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Technical note

Mapping earthflows and earthflow complexes using topographic indicators

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ABSTRACT

Practical methods of mapping earthflows and earthflow complexes using topographic recognition keys are briefly profiled in this article. These methods can be employed to tentatively identify earthflow features that may not be recognized on stereopair aerial photographs because of vegetation, mollification of the features with age, and/or unfavorable sun angle on the images. Conventional USGS 7.5-min topographic maps (1:24,000 scale) with contour intervals of >20 ft/6.1 m are not generally useful in identifying earthflows with much less than ~18 to 60 m of vertical relief. Useful recognition keys for the topographic expression of earthflows are presented. These keys include divergent contours along a slope fall line with headward cutting upslope and depositional fans downslope. Fans tend to widen and deepen downslope. Earthflows in first- and second-order watersheds may exhibit more dissection of their toe lobes than those in zero-order basins. Earthflows commonly occur in large coalescing complexes, with one event, or lobe, superceding another. This forms a series of superposed lobes, with the most recent lobes being easiest to discern, while older lobes are increasingly mollified with time. The soft cohesive clay and silt debris deposited by earthflows is most easily eroded in the headscarp area, and compacted naturally in the depositional lobe. This makes the recognition of earthflows increasingly difficult with age. Earthflow debris is often interpreted to be colluvium when deposited on slopes without appreciable shearing to form slickensided contacts. Discernment of earthflows using topographic recognition techniques depends on the scale and quality of the topographic maps being evaluated.

1. Introduction

Since the early 1950s evaluation of stereopair aerial photos has been the most widely employed method to identify various types of landslides (Liang, 1952; Liang and Belcher, 1958; Zellmer and Eastman, 1997; Su and Stohr, 2000; Hart, 2008; Darrow et al., 2012; Petley, 2012; Tang et al., 2013). Recognizing landslide features on stereopair aerial photos depends on a number of factors, including density of foliage and height of tree cover; age of the slope movements; time of year; and sunlight azimuth (the time of day the photos were imaged; Hart et al., 2009; Griffiths and Whitworth, 2012). For most earthflows, a low sun angle from behind the headscarp forms long shadows across slight scarps and hummocks, giving the best results (Fig. 1a).

The position of the sun's azimuth and consequent ground shadows is of paramount importance in discerning earthflows on aerial photos. Fig. 1a shows a northeast-facing slope in 1946 with slight backlighting, at the upper left side of the image (these slides were likely reactivated in the late 1930s–early 1940s). Fig. 1b shows the same ridge imaged in 1984, with late morning sun shining directly on the slope. Although there appears to be increased vegetative cover (Fig. 1b), the earthflows are largely undiscernable. Five of the eight earthflows seen in Fig. 1a had been reactivated in 1983, within a year of the imaging of Fig. 1b! This was because the slope was facing the morning sunlight, and no scarp, hummock, or flow lobe shadows are discernable. This comparison suggests that aerial photos may not be inclusive tools for landslide mapping, especially if limited to just a single set of images.

The increasing use of Light Detection and Ranging (LiDAR), Laser Detection and Ranging (LADAR) and Interferometric Synthetic Aperture Radar (InSAR) methods for imaging ground surfaces may alleviate many of the mapping problems inherent with visual photographic images (Chen et al., 2006; Jensen, 2006; Harp et al., 2011). Although these methods are potentially more useful than aerial photos or topographic maps (discussed below), LiDAR coverage is much more expensive and far less available than topographic maps for most rural areas. Since 2008, Google Earth imagery, which can be obtained at no cost, has been tested to map ancient landslides or seismically induced landslides; the more landslides, the higher resolution data. Its limitations/disadvantages are that the Google Earth provides too low-resolution imagery in hilly areas to map accurate landslides and cannot be used to directly calculate slope angles (Sato and Harp, 2009; Petley, 2012).

Fortunately, recently active landslides exhibit varying degrees of topographic expression that can be discerned on topographic maps. As with the use of aerial photos, some background information on the bedrock geology, underlying structure, and landslide mechanisms commonly exhibited in the study area is useful before embarking on any program of reconnaissance-level landslide hazard mapping (Doyle and Rogers, 2005).

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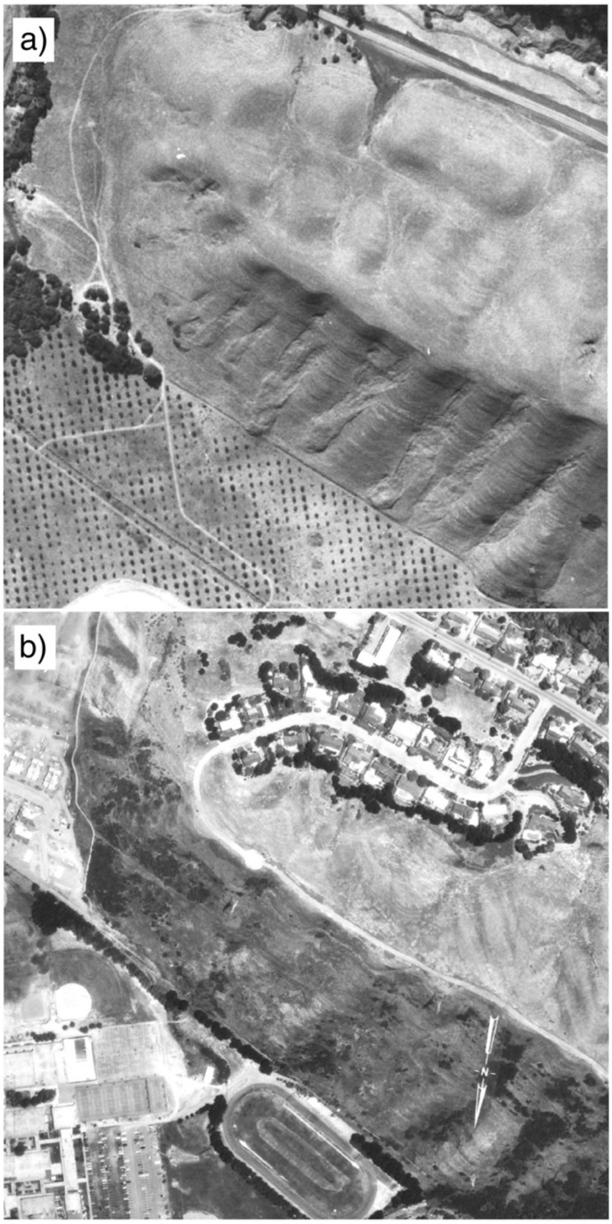

Fig. 1. (a) Vertical photo of Campolindo Ridge in Moraga, CA taken in 1946 with oblique backlighting, which shows a series of dormant earthflows to good effect. (b) The same view as the previous figure, but imaged in 1984, with morning sunlight shinning directly on the slope. The earthflows seen on (a) were reactivated in 1983, but are not discernable on this image because of the absence of back shadows.

For this reason, we suggest that topographic maps can easily be exploited for reconnaissance-level landslide hazard mapping, with certain limitations of scale and map quality affecting the end product. The end product of any reconnaissance hazard mapping is a map showing areas or zones thought to be affected by past landslippage, which can only be verified through site-specific field investigation. Most Holocene-age landslides can be identified by anomalous topographic expression, which is laterally restrictive (is not contiguous on the same slope, up and down the valley), because each type of landslide exhibits distinct forms and profiles engendered by dilation that accompanies downslope translation.

The goal of this article is to present a method of identifying earthflow and earthflow complexes using topographic recognition. Keys for recognizing the topographic expression of earthflows include divergent contours along a slope fall line with headward cutting upslope, along the same fall lines depositional fans formed downslope.

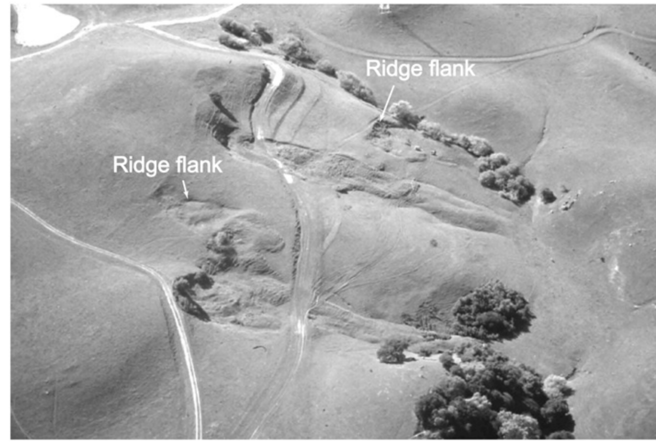

Fig. 2. Active earthflows occupying the axes and flanks of colluvial-filled bedrock ravines near El Sobrante, CA, imaged in January 1993. Portions of these earthflows reactivate every 8 to 15 years, move a few meters, then stop.

2. Background

A key factor in exploiting topographic information is the density and quality of the data. Small-scale maps will tend to mask out details of smaller slides because they are derived from high altitude/low ground resolution imagery, or derived from slopes covered by heavy vegetation. Several physical features appear to bias topographic maps prepared from orthorectified stereopair aerial photography to the point of producing errors in surface topography. These factors include:

- the severity of the topography being mapped;
- the altitude of the source imagery;
- the density of the ground cover on the slopes;
- the height of the vegetation cover;
- the time of year the images were made (trees with or without leaf canopies);
- the stereo model set-up techniques; and
- the topographic control used for the map area.

Dense foliage, high trees, and steep slopes may combine to produce topographic maps that are not spatially accurate on slopes because the mapping protocols employ linear interpolation between visible control points to set the contours. This means that slight nuances in the slope profile are often missed in preparing maps of heavily wooded, or steeply-inclined slopes.

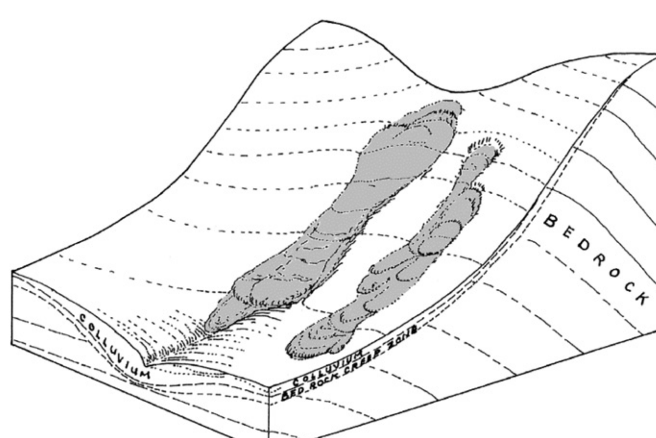

Fig. 3. Block diagram illustrating how shallow earthflows commonly develop upon colluvial-filled bedrock ravines, when the colluvial material is dominantly cohesive.