

# Constraints From Precariously Balanced Rocks on Preferred Rupture Directions for Large Earthquakes on the Southern San Andreas Fault



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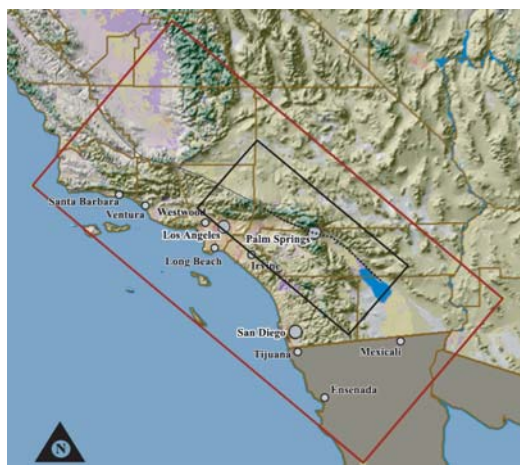
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## Objective

Compare 0-0.5 Hz peak ground motions (PGVs) from seven TeraShake simulations to precariously balanced rock (PBR) locations in search of constraints for a preferred rupture direction of the southern San Andreas fault. Due to the large directional near-field ground motions predicted by the simulations we expect the PBRs to be located primarily in the backward rupture direction or near the epicenter.

## Location Map



Location map for the TeraShake simulations. The red rectangle depicts the simulations area, which is rotated 40 degrees clockwise from North. The black rectangle depicts the area used for comparison of PGVs and locations of PBRs. The dotted line depicts the part of the San Andreas fault that ruptured in the TeraShake simulations.

## Examples of Precariously Balanced Rocks in Southern California



Precariously balanced rocks at Lovejoy Buttes.

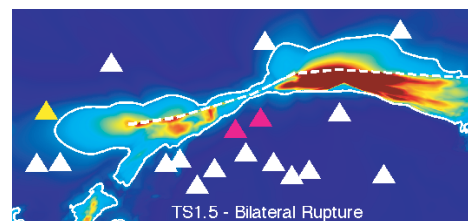
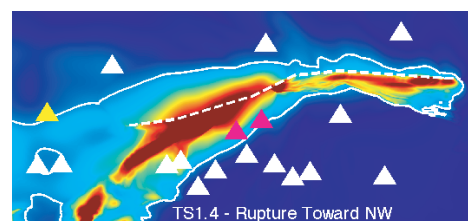
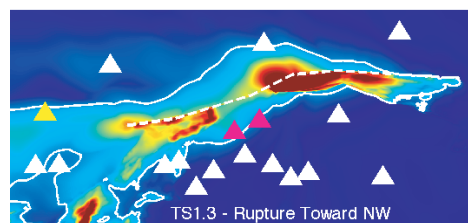
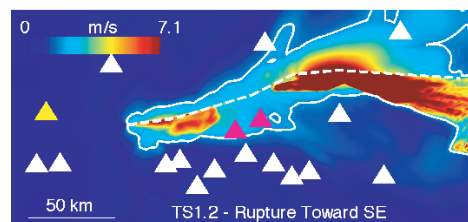


Precariously balanced rocks at Banning.



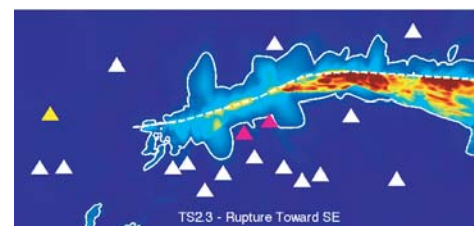
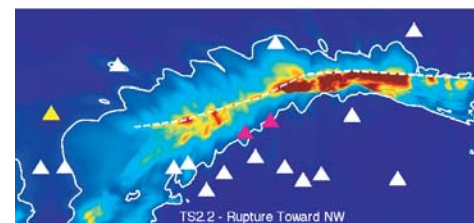
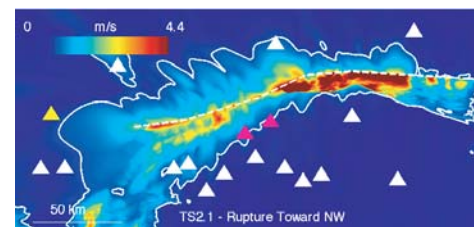
Precariously balanced rocks at Beaumont.

## Correlation of PBRs and TeraShake-1 PGVs



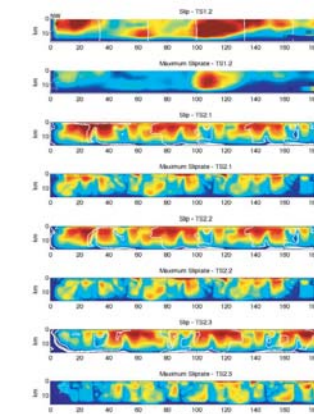
PGV distributions from 4 TeraShake-1 simulations (TS1.2-5). The dashed line is the section of the San Andreas fault that ruptured in the simulations. The solid line is the 50-cm/s PGV contour. The triangles depict precarious rock locations, with sites at Banning and Beaumont in magenta and Lovejoy Buttes in yellow. The TS2.3 simulation (rupture toward the SE) generates, on average, a narrower cone of PGVs expanding in the rupture direction for a Mw7.7 event occurring on this part of the San Andreas fault, with all mapped PBRs experiencing PGVs less than 35 cm/s. In contrast, several PBRs are located inside or near (including those at Banning and Beaumont) the 35-cm/s contour for TS1.2-1.5 (rupture toward the NW). Thus, the TeraShake-2 results tend to favor a NW-SE rupture direction over a SE-NW rupture direction for the southern San Andreas Fault.

## Correlation of PBRs and TeraShake-2 PGVs

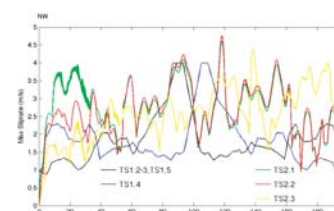
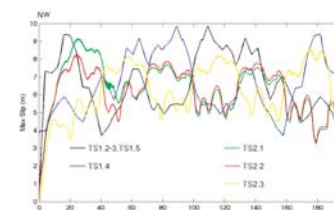


PGV distributions from 3 TeraShake-2 simulations (TS2.1-3). The dashed line is the section of the San Andreas fault that ruptured in the simulations. The solid line is the 35-cm/s PGV contour. The triangles depict precarious rock locations, with sites at Banning and Beaumont in magenta and Lovejoy Buttes in yellow. The TS2.3 simulation (rupture toward the SE) generates, on average, a narrower cone of PGVs expanding in the rupture direction for a Mw7.7 event occurring on this part of the San Andreas fault, with all mapped PBRs experiencing PGVs less than 35 cm/s. In contrast, several PBRs are located inside or near (including those at Banning and Beaumont) the 35-cm/s contour for TS2.1-2 (rupture toward the NW). Thus, the TeraShake-2 results tend to favor a NW-SE rupture direction over a SE-NW rupture direction for the southern San Andreas fault.

## Variation of TeraShake Source Parameters



Final and maximum sliprate distributions for the TeraShake simulations. The top two panels summarize the kinematic TeraShake sources (TS1.2-5), and the bottom six panels show the distributions for the TeraShake-2 simulations with dynamic sources. The contours depict rupture times.



(top) Maximum slip and (bottom) maximum sliprate for the TeraShake simulations from the NW (left) to the SE (right) end of the segments of the San Andreas fault that ruptured in the simulations.

## Results

We have used comparison of near-fault ground motions from four TeraShake-1 and three TeraShake-2 scenario earthquake simulations with PBR locations to constrain the preferred rupture direction of the southern San Andreas fault. The observed PBRs closest to the segments of the San Andreas fault rupturing in the TeraShake simulations are located near Banning and Beaumont, approximately 1/3 of the distance from the NW end to the SE end of the rupturing fault. The presence of the two near-fault PBRs suggests that large earthquakes on the southern San Andreas consistently generate lower strong ground motions along the fault in this area. Analysis of near-fault rupture patterns for the TeraShake simulations suggests that the epicentral area generally experiences smaller PGVs as compared to sites along the fault in the rupture direction. This observation is consistent with the effects of rupture directivity for large, shallow-crustal earthquakes on near-vertical faults. Furthermore, the seven TeraShake simulations cover a realistic range of maximum slip and sliprates, including the part of the fault near the Banning and Beaumont PBRs. Thus, any bias from the rupture models affecting the correlation of PGVs and PBRs is likely limited.

## Conclusions

We conclude that the distribution of PBRs is consistent with persistent nucleation of large earthquakes on the southern San Andreas fault near Palm Springs. The PGVs for the bi-lateral rupture scenario TS1.5, with epicenter close to the Banning and Beaumont PBRs, and the NW-SE rupture scenario TS2.3, produce the best correlation with the location of near-fault PBRs. Two different possibilities for a preferred rupture direction, both with nucleation toward the north-central or northern part of the causative fault in the TeraShake scenarios, are consistent with the results: (1) that successive ruptures on the southern San Andreas have propagated in both directions, or (2), that the ruptures have propagated bi-laterally.

## Future Work

The TeraShake simulations currently only contain frequencies less than 0.5 Hz, while near-fault peak motions often times occur at frequencies larger than 0.5 Hz. Thus, near-fault peak ground motions estimated from the simulations, in particular PGAs required to determine the toppling threshold for the PBRs, are likely underestimated. Future efforts should therefore work toward increasing the maximum frequency of the synthetic seismograms for the southern San Andreas scenarios.