

**Ground motion directionality and precariously balanced rock overturning orientations**

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**INTRODUCTION**

Precariously and semi-precariouly balanced rocks (BRs), as viewed from above, are often elongate objects. As a result, BRs are most sensitive to ground motions oriented perpendicular to the elongate axis. Purvance et al. (2004) demonstrated that BRs located halfway (~ 15 km fault distance) between the San Jacinto and Elsinore faults (see Figure 1 for locations) are most sensitive to fault perpendicular ground motion (Figure 2). This surprising result may be due to preexisting fractures (geological origin), stronger fault parallel than fault perpendicular ground motion at some time in the past (seismological origin), or a combination of these two factors. Should the distribution of BR overturning orientations (e.g., azimuths perpendicular to the BR elongate axes) be a result of the distribution of strong ground motions, one might expect that the long-term seismic hazard between the San Jacinto and Elsinore faults be dominated by fault parallel ground motion. In addition, Purvance et al. (2004) suggested that a seismological origin might constrain the physical characteristics of rupture that have produced the maximum ground motions at these sites (e.g., supersonic or mode III ruptures). In order to distinguish between these origin hypotheses, additional field investigations have been undertaken at BR sites in southern California.

**PRELIMINARY RESULTS**

We have recently surveyed BR sites in southern California with varying levels of seismicity and at varying distances from active faults. These sites include Lovejoy Buttes, Victorville, and Granite Pediment (Figure 1). Both BR overturning orientations and any predominant fracture orientations have been catalogued. The following sections detail the results of these explorations and discuss their implications.

**LOVEJOY BUTTES**

Lovejoy Buttes is located within ~ 15 km of the San Andreas fault. In order to accommodate the relative motion between the North American and Pacific plates, perhaps several hundred to more than a thousand  $M > 7$  earthquakes have ruptured past these BRs over their presumed life span (10 ka, Bell et al. 1998). The overturning orientations of 29 BRs at Lovejoy Buttes are not predominantly oriented in any one direction (Figure 3). This result is in contrast to the findings for sites between the San Jacinto and Elsinore faults at similar fault distances (Figure 2). It may be the case that

the strongest ground motions produced by the San Andreas ruptures in this region have not been preferentially oriented. Aerial photographs do reveal a number of conjugate fractures that are oriented nearly parallel and perpendicular to the fault trace. This may account for the higher than average concentrations of overturning orientations within  $\pm 20$  degrees of north and  $\pm 20$  degrees of east. These results, though suggestive, are inconclusive and additional BR overturning orientations must be catalogued at this site.

## **VICTORVILLE**

Victorville is located ~30 km from the San Andreas fault. The 9 BR overturning orientations sampled in this region are not preferentially oriented (Figure 4). Due to the low level of presumed ground motion at this site, it is expected that the distribution of overturning orientations has not been significantly augmented by ground motion directionality. Aerial photographs show a number of fractures sub-parallel to the San Andreas fault. This limited data suggests that the fracture pattern observed from aerial photographs may not control the BR overturning orientations. Again, the limited distribution of BR overturning orientations obtained to date at this site is not conclusive on this matter.

## **GRANITE PEDIMENT**

Granite Pediment is located in the Mojave National Preserve on the eastern edge of the Southern California Shear Zone. Ground motions at this site are very low and it is expected that there is no strong directionality in ground motion. The overturning orientations of 20 BRs show no systematic trends (Figure 5). Aerial photographs reveal fractures with orientations in nearly all directions at this site.

## **DISCUSSION**

Recent field investigations have delineated the distributions of overturning orientations of BRs at 3 sites in southern California. The goal of this study is to differentiate between the geological and seismological origin hypotheses to the BR overturning orientation distributions. The ramifications of a seismological origin would provide insights into both earthquake source physics and long-term seismic hazards. These preliminary investigations do not conclusively support either of the origin hypotheses. The BRs at Victorville are not aligned with large-scale fractures visible in aerial photographs. The BRs at Lovejoy Buttes may be aligned with fractures visible from aerial photographs. Our field experiences do suggest that BR shapes are influenced by local fracture orientations. The degree to which local fracture orientations are visible from aerial photographs is uncertain. Additional field excursions are being planned to discriminate between these origin hypotheses and investigate the relationship between fractures that control BR shapes and those visible from aerial photographs.

## **REFERENCES**

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Purvance, M.D., J.N. Brune, A. Anooshehpour, and R. Brune (2004). Evidence of large fault parallel/perpendicular PGV ratios, *Proceedings 2004 SCEC Conference*, Palm Springs, Ca., Sept. 20-22.

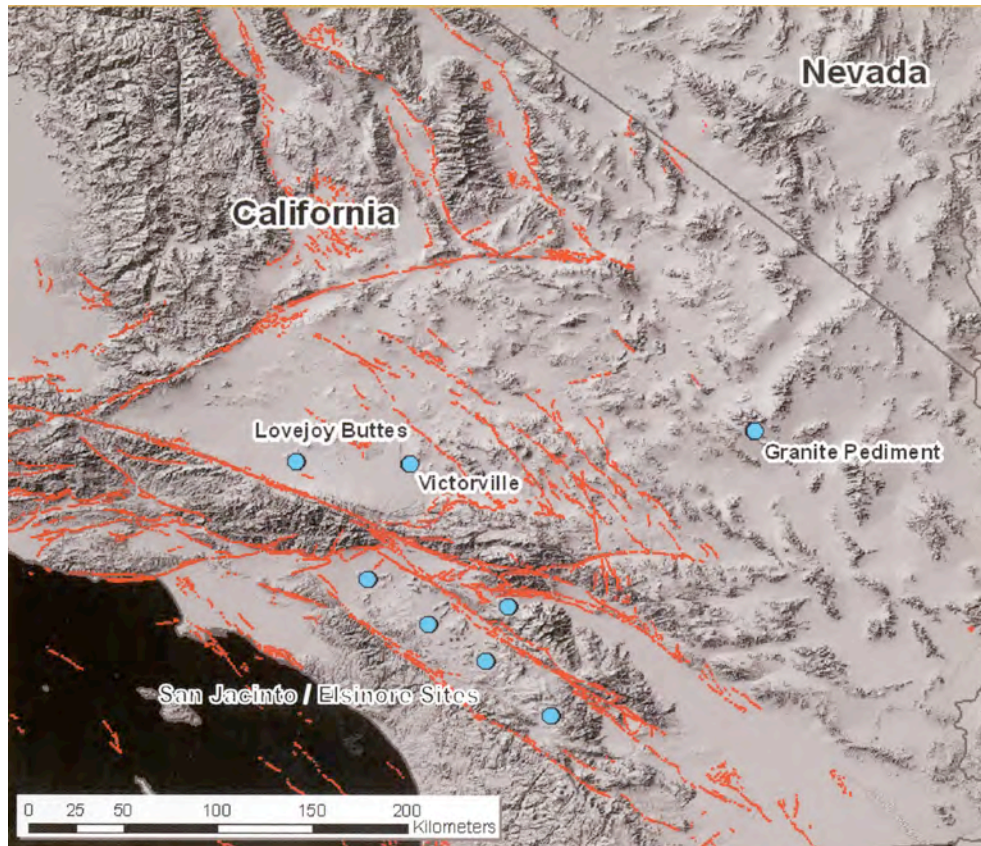


Figure 1 – Map of southern California overlain by the CGS fault database (red lines) and BR sites (blue symbols).

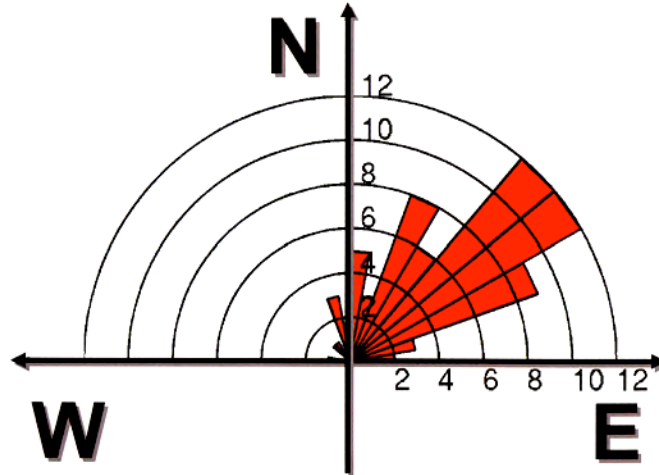


Figure 2- Overturning orientations of 67 BRs located at sites between the San Jacinto and Elsinore faults. This distribution is highly clustered in a fault perpendicular direction (fault orientation  $\sim$  N50W).

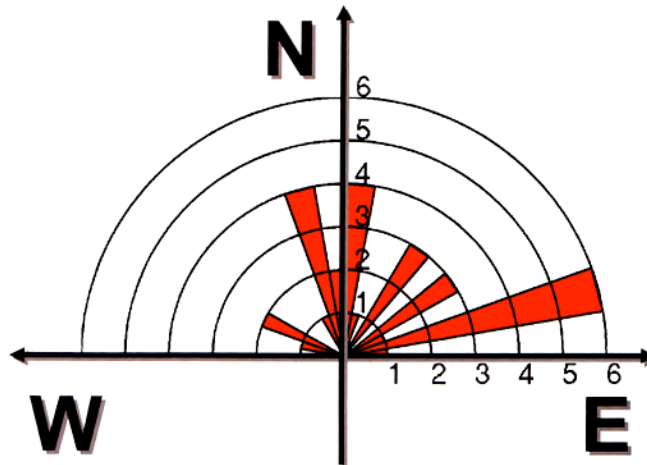


Figure 3 – Overturning orientations of 29 BRs at Lovejoy Buttes. The San Andreas fault is oriented  $\sim$  N80W.

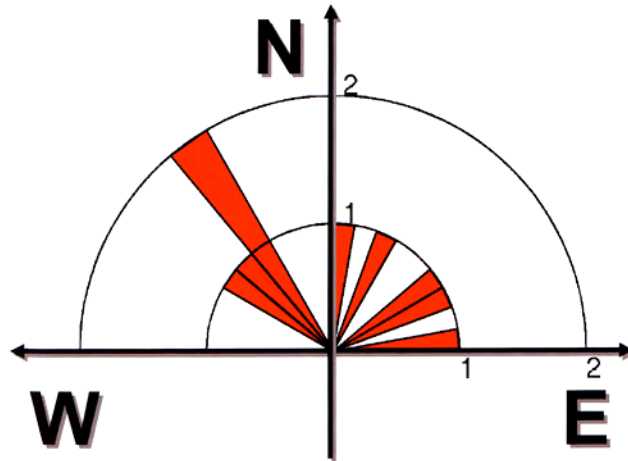


Figure 4 – Overturning orientation of 9 BRs located at Victorville. Fractures observed from aerial photographs strike ~ N80W.

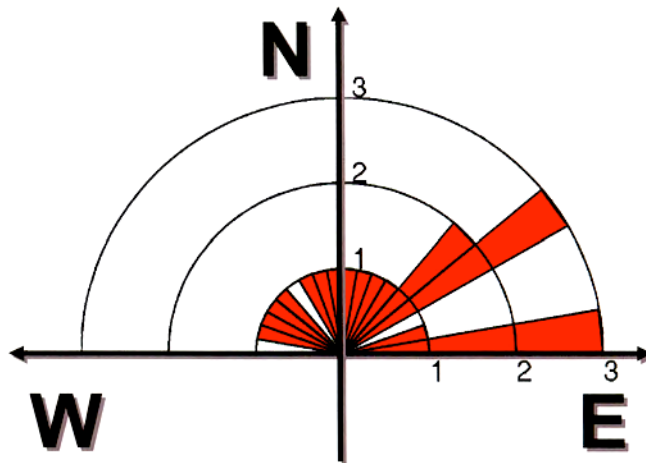


Figure 5 – Overturning orientations of 20 BRs located at Granite Pediment. Fractures are observed in all orientations.