Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California

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ABSTRACT

We synthesize and interpret local earthquake data recorded by the Caltech/USGS Southern California Seismographic Network (SCSN/TriNet) in southern California. The goal is to use the existing regional seismic network data to: (1) refine the regional tectonic framework; (2) investigate the nature and configuration of active surficial and concealed faults; (3) determine spatial and temporal characteristics of regional seismicity; (4) determine the 3-D seismic properties of the crust; and (5) delineate potential seismic source zones. Because of the large volume of data and tectonic and geologic complexity of the area, this project is a multi-year effort and has been divided into several tasks.

RESULTS

The 1999 Mw7.1 Hector Mine, California Earthquake Sequence: Complex Conjugate Strike-Slip Faulting

The 1999 Mw7.1 Hector Mine mainshock showed right-lateral strike-slip faulting, with an initial strike of N6°W and vertical dip. The mainshock was preceded within 20 hours by 18 recorded foreshocks of $1.5 \leq M \leq 3.8$ within a few km distance of the mainshock hypocenter. The aftershocks delineate how the Hector Mine earthquake ruptured with strike N6°W to the south for a distance of 15 km, and possibly to the north for a distance of several km. The two largest aftershocks of M5.9 and M5.7 occurred near the north and south ends of the first mainshock rupture segment. The second segment of rupture, starting 15 km to the south away from the mainshock hypocenter, delineated by strike-slip and thrust faulting aftershocks, extends 10 km farther away with a strike of S140°E along the Bullion fault. The aftershocks also outline an unusual third rupture segment, extending from about 5 km south of the hypocenter, to the N30° to 35°W for a distance of 20 km. Approximately 10 to 25 km farther to the north and west of the mainshock epicenter, several clusters form a complex aftershock distribution.

Three-dimensional Vp and Vp/Vs models of the region exhibit only small regional changes, as is typical for the Mojave region (Figure 1). Nonetheless, the mainshock rupture started within a region of rapidly varying Vp and at least three regions of low Vp/Vs are imaged within the aftershock zone. The rate of decay for the Hector Mine earthquake sequence has been slightly above the mean for both p-values and b-values in southern California. The focal mechanisms of the aftershocks and the state of stress are consistent with strike-slip faulting, including a component of normal faulting most prominent to the north. The orientation of the regional maximum horizontal stress, the variation in orientation of the mainshock fault segments by 30°, and scattered distribution of aftershocks suggest that the mainshock and aftershock deformation field exhibit volumetric shear deformation accommodated by complex conjugate sets of strike-slip faults (These results are published in Hauksson et al., 2002).

Comparison between Crustal Density and Velocity Variations in Southern California

We predict gravity from a three-dimensional V_p model of the upper crust and compare it to the observed isostatic residual gravity field. In general this comparison confirms that the isostatic residual gravity field reflects the density variations in the upper to middle crust. The isostatic residual and predicted gravity show similar density variations for the upper crust in areas such as the Peninsular Ranges and the Los Angeles and western Ventura basins. Further, both data sets show similar variations across major faults, such as the San Andreas and Garlock faults in the Mojave Desert. The difference between the two data sets in regions such as the Salton Trough, the Eastern California Shear Zone, and the eastern Ventura and Los Angeles basins (where the depth to Moho is less than 30 km), however, suggests high-density middle to lower crust beneath these regions. Hence the joint interpretation of these data sets improves the depth constraints of crustal density variations.

The results of this study demonstrate a close correlation between the isostatic residual and predicted gravity from a 3-D V_p model down to depths of 10 km (Figure 2). Jointly the models provide constraints on the depth of density anomalies in the crust of southern California. The overall agreement demonstrates that the sources of most isostatic residual anomalies are located in the upper and middle crust. At lower crustal depths, negative density anomalies are imaged in the Sierra Nevada and the western Peninsular ranges and coincides with the region of deepest Moho in southern California. These areas are flanked by positive density anomalies that occur in the Salton Trough, ECSZ, western Transverse Ranges, and Los Angeles basin, suggesting high-density lower crust. In some regions, the higher-resolution isostatic residual gravity map can be used to map major geological features such as sedimentary basins and thus complement and improve available 3-D V_p crustal models (These results are published in Langenheim and Hauksson, 2001).

Emerging from the Stress Shadow of the 1992 Mw7.3 Landers Southern California Earthquake? A Preliminary Assessment

Numerous felt earthquakes have occurred in southern California in 2001. The most prominent sequences have been near Big Bear, in the Coso region in eastern California, in the northern Los Angeles basin, and along the San Jacinto fault (Figure 3). These mainshocks have been followed by productive aftershock sequences and in some cases by enhanced microseismicity in adjacent regions, which were recorded by the Caltech-USGS TriNet (Hauksson et al., 2001). These sequences thus raise the possibility that background seismicity has increased regionally, as has happened in the past.

The late 1980s and early 1990s were a particularly active time in southern California, with numerous earthquake sequences. The Mw5.9 1987 Whittier Narrows earthquake (Hauksson, et al., 1988), the M_L4.9 1988 Pasadena earthquake (Jones et al., 1990), the 1988 and 1990 Upland earthquakes (Hauksson and Jones, 1991), the M_L5.8 1991 Sierra Madre earthquake (Hauksson, 1994), and the Mw6.7 Northridge earthquake (Scientists, USGS and SCEC, 1994) occurred in the Los Angeles basin. To the east, the Mw6.0 1986 North Palm Springs, Ms6.6 1987 Superstition Hills (Magistrale et al.,1989), and the 1992 Mw6.1, Mw7.3, and Mw6.4 Joshua Tree, Landers, and Big Bear earthquakes occurred adjacent to the San Andreas system and within the eastern California shear zone (ECSZ) (Sieh et al., 1993).

Following the 1992 Landers earthquake, seismic activity throughout southern California appeared to drop off dramatically. To quantify the change in seismicity rate, Jones and Hauksson (1997) analyzed the rate of seismicity from 1945 to 1997. They showed that there were periods of high activity, with 90-100 events/yr of M≥3, from 1945-1952 and 1992-1997 and periods of low activity with 60-70 events/yr of M≥3 from 1952-1969 and 1992 to 1997. They attributed the low activity periods to "stress shadows" cast by the Mw7.5 1952 Kern County and the Mw7.3 Landers earthquakes. They speculated that the seismicity rate would emerge from the current stress shadow between 2002 and 2007. They also pointed out that larger, damaging earthquakes are more likely to occur during the periods of high seismicity.

In this paper we discuss significant felt earthquakes that occurred in southern California in 2001. These earthquakes attracted attention at the time of their occurrence because of their tectonic setting, high aftershock productivity, or their relation to past earthquake activity. In addition to the M≥4 earthquakes discussed in this paper, numerous M>2.5 earthquakes have occurred in the greater Los Angeles area. Many of these, such as the M_L2.8 San Marino in late September, M_L3.0 Silver Lake in early October, and several small earthquakes located along the east side of the Los Angeles basin were felt. The occurrence of these events has increased the awareness of earthquakes and potential earthquake hazards in the Los Angeles area.

On an annual scale, 2001 is not an abnormally active year so far (Figure 2). The long term annual average for southern California (32.5°-36.0°N, 115.5°-121.0°W) is 79 sequences with at least one event of M≥3.0. The extremely low rate of earthquakes (<60/yr) seen after Landers lasted only through 1996. The rate began to increase in 1997, only to drop again after the Hector Mine earthquake in 1999. As of 3 November, 59 sequences were recorded in 2001, for an annual rate of 72 events. However, of these sequences sixteen were recorded in September and October alone, for an annual rate of 96 events. It is impossible to say yet whether this is a statistically significant change. We need data for a longer time period. It is noticeable that the two earthquakes of M5.1 in 2001 are the first events above M5 to have occurred since 1994 outside Owens Valley, and the Landers and Northridge aftershock zones (These results are published in Hauksson, et al., 2002).

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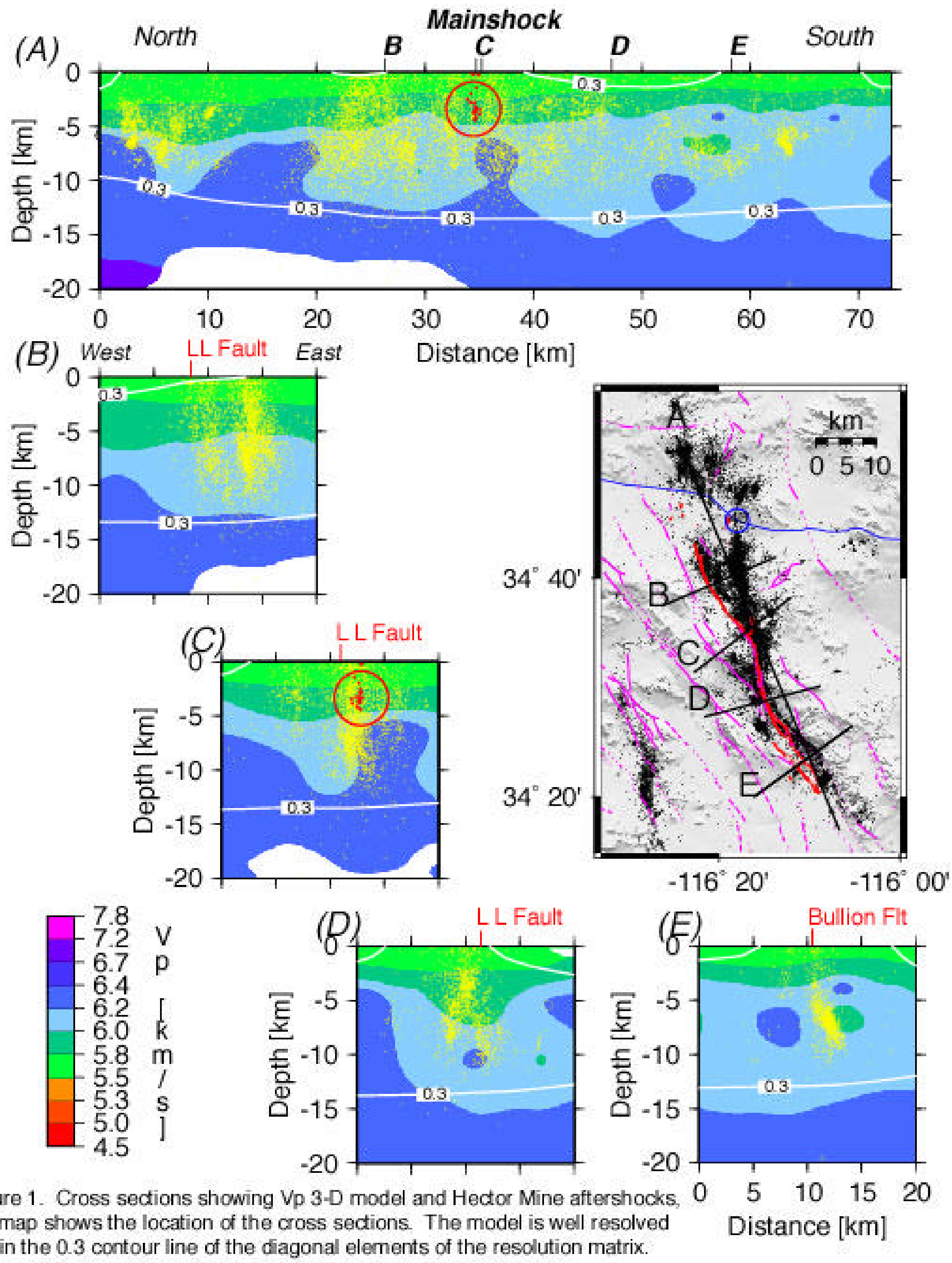

Figure 1. Cross sections showing Vp 3-D model and Hector Mine aftershocks, the map shows the location of the cross sections. The model is well resolved within the 0.3 contour line of the diagonal elements of the resolution matrix. Only model areas with adequate ray coverage are shown in color.

(a) Vp cross section along the strike of the fault, foreshocks and mainshock shown in red;

(b) Vp cross section to the north of the mainshock epicenter;

(c) cross section across the foreshock and mainshock hypocenters shown in red ;

(d) cross section across the intersection of the Lavic Lake and Bullion faults;

(e) cross section across the Bullion fault.

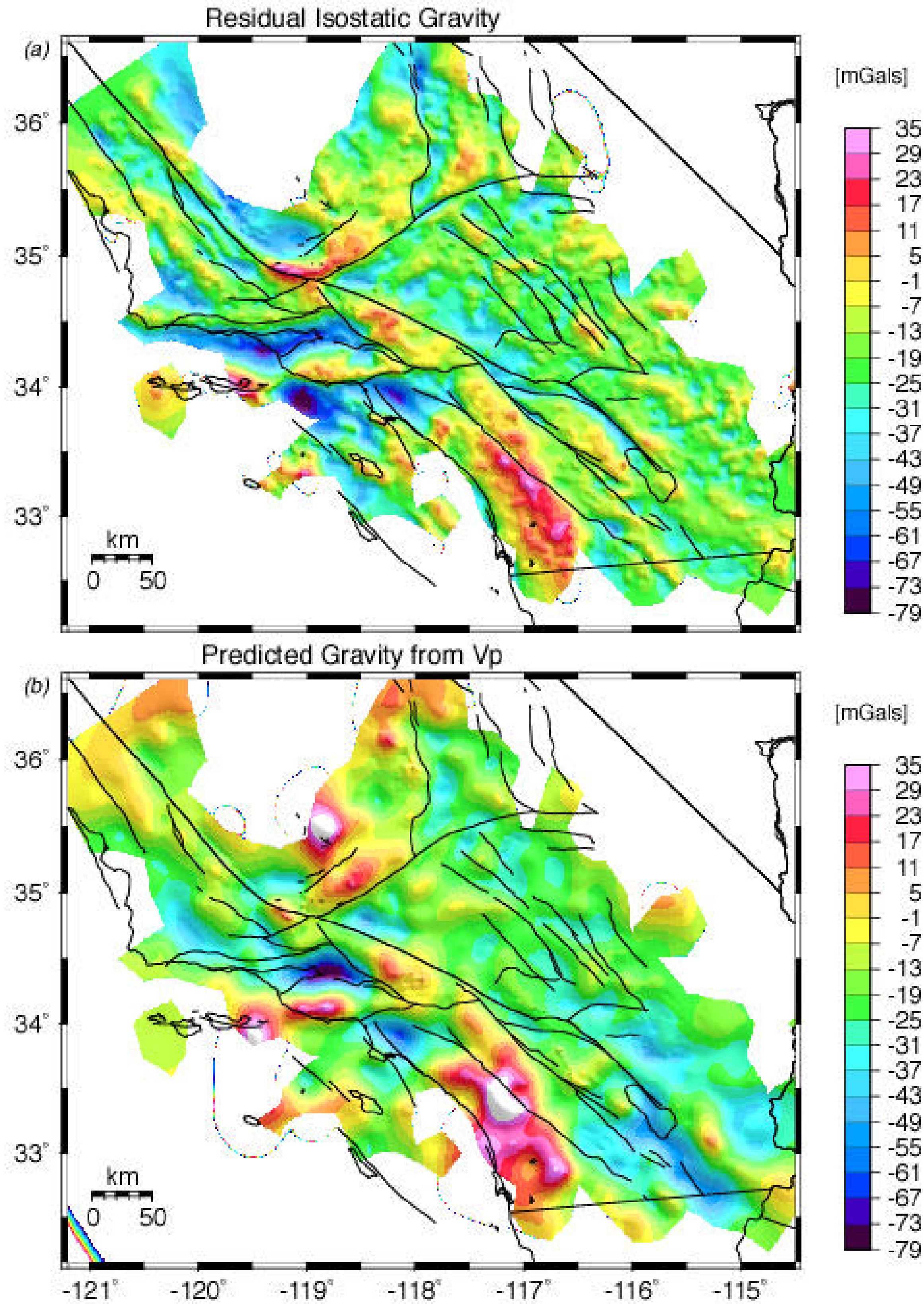

Figure 2. (a) Observed isostatic gravity and (b) predicted gravity from the upper part (0 to 10 km) of the Vp model.

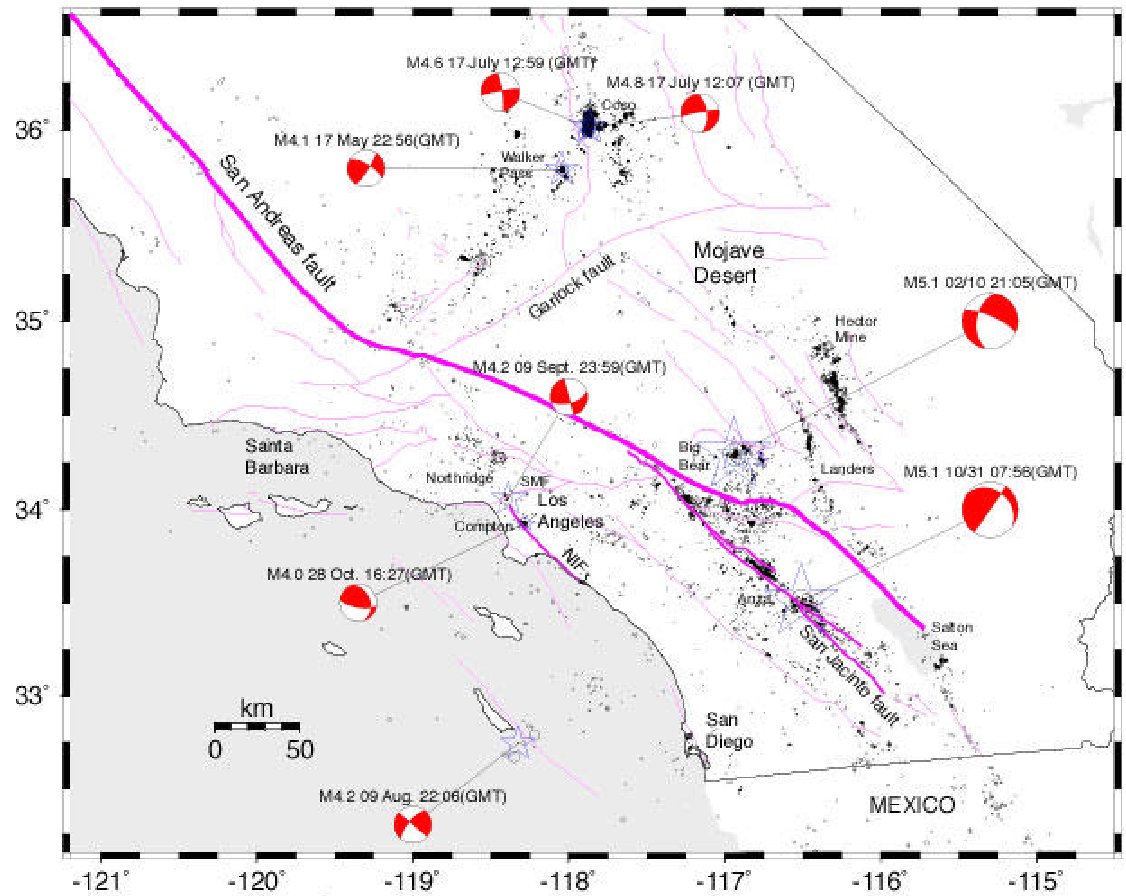

Figure 3. Map of southern California showing seismicity from 1 January to 3 November, 2001. The symbols (circles) scale with magnitude. Earthquakes of magnitude greater or equal to 4.0 are shown as stars. Lower hemisphere first motion focal mechanisms are shown and labeled with the magnitude, date, and time. Late Quaternary faults are from Jennings (1994). NIF-Newport-Inglewood fault, and SMF-Santa Monica fault.

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We synthesize data from earthquakes that occur in southern California and the Los Angeles area in particular, to improve understanding of the earthquake hazards. We have analyzed earthquake data from the 1999 Mw7.1 Hector Mine earthquake sequence to facilitate our understanding of the spatial and temporal evolution of this sequence.

In a different study we predict gravity from our three-dimensional V_p model of the upper crust and compare it to the observed isostatic residual gravity field. In general this comparison confirms that the isostatic residual gravity field reflects the density variations in the upper to middle crust.

Numerous felt earthquakes have occurred in southern California in 2001. The most prominent sequences have been near Big Bear, in the Coso region in eastern California, in the northern Los Angeles basin, and along the San Jacinto fault. These mainshocks have been followed by productive aftershock sequences and in some cases by enhanced microseismicity in adjacent regions, which were recorded by the Caltech-USGS TriNet. These sequences thus raise the possibility that background seismicity has increased regionally, as has happened in the past.

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NON-TECHNICAL SUMMARY