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Non-Double-Couple Earthquakes in the Long Valley Volcanic Region

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Abstract To better understand the connection between earthquake production and geothermal/magmatic systems, we studied the extent of fluid-influenced faulting in the Long Valley volcanic region. We focused on a 100-km-wide circular area centered at the Long Valley caldera that also encompassed the Mono-Inyo craters to the north and the Sierra Nevada mountain block to the south. We performed a comprehensive search for events greater than *M* 3.5 since 1993 with significant coseismic volume changes in their source region. Using three-component broadband digital waveforms at regional distances, we solved for four different source models: double couple (DC), deviatoric DC + isotropic, and full moment tensor. Using the *F*-test as a statistical aid, we determined which of the four models was most appropriate for each event. We then conducted stability tests to determine the robustness of the focal mechanism solutions and isotropic components. Our results show that fluid-influenced earthquakes in the magnitude range studied are quite rare in the Long Valley volcanic region. Of 33 high-quality events, 28 are best characterized by a simple DC source model, 4 by a DC + isotropic source model, and 1 by a full moment tensor model.

Introduction

In volcanic areas, deviations from the usual double-couple (DC) model of shear faulting may be able to illuminate a link between the source process of an earthquake and fluids associated with the geothermal or magmatic system. These non-DC earthquakes have mechanisms vastly different from simple shear along a planar fault and are characterized by a compensated-linear-vector-dipole (CLVD) component, suggesting either fluid involvement or complex shear failure, and/or an isotropic component that describes volume changes in the source region. Many possible physical mechanisms have been proposed to account for these two non-DC components; however, the details of these physical source processes are still not well understood (Julian *et al.*, 1998).

Non-DC events with significant volumetric components have been observed in various volcanic and geothermal areas such as The Geysers geothermal area, California; Aso Volcano, Japan; and Mt. Etna and Campi Flegrei, Italy (Ross *et al.*, 1999; Legrand *et al.*, 2000; Saraò *et al.*, 2001; Guidarelli *et al.*, 2002). These studies have shown that the percentage of events with isotropic components and the strength of the isotropic component can vary with location. These differences appear to be due to different underlying physical mechanisms. Four non-DC events have also been previously identified in the Long Valley caldera, California (Dreger *et al.*, 2000). In this article, we consider the Long Valley caldera along with the Mono-Inyo craters and the seismically active Sierra Nevada block to be part of the Long Valley volcanic region located in eastern California within the Sierra Nevada frontal fault system (Fig. 1).

Since the installation of geophysical monitoring equipment, Long Valley caldera has displayed periods of unrest characterized by increased seismicity, ground deformation, localized increases in volcanic gas emissions, and subsurface magma movement. The most recent episode of unrest within the caldera began in 1997 with progressively increasing deformation rates across the resurgent dome followed by an increase in the rate of earthquake production in the south moat of the caldera (Hill *et al.*, 2003). Well water-level changes due to local large earthquakes associated with this swarm have been attributed to the upward migration of high-temperature fluids beneath the south moat of the caldera (Roeloffs *et al.*, 2003). Surface deformation within the caldera over this time period has been modeled using two deep magmatic inflation sources, one 6–7 km below the resurgent dome and another 10–20 km below the south moat of the caldera combined with right-lateral slip on a steeply dipping plane in the south moat (Langbein, 2003). This modeling is consistent with previous seismic studies using *S*-to-*P* amplitude ratios, teleseismic *P*-wave polarizations, and P_s converted waves that have mapped an anomalous region 7–12 km below the resurgent dome, indicating a high-temperature region containing an area with a significant percentage of melt and the top of the offset central magma body (Steck and Prothero, 1994; Sanders and Nixon, 1995).

Equivocal evidence for fluids has also been identified