Precariously balanced rocks in Nevada and California: Implications for earthquake hazard in Nevada, particularly at Yucca Mountain

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In several localized areas of Nevada and California there are large numbers of precariously balanced rocks – rocks which could be knocked down by earthquake ground motion with peak accelerations of about 0.2 *g* or less. In some cases geomorphic evidence indicates that these rocks have been in these precarious positions for thousands of years. Brune and Whitney (*Seis. Res. Letts.*, **63**, (1), 21) suggested that at Yucca Mountain, NV, these rocks could be used as paleoindicators of peak ground acceleration. The locations of regions of precarious rocks compare well with probability maps for strong ground motion and intensity maps for known large earthquakes.

No precarious rock zones are found within 15 km of known historic large earthquake rupture zones (e.g., Olinghouse, Fallon-Stillwater, Cedar Mountains, NV; Fort Tejon, Owens Valley, Borrego Mtn., Tehachapi, Parkfield, CA).

Large numbers of precarious rocks have been found in the region around Yucca Mtn., NV, site of the proposed high level nuclear waste repository. They have also been found near Lida, NV, 20 km southeast of the spectacular Holocene scarps in Fish Lake Valley; in the West Walter River Canyon 15 km south of Yerington, NV; 25 km north of the ground rupture in the 1932 $M = 7.4$ Cedar Mtn. earthquake; the center of the Peninsular Ranges in southernmost CA; and in the centre of the Sierra Nevada batholith. In California these observations correlate well with published ground acceleration maps, but in Nevada there are significant discrepancies with important implications for seismic hazard in Nevada and particularly at Yucca Mtn.

The observations suggest that for the last few thousand years peak ground accelerations at Yucca Mtn., NV have been limited to values considerably lower than those which have occurred recently in the neighbourhood of the several historic earthquakes in northern Nevada (Pyramid Lake, 1845 or 1852; Olinghouse, 1869; Fallon-Stillwater, 1954; Dixie Valley-Fairview Peak, 1954; Cedar Mtns., 1932). The ground accelerations necessary to topple particular precarious rocks can be estimated fairly accurately with stability calculations, numerical and physical modelling, force tests in the field, and artificially induced ground accelerations.

Frequency-dependent threshold equation for peak acceleration of a harmonic accelerogram required to topple a rock validates physical experiments. The original analytical equation given by Housner (1963) over-predicts the threshold acceleration because he only considered the ground acceleration until it reached its peak value whereas we consider the acceleration until it changes direction. For a given strong ground motion, we can thus determine the possible rock geometries which will withstand the earthquake. Studies in areas of recent high ground acceleration, e.g. in the neighborhood of recent earthquakes, (like 5.7 Little Skull Mtn. earthquake of June 1992), and NTS explosions, further calibrate the method.