REACTIVATION OF DEEP-SEATED LANDSLIDES IN NORTHWESTERN CALIFORNIA AFTER WILDFIRES IN 2006 AND 2008

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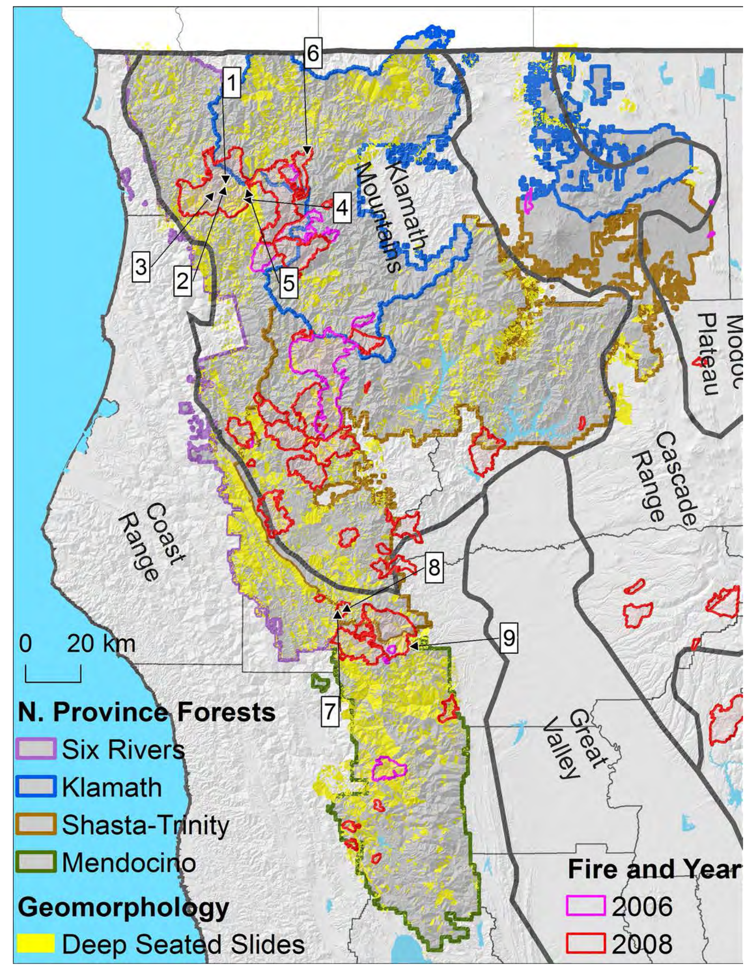
Abstract

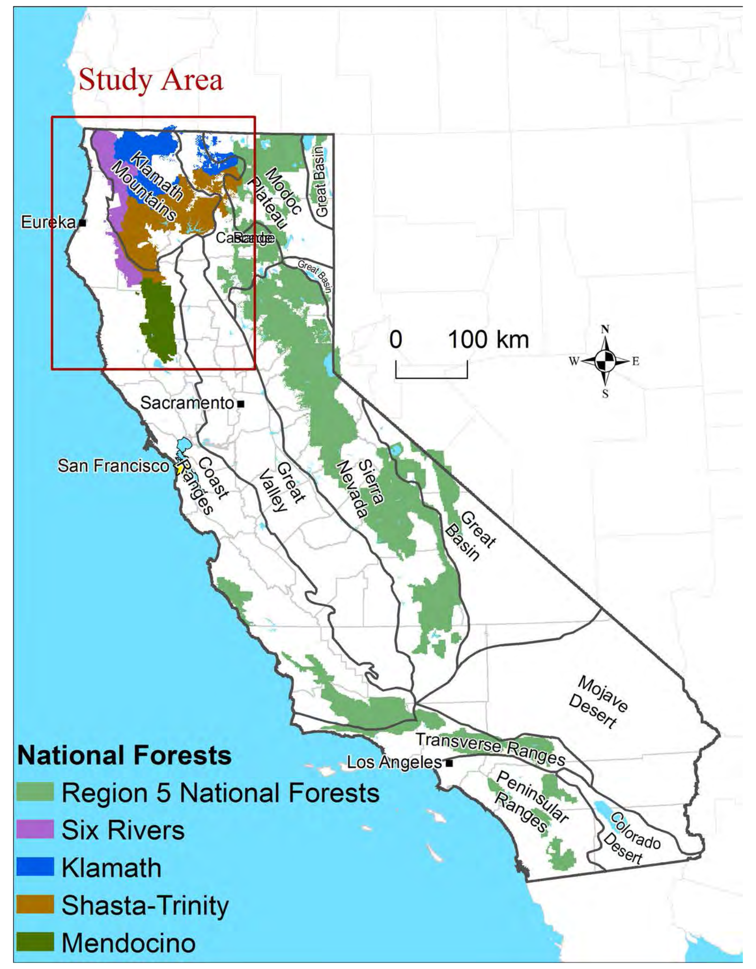
Widespread wildfires in the Klamath Mountains and Coast Ranges of northwestern California burned tens of thousands of acres within the Klamath, Shasta-Trinity, Six Rivers, and Mendocino National Forests in 2006 and 2008. Much of the area burned was underlain by older dormant, deep seated landslide deposits. Numerous landslides were activated within the older complexes during the winters of 2009-2010, and 2010-2011, years with average precipitation.

Post-fire debris flows associated with shallow landslides and mobilization of shallow hill slope material and channel bed deposits are well-documented in the literature. These responses typically occur in the first few years after the fire. They have been attributed to fire-induced reduction in soil permeability, loss of ground cover and organic material, and loss of fine root support. In contrast, activation of deep-seated landslides after wildfire has been observed but not as thoroughly documented. Such activations can occur immediately after the fire, in response to ordinary precipitation events. However, delayed responses of 10 years or more are known. Fire-related loss of root support is not likely a factor in the activation of these landslides because their failure planes are typically located well below the rooting depth. The 10 plus year reaction time strongly suggests that movement is related to changes in slope hydrology, since landslide deposits are known to have complex groundwater flow paths (Iverson and Major 1987, Iverson 2000). Activation of such landslides can have far-reaching watershed effects, involving large debris slides from the margins and toes of the older landslides. These debris slides may generate debris flows. In rare cases, landslide dams can form. For these reasons, it is essential to identify dormant landslides within burned areas, and their burn severity, in order to better understand how they react in response to varying wildfire severities. Nine landslides which occurred after 2008 are examined and compared with observations made after widespread wildfires in 1987.

Burn severity at the landslides ranged from severe to low, and roads were associated with seven of them. These case studies are not intended to clearly represent examples of cause/effect relationships between landsliding and wildfire, since interactions between fire, geomorphic conditions, and road-related earthwork are complex. Rather, they provide insights into possible interactions and suggest monitoring which could test some of these ideas. Newly evolving InSAR remote sensing technology allows inexpensive monitoring of slope movement over broad areas, and if coupled with precipitation monitoring, could yield better understanding of these processes across a broad range of geomorphic terranes. Such monitoring could also reveal precursors to catastrophic failure, and improve assessments of similar areas during the Burned Area Emergency Response assessment (BAER) conducted by Federal land management agencies after wildfires.



Map 2: Dormant Landslides and Fire Perimeters with Forest Boundaries and Geomorphic Provinces



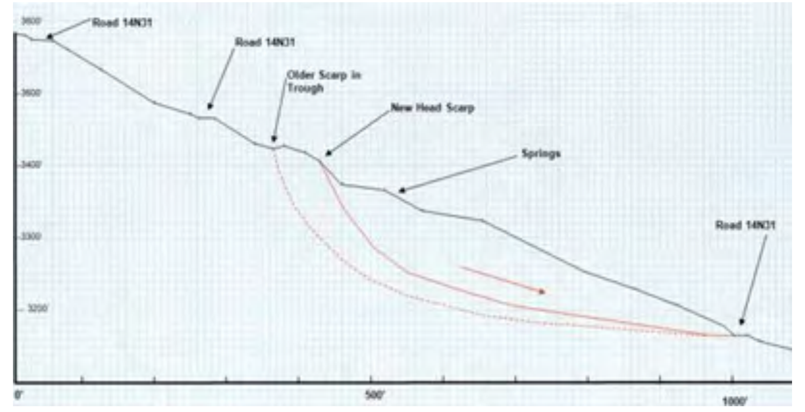
Map 1: Index Map; US Forest Service California Region Northern Province

Presented at AGU Fall Meeting 2012, San Francisco, CA

Questions at Hand

1. Why did most of the deep slides reported in 2010-2012 which damaged roads or delivered sediment to streams occur in recently burned areas? Was this relationship random?
2. How have landscapes in this area responded following previous fires, such as 1987?
3. What slope processes could account for this pattern?
4. What monitoring tools might improve our understanding of these processes?

Siskiyou Fire - Slide #2 has rotational translational and earthflow components, and is about 200' wide here. View downhill to the west.



Field Cross Section of Slide #2

Methods

A total of 9 landslides were investigated in the field. Maps and photos for 5 of them, and a sample cross section are presented by this poster. Data for the others is presented in Table 1.

Selection Criteria - All landslides investigated were: a) Deep-seated landslides (rotational /translational, slumps, earthflows); b) Burned by the fires of 2006-2008;) c) Damaged roads or put sediment into streams at a level high enough to raise Forest Service concerns.

Field/Office Investigations - Field cross sections (tape and clinometer) were developed for the landslides to characterize landslide processes and geometry and to estimate the depth to failure planes. Air photos were reviewed to determine the geomorphic setting.

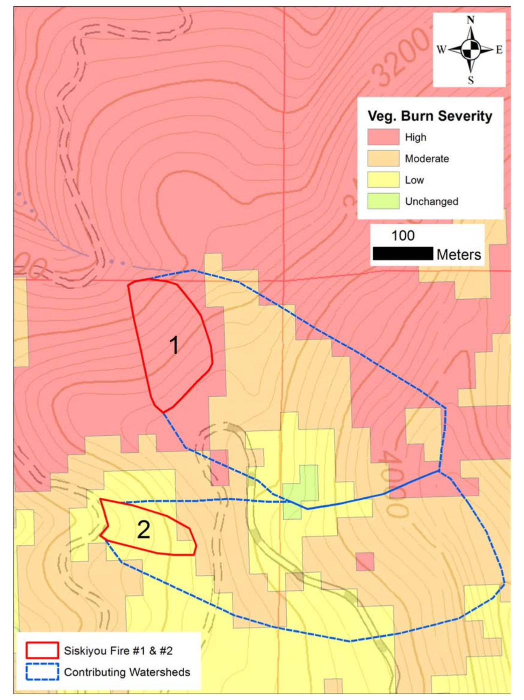
GIS Analysis - Existing GIS coverages for landslides and bedrock were examined, and hydrologic basins delineated on existing topographic maps. The proportion by fire severity class for the area draining to each landslide was determined with the BARC imagery (Burned Area Reflectance Classification).

Findings

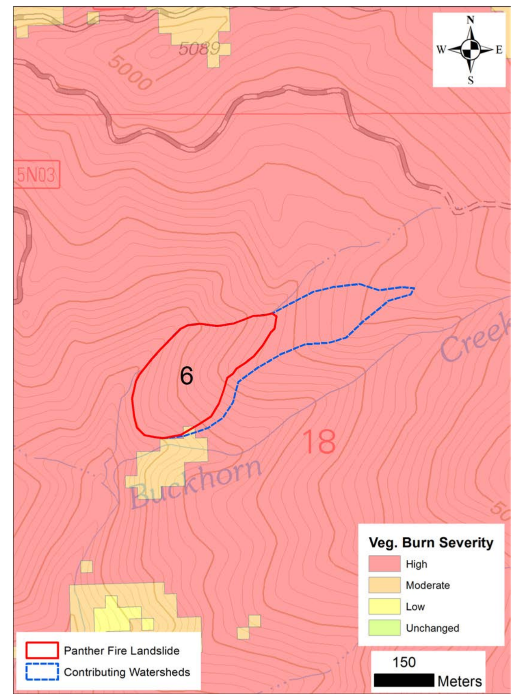
Fire Effects - With the exception of landslide #9, all were activated after the fires of 2008, and of all landslides addressed by Northern Province geologists as having activated from 2008-2012, nearly half were within 2006 & 2008 fires. Fire severity in the hydrologic basins draining to the landslides ranged from 9-100 % High/Moderate severity, with most >24% (Table 1).

Road Relationships - Seven of the 9 landslides were along roads, and were likely influenced by cuts, fills, and drainage.

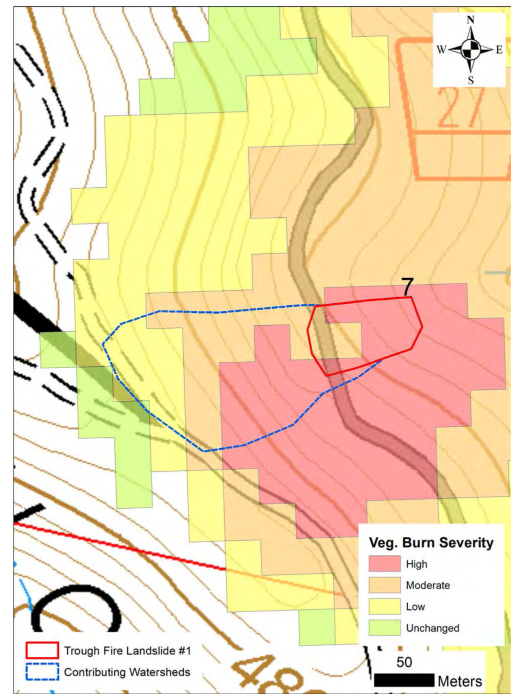
Geomorphic Setting - All landslides investigated were situated within much older deep seated landslide complexes.



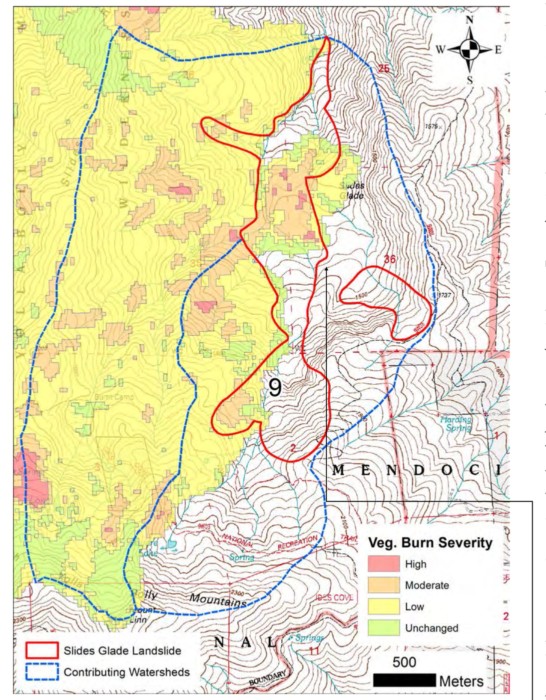
Map 3 Siskiyou Fire: Slide #1 (5 acres) & #2 (2 acres)



Map 4 Panther Fire: Slide #6 (15 acres)



Map 5 Trough Fire: Slide #7 (1 acre)



Map 6 Iron Basin Fire: Slide #9 (438 acres)

Siskiyou Fire- #1, debris slide about 150 feet wide at toe of much larger rotational/ translational landslide.

Panther Fire - #6, activated toe of rotational/translational landslide (raw area in center about 250 feet wide), producing shallow debris slides.

Trough Fire - #7, road segment (100 ' wide) damaged by rotational/translational slide complex.

Iron **Basin Fire** - #9, trees on body of large rotational/translational/ earthflow complex killed by fire. Slide is about 2 miles long and ¼ mile wide at photo location.

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Table 1: Landslide Attributes

Summary of Landslide Activity

Siskiyou #1 - Minor movement likely occurred in winter 2010-2011, (not field verified) generated small debris flow from the toe; Renewed movement in winter 2011-2012 included a debris slide about 150 feet wide, which sent a debris flow down stream, taking out a road fill.

Siskiyou #2 - Activated winter 2009-2010, 15 foot scarps at head, and earthflow in lower portion (blocked road). Very minor movement in 2010-2011, and 2011-2012 (earthflow creep at toe, but little change to the head scarp);

Panther #6 - First noticed in spring 2011, toe of older slide mobilized, forming raw scarps to 30 feet in height; Toe encroaching on Buckhorn Creek; In winter 2011-2012, little change other than shedding of sediment into stream by shallow debris slides at toe. Movement in head of slide on the order of a few feet.

Trough #7 & #8 - Movement on #1 dropped the outside 1/3 of the road about 4 feet, in spring 2011, with cracks immediately above road ditch. Small debris slide (10' wide) on toe. Slide #8 dropped outside shoulder of the road a few inches in spring 2011 , and exhibited 6 foot head scarps below the road. In winter 2011-2012, very minor movement on Trough #7, and virtually none on Trough #8.

Iron Basin #9 - Huge slide, slope processes and response to fire likely different from the other slides examined due to difference of scale. First occurred in 1996, and field monitoring from 1998 through 2010 showed continued creep of the head of the slide (inches per year). Monitoring pins installed in summer 2010 revealed movement in the head of several inches in summer 2011, but virtually no movement in summer 2012.

Discussion

Fire Association- The high concentration of recently activated deep landslides within fire areas of 2006 and 2008 suggests a causal relationship;

1987 Fires - Fires in 1987 burned about 300,000 acres and many burned on dormant landslides, many of which were reactivated in the subsequent 5 years. These generally ceased movement after a few years, but these plus many others showed renewed activity in association with the flood of 1997.

Monitoring - A region-wide monitoring system would be invaluable in tracking post fire movement of deep landslides. See AGU poster G43A-0919: "Large-area Active Landslide Detection and Monitoring with ALOS/PALSAR Imagery over Northern California and Southern Oregon, USA" (12-6-12). LiDAR data will soon be available for slides #6 and #9 and will be used in conjunction with InSAR to track future movement of these slides. Rain gages are essential to track on-site precipitation and correlate it with landslide movement.

Emergency Fire Response - The effect s of fire on deep landslides can be very important, pointing out the importance of identifying these features during the BAER (Burned Area Emergency Response) assessments conducted by land management agencies after wildfires.

Earthquake of 2010 - The earthquake off the coast of Eureka, CA in January of 2010 may have had an effect on the slides in the Siskiyou and Panther Fires areas where ground accelerations were highest.

Activity Patterns - Most slides activated in 2010 showed declining activity in the two succeeding winters (except for #2). Some slides showed evacuation of material from the toe which could have destabilized the pre-existing landslide and precipitated failure in the head. Others exhibited scarps and cracks in the head without any evacuation of debris from the toe.