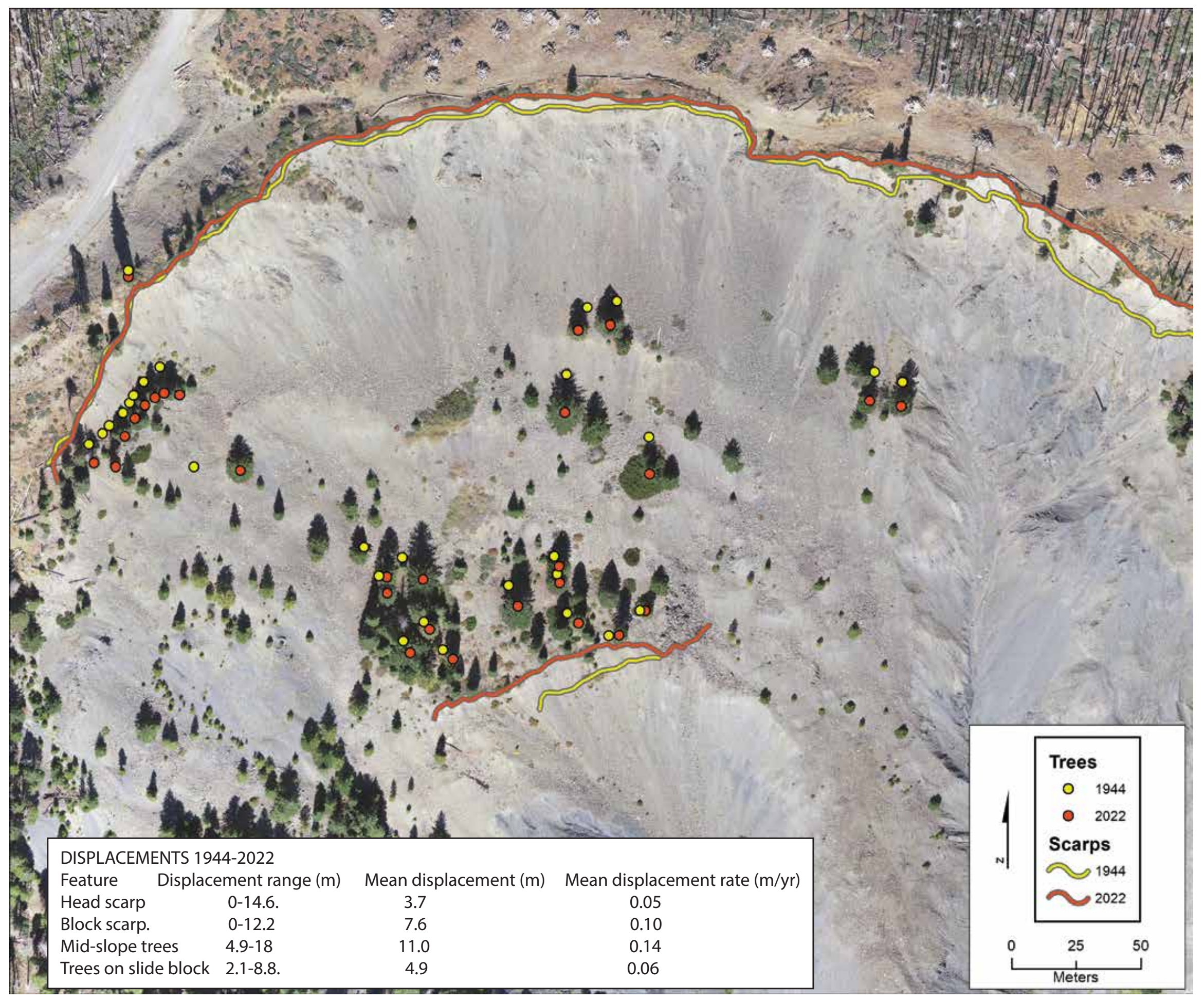
-- Positions of mapped features compared in GIS to quantify displacement magnitudes and rates over period of record (1944 to 2022).

-- Displacement of scarps is manifest as upslope retreat

-- Displacement of trees is manifest as downslope translation

-- Mid-slope trees have translated downslope at greater average rates than trees on the slide block, (0.14 m/yr compared to 0.06 fm/yr).

-- Scarps have had no retreat in some locations and minor to moderate retreat rates in other locations (up to 0.05 fm/yr on the headscarp and 0.10 m/yr on the block scarp).



DISPLACEMENTS 1944-2022

Feature	Displacement range (m)	Mean displacement (m)	Mean displacement rate (m/yr)
Head scarp	0-14.6.	3.7	0.05
Block scarp.	0-12.2	7.6	0.10
Mid-slope trees	4.9-18	11.0	0.14
Trees on slide block	2.1-8.8.	4.9	0.06

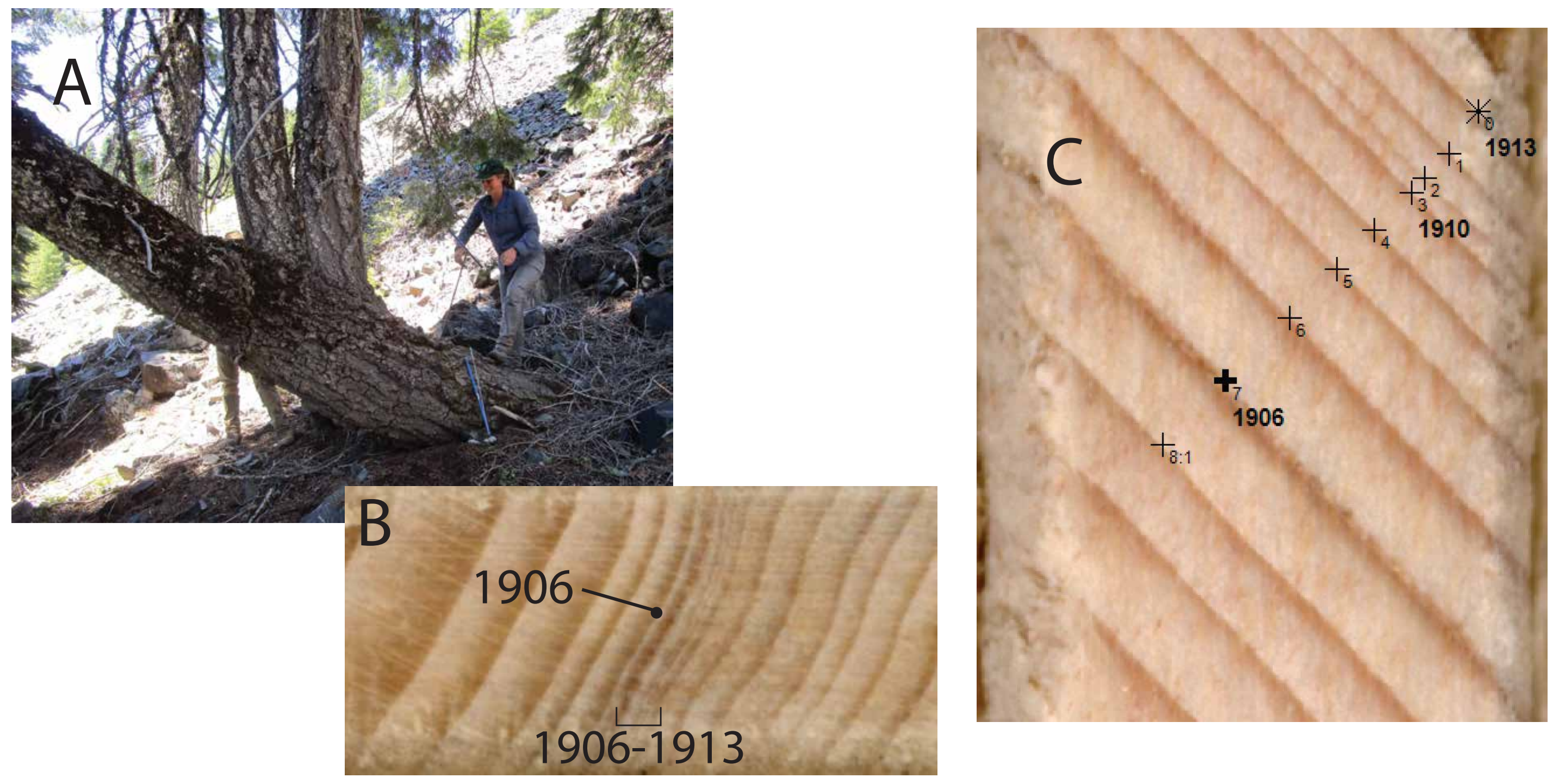
Over the last 78 years, the midslope slide block (now removed 200-220 m from the former headscarp location) has creeped downslope at a rate of 6 mm/yr (~4.7 m total displacement). If the blocks detached from the headscarp ca. 1906 (i.e. 116 yrs ago), then they could only have arrived at their mid slope position by catastrophic movement relative to their slow downslope creep in the last 78 years.

Red Lassic: debris avalanche fill and buried riparian corridor testifies to catastrophic failure

The 9.06 x106 m^3 debris avalanche translated downslope and downstream and was deposited as a poorly sorted alluvial fill. This alluvial fill, extending along channel for 1.5 km and up to 27.5 m thick, buried a riparian stand of Douglas fir trees, 1.0-1.5 m in diameter, that had been growing along Red Lassic Creek and the South Fork of the Van Duzen River.

The victim: a Douglas fir killed by burial in avalanche debris. Photos show sampling of tree with bark still attached. Using dendrochronology, the year of death of this victim will be determined.

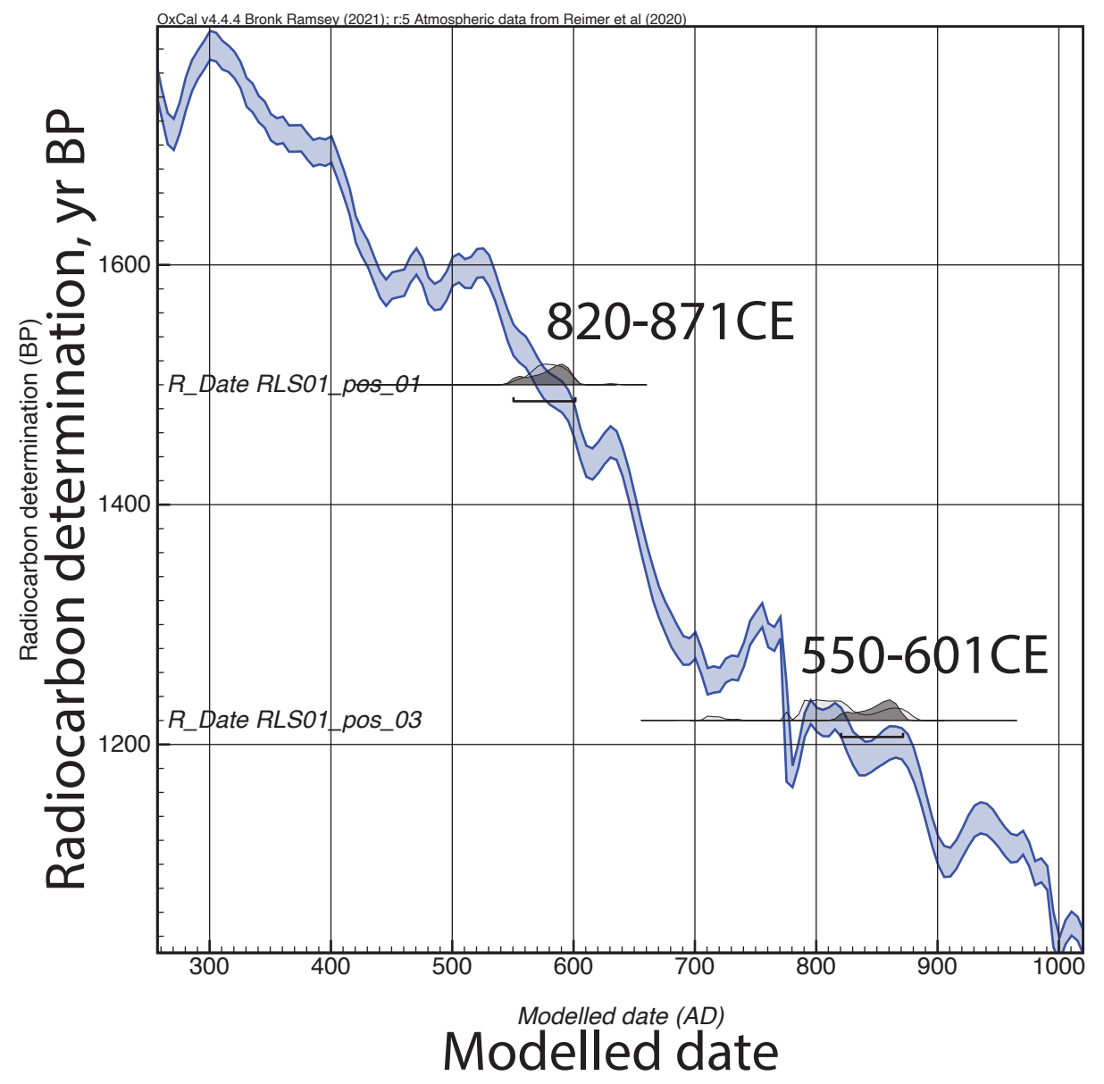
LANDSLIDE DENDROCHRONOLOGY: Mule Slide

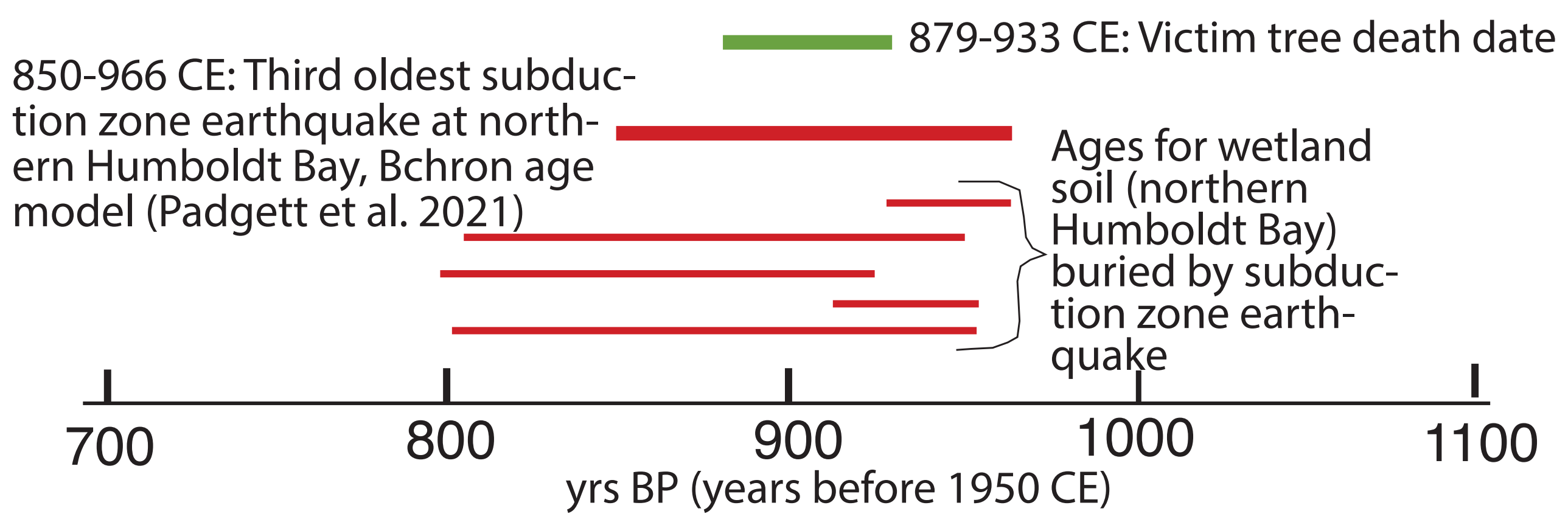


Mule Slide tree-ring width suppression and traumatic resin ducts. A. MSF02, tilted tree with two trunk-like stems growing upright. B. Ring pattern of MSF02. Traumatic resin seen in the year 1906, with micro rings and missing rings in the period of 1906-1913. C. Traumatic resin in 1906 and 1907 on MSS02 (snag in the middle of the block).

LANDSLIDE DENDROCHRONOLOGY: Red Lassic debris avalanche

Wiggle matching of two 14C dates (one (pos03) from ring 69 from the bark, the other (pos1) from ring 330 from the bark) places the death date of the Red Lassic victim tree at 879-933





COMPARE LANDSLIDE AGE TO TIMING OF PLATE BOUNDARY EARTHQUAKES

Mule Slide: Ring width suppression and trauma to the resin ducts initiated on trees in the mid slope slide block in 1906 CE, which is the year of the most recent northern California San Andreas fault earthquake. Mule Slide is in a region where felt intensities for the 1906 earthquake were in the VI-VII range (Boatright and Bundock, 2005).

Red Lassic: The death of the Red Lassic tree overlaps the age range of the third oldest earthquake at northern Humboldt Bay (Padgett et al. 2021). Similarly, the death of the Red Lassic victim tree overlaps in age with the age range of the third oldest subduction zone earthquake in the Maximum Rupture Model of Nelson et al. (2021). Identification of the Miyaki event (huge solar flare 14C spike , 774-775 CE) in the victim's tree-ring chronology (forthcoming) will enable assignment of the exact year of victim tree death.

REFERENCES
Booatright, J. and Bundock, H., 2005, Modified Mercalli intensity maps for the 1906 San Francisco earthquake plotted in ShakeMap format, in USGS Open-File Report 2005-1135.
Dunham, A. M., Kiser, E., Kargel, J. S., Haritashya, U. K., Watson, C. S., Shugar, D. H., et al., 2022, Topographic control on ground motions and landslides from the 2015 Gorkha earthquake. Geophysical Research Letters, 49, e2022GL098582. https://doi.org/10.1029/2022GL098582
Nelson et al., 2021, A maximum rupture model for the central and southern Cascadia subduction zone – reassessing ages for coastal evidence of megathrust earthquakes and tsunamis, Quaternary Science Reviews, https://doi.org/10.1016/j.quascirev.2021.106922
Padgett et al., 2021, Timing and amount of southern Cascadia earthquake subsidence over the past 1700 years at northern Humboldt Bay, California, USA, Geological Society America Bulletin, v. 133, p. 2137-2156.