External Grant Award Number 05HQGR0067

IMPROVED THREE-DIMENSIONAL VELOCITY MODELS AND EARTHQUAKE LOCATIONS FOR CALIFORNIA

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Abstract

Our work focused on the development of a three-dimensional (3D) seismic wavespeed model for the greater San Francisco (SF) Bay Area and for Northern California. The model has been used to help validate the USGS 3D velocity model. That model in turn is being used to compute hypothetical strong ground motions in a simulation of the great 1906 San Francisco earthquake in preparation for the centennial of the 1906 event. Our models will also help to characterize both well-known and hidden seismogenic structures, allowing the determination of improved absolute locations and focal mechanisms for Northern California earthquakes. The model itself provides new insights into the structure of the California crust and upper mantle.

The datasets combine P-wave arrival times from well-distributed sets of thousands of earthquakes with a complete archive of available active-source (i.e., explosion) P-wave travel times from the region. The wavespeed modeling was carried out with a combination of conventional and "double-difference" seismic tomography. To date, only catalog differential data have been incorporated.

A number of features are identified in the 3D model, some new and others confirming previous results. Among these are: the subducting Gorda Plate in the northwest; high-Vp bodies beneath the northern Great Valley and Sacramento River Delta areas, both interpreted to be ophiolite bodies; and tentative identification of a detachment fault beneath the SF Bay Area.

Project Results

We have been working in collaboration with Tom Brocher of the USGS to assemble an active-source dataset that is as complete as possible for the Northern California region, including some data that have never been utilized previously for seismic tomography. We have also extracted catalog phase arrivals for some of the larger shots recorded at the NCSN stations. That effort included cross-checking of source and receiver coordinates, examination of individual and merged travel time curves, and receiver-name rationalization across all experiments (plus the NCSN). Maps showing the active-source lines for the Bay Area and Northern California are presented in Figures 1 and 2, respectively.

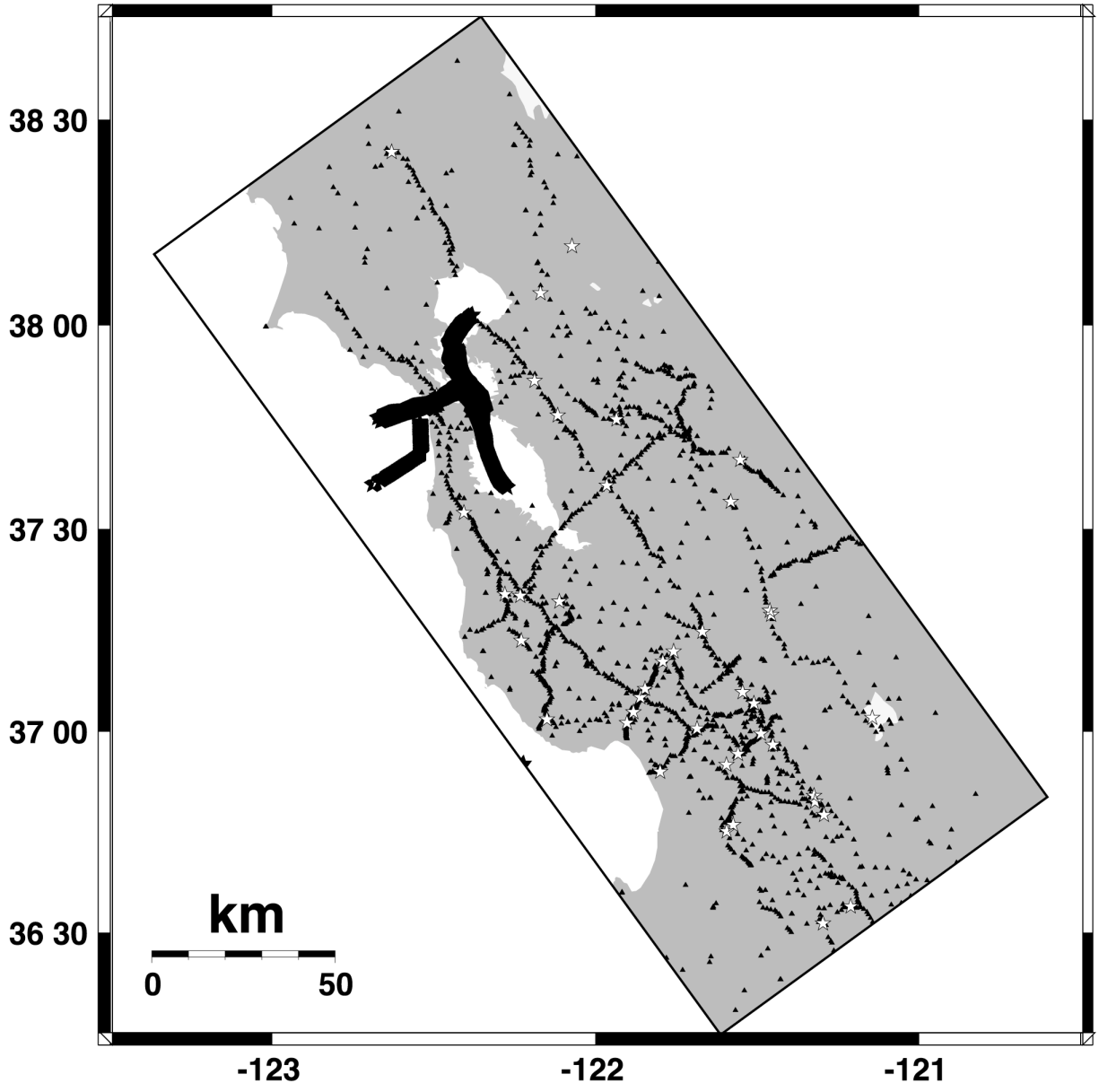

Figure 1. Map of active-source (explosion and air-gun) surveys compiled by Tom Brocher for the Bay Area model. Integration and reformatting of these data has been completed.

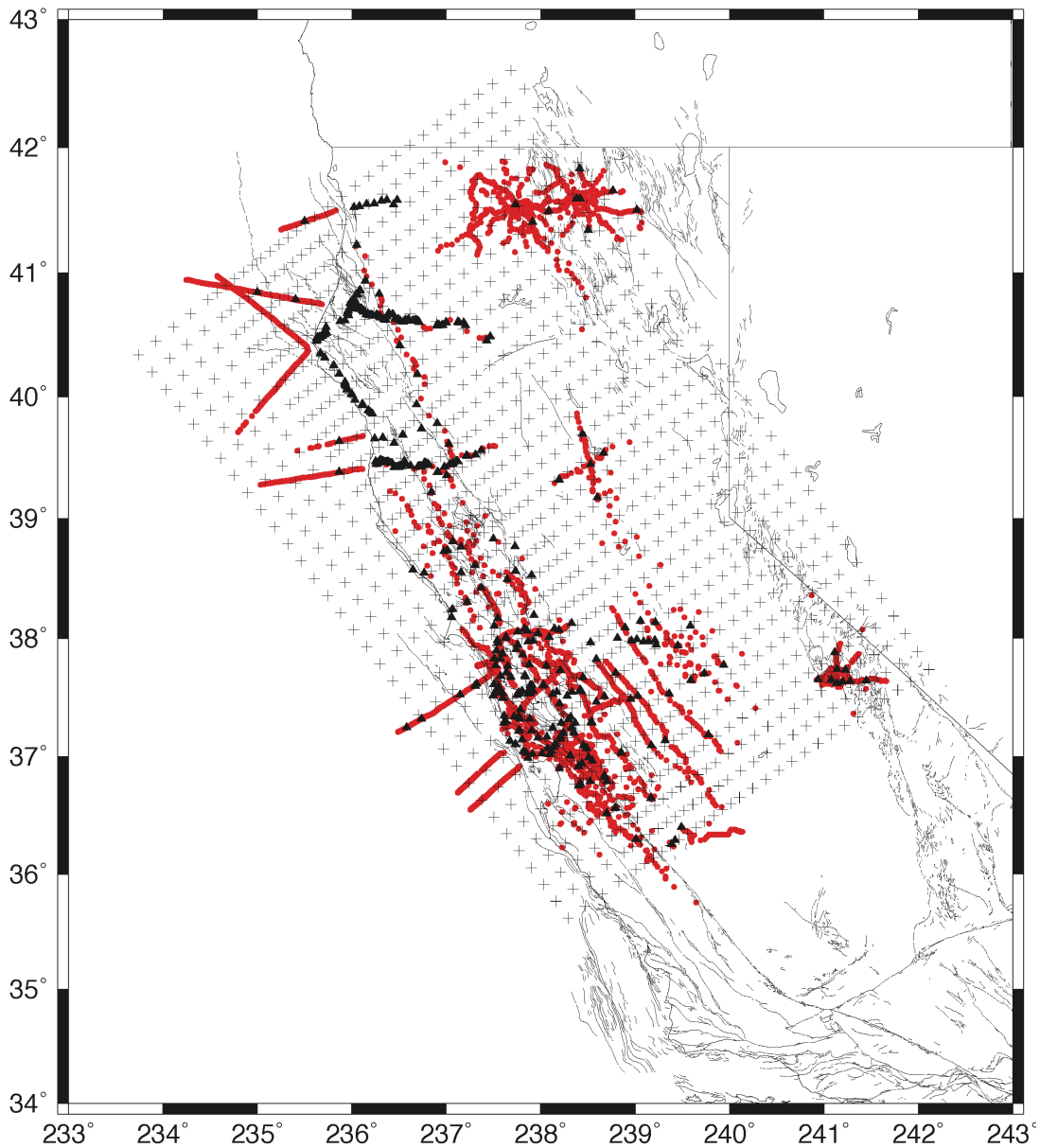

Figure 2. Map of active-source (explosion and air-gun) surveys compiled by Tom Brocher for the Northern California model (sources in red, stations in black). The crosses indicate the nodes of the grid used for tomographic inversion.

In parallel, we have extracted arrival-time data for thousands of earthquakes that are optimally distributed throughout the two study regions (Figures 3 and 4). We have compiled and merged all of these data and carried out a preliminary "conventional" tomography analysis using simul2000 [Thurber and Eberhart-Phillips, 1999], followed by double-difference (DD) tomography [Zhang and Thurber, 2003]. The final model grid for the Bay Area inversion uses 5 to 10 km spacing in the horizontal directions and gradually increasing grid intervals, from 1 to 5 km, in the vertical direction. We use a one-dimensional model from Hole et al. [2000] as our starting model. We also experimented with using a geologically-based starting model.

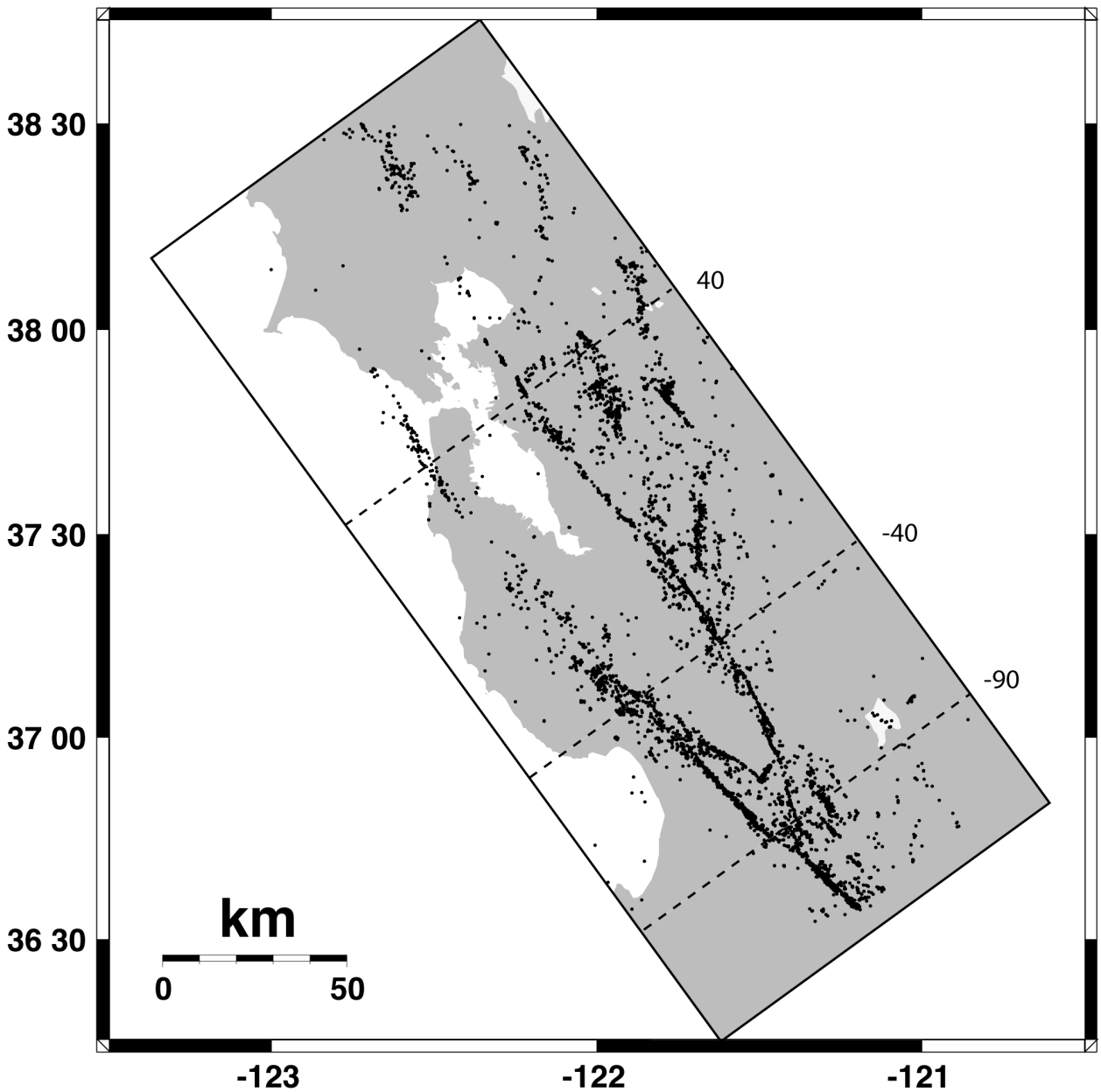

Figure 3. Map of the earthquakes (circles) for the Bay Area inversion and locations of example cross-sections through the 3D model (dashed lines) shown in Figure 5.

The Bay Area model covers the region west of the Great Valley from Hollister to Clear Lake. The geometries of the major faults are clearly defined by the relocated seismicity, and most of the seismogenic faults are marked by significant wavespeed features (Figure 5). The San Andreas Fault is southwest-dipping (~70°) and the Calaveras Fault is northeast dipping (~75°) in the southern part of the model. Bedrock blocks appear to control the distribution of seismicity in many areas, including an apparent blind thrust fault beneath the edge of the Great Valley in the northern section (Y = +40 km). The deep high-Vp body associated with these earthquakes is consistent with Coast Range ophiolite, as proposed by Godfrey et al. (1997).

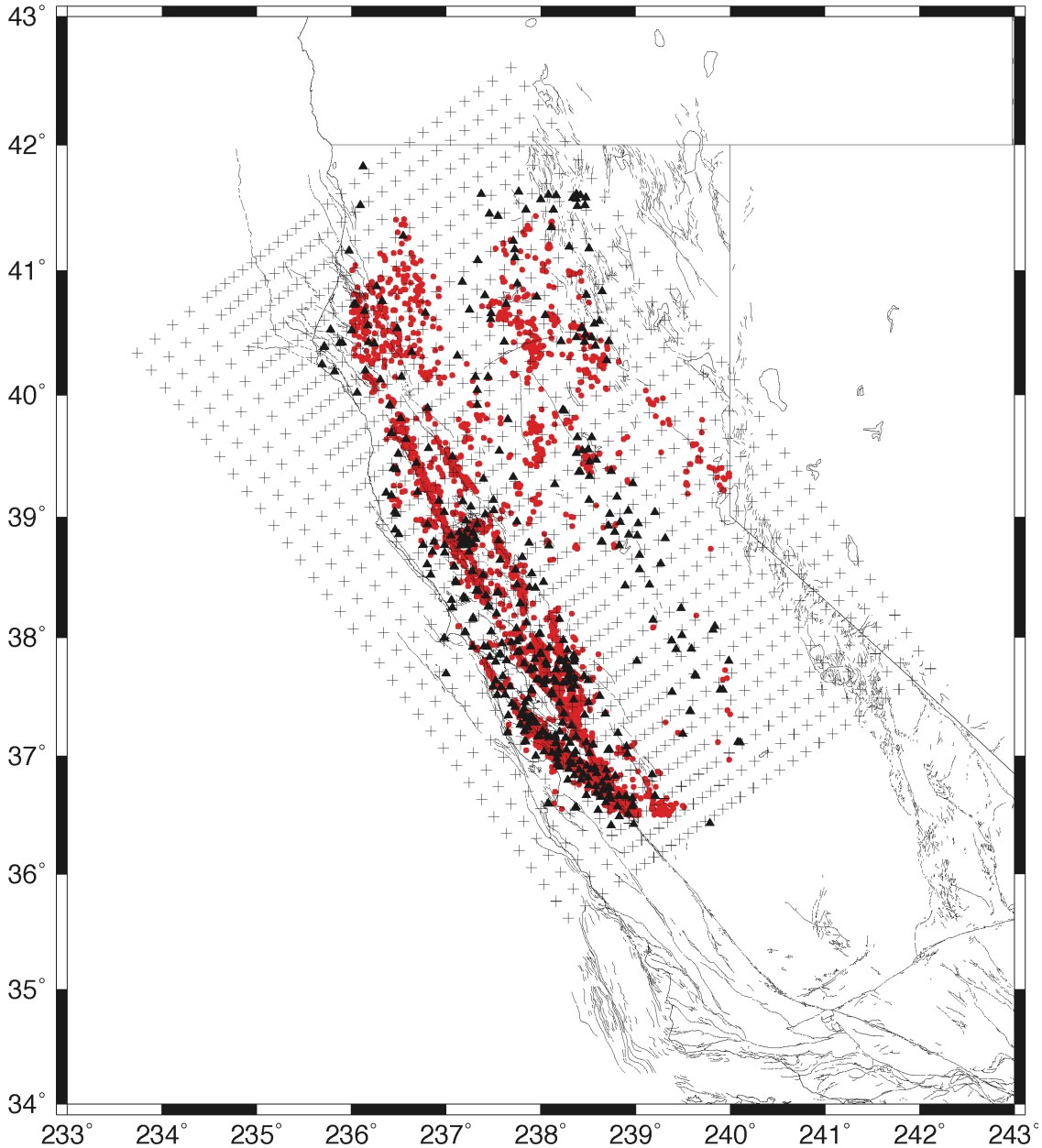

Figure 4. Map of the earthquakes (red circles) and network stations (black triangles) used for our Northern California model, along with the inversion grid nodes (crosses).

We expanded the active-source dataset (again thanks to the efforts of Tom Brocher; Figure 2) and constructed a new earthquake dataset (emphasizing events with slightly larger magnitudes; Figure 4) for our Northern California model. The horizontal gridding ranged from 10 to 20 km, with the vertical gridding comparable to the Bay Area model (1 km near the surface, increasing to 5 km at depth). The grid extends from the vicinity of Parkfield in the south to the Oregon border, and from the coast to Nevada except for the far northeastern corner of the state (Figure 4).

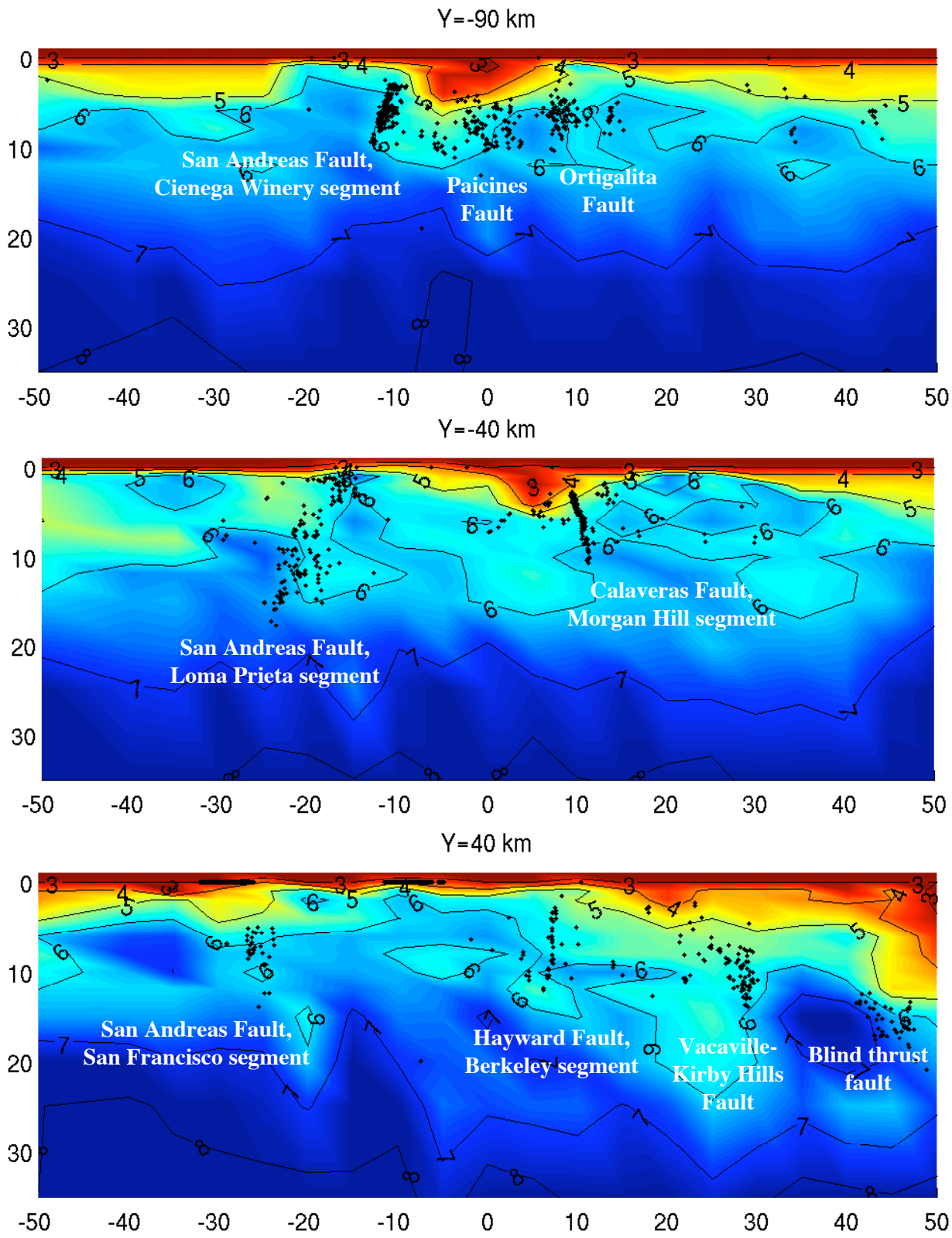

Figure 5. Cross-sections through the Bay Area Vp model along the profiles indicated in Figure 3. Earthquake hypocenters within 5 km of each section are indicated by circles.

Interpretation of the model is at a preliminary stage, but some intriguing features are already evident. To the north, the subducting Gorda Plate is an obvious seismically active, high-Vp anomaly (Figure 6). A presumed ophiolite body, also with high Vp, is present beneath the northern Great Valley (Figure 7). Intriguing evidence for a seismically active detachment fault is observed in the Bay Area (Figure 8).

Both the Bay Area and Northern California 3D models have been put to use by Tom Brocher for validating his geologically based 3D models. Brocher's models are currently being used by several research groups for strong-motion simulation and validation work. We are also beginning to collaborate with Southern California scientists to prepare for the development of a statewide 3D model.

Acknowledgements

We are indebted to Tom Brocher for his tireless efforts to assemble the most complete active-source dataset possible, and to Doug Neuhauser for maintaining a superb earthquake data archive at the Northern California Earthquake Data Center, from which data critical to this project was obtained.

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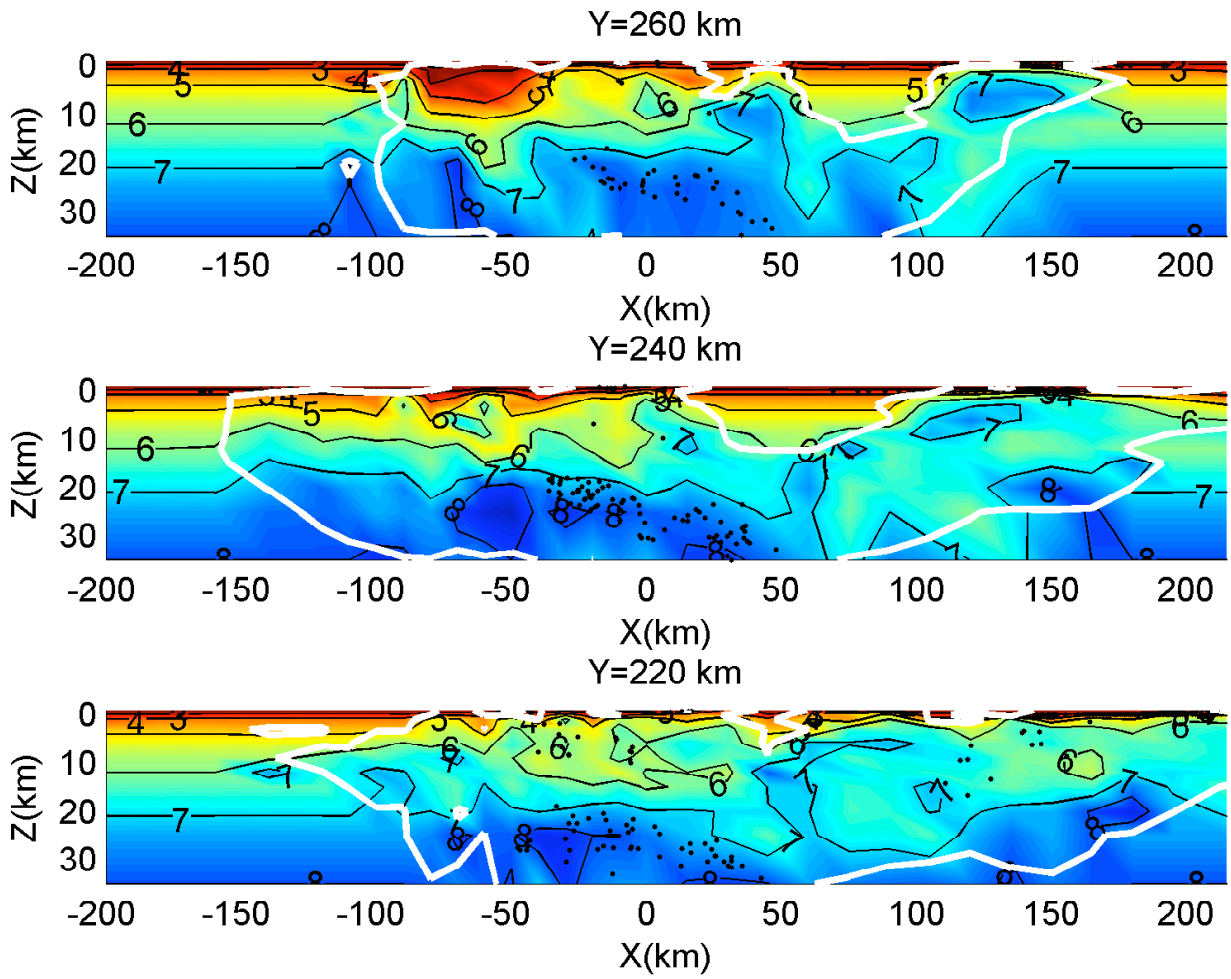


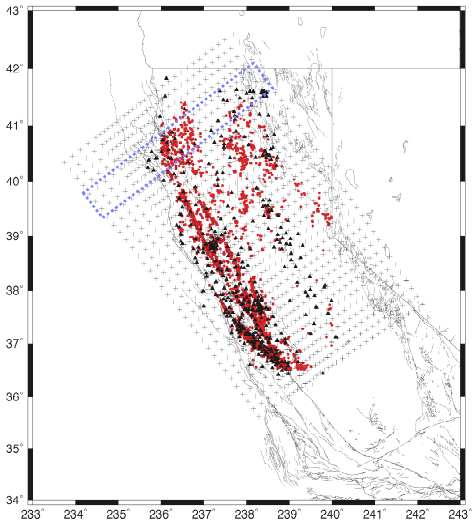
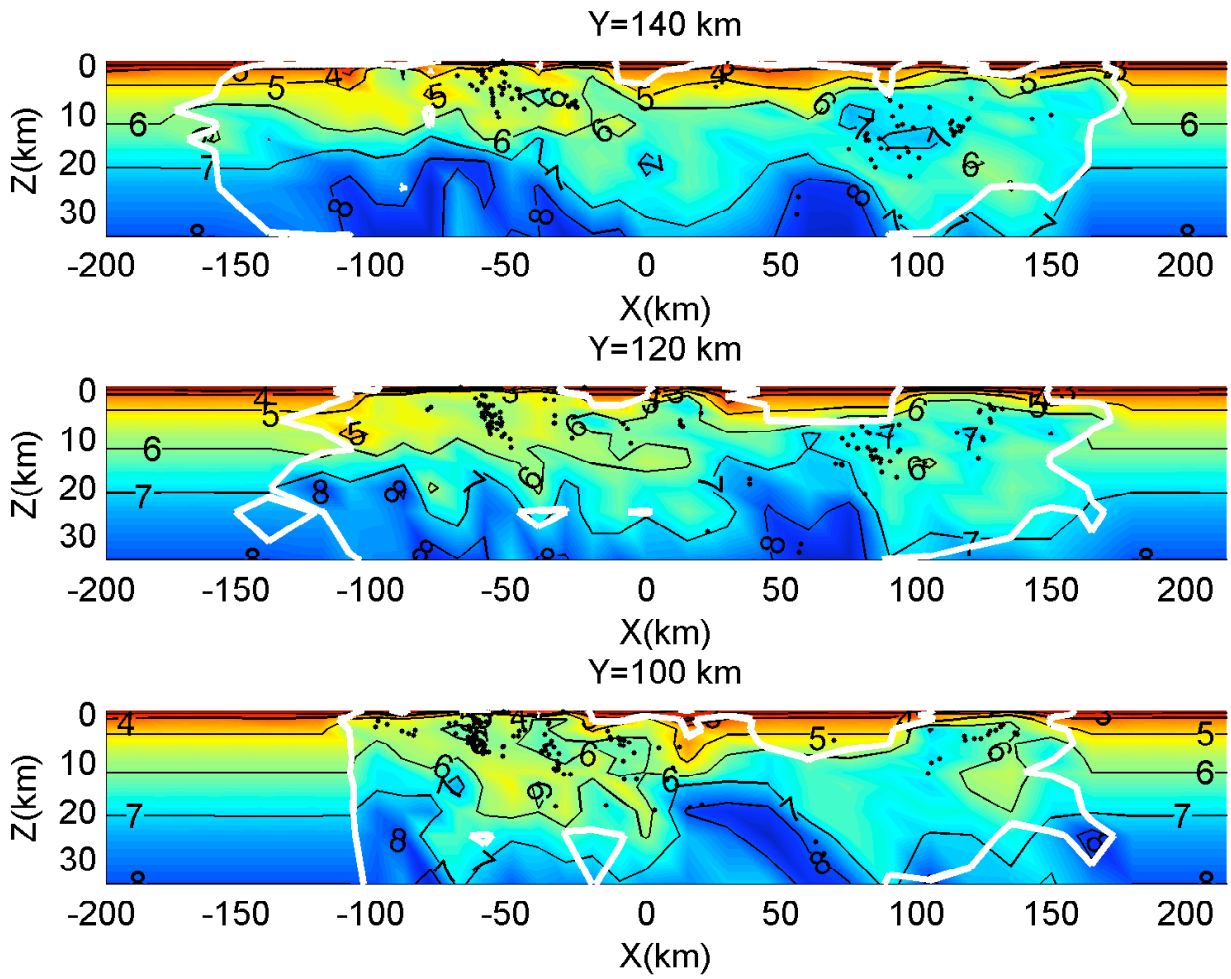


Figure 6. Northeast-southwest cross-sections stepping from northwest to southeast (above) through the northern portion of our 3D Northern California model (left). The seismicity and high Vp of the subducting Gorda Plate is clearly evident centered near X = 0 km. Low near-surface velocities between X = -100 and -50 in the Y = 260 km section represent the Eel River Basin. The white contours enclose the regions of adequate resolution.



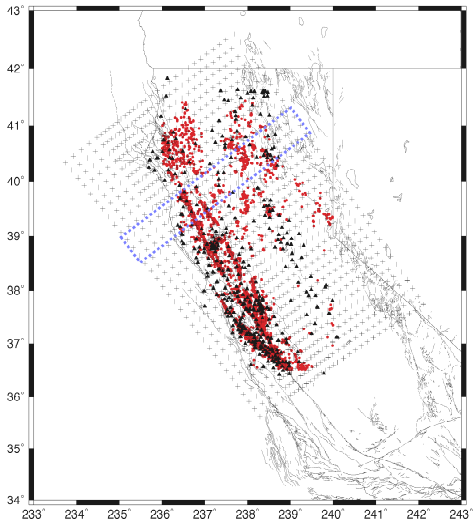
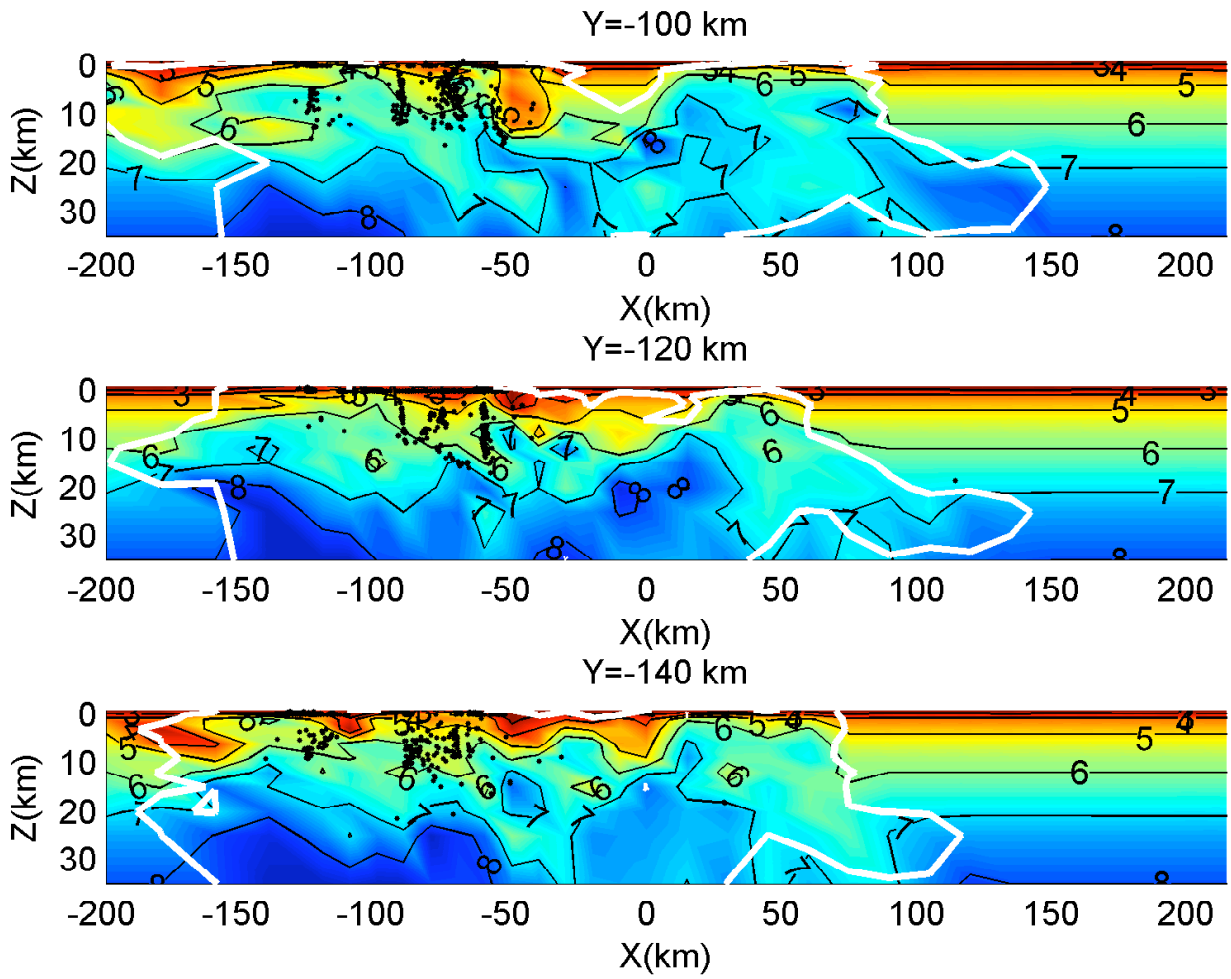


Figure 7. Northeast-southwest cross-sections stepping from northwest to southeast (above) near Point Arena in our 3D Northern California model (left). The deep high-Vp anomaly near X = 50 km is interpreted to be Coast Range ophiolite, consistent with the findings of Godfrey et al. (1997). The white contours enclose the regions of adequate resolution.



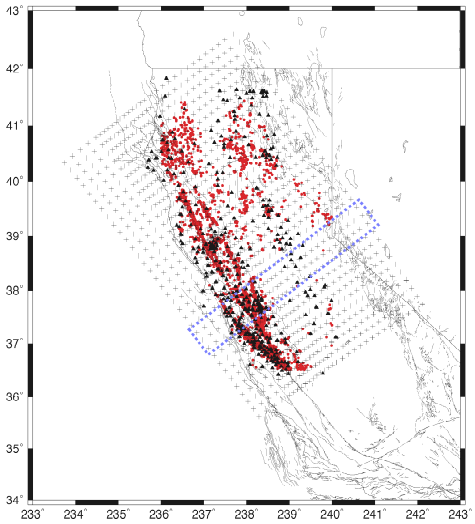


Figure 8. Northeast-southwest cross-sections stepping from northwest to southeast (above) through the SF Bay portion of our 3D Northern California model (left). Note the possible basement-controlled detachment fault around 15 km depth near X = -75 km in the Y = -120 km section. The white contours enclose the regions of adequate resolution.