Annual Report, 2000, to the Southern California Earthquake Center:
Velocity and density structure of the Los Angeles basin from borehole logs and industry seismic reflection data (Continuation Project)

John H. Shaw (PI), Christiane Stidham, & M. Peter Suess*
Dept. of Earth & Planetary Sciences
Harvard University
20 Oxford St..
Cambridge, MA 02138 (shaw@eps.harvard.edu)
*now at University of Tubingen, Germany

Our ongoing work aims to expand our contribution to SCEC's 3D velocity modeling efforts through analysis of borehole sonic and density logs in the Los Angeles basin. In previous efforts, we have used borehole sonic logs to evaluate the SCEC Phase 1 velocity model in the Los Angeles basin, and to develop new velocity functions for the San Fernando basin (see '99 progress report). In recent years, we have added more than 800 density logs to our Los Angeles basin database. These logs use gamma ray emissions to determine formation density at samples of about one meter. We plan to use these logs to help constrain density values in the SCEC Phase III model. Density structure, as well as velocities, must be defined in the 3D model for its use in performing simulations of earthquake wave propagation to predict the distribution of hazardous ground shaking during large events. Currently, density values used in simulations are primarily defined by laboratory measured relationships between density and p wave velocity, rather than by observed field relationships. Modeled densities can also be compared with observed gravity anomalies to test and calibrate the modeled basin structure.

Figure 1 shows the distribution of density logs that have been catalogued and referenced in our database; the grey circles are wells for which digitization is underway. In total, we have more than 800 density logs, many of which have not yet been entered into our database or digitized. The names and locations of wells where the density logs have been digitized and interpreted are shown as black circles or stars. The wells represented by stars are those for which both density logs and sonic logs have already been digitized; seven of those are shown in Figure 2. At each well in Figure 2, the blue trace represents the velocity log (as interval transit time, in milliseconds/foot) and the red trace corresponds to the density log. The logs are digitized with a spacing of 10 meters. The deepest well shown, CCT2, extends to approximately 3 km.

For the wells with both sonic and density logs digitized, we have derived relationships between depth and density, and velocity and density. A plot of velocity (in m/s) vs. rhob (in g/cm3) is shown in Figure 3, for all the measurements (1600 points) in these wells. The color of each point represents spontaneous potential (sp), measured in millivolts, which is generally interpreted as a measure of lithology and porosity. The bulk density (rhob) values vary from 1.6 g/cm3 to 2.8 g/cm3, where the mean is 2.318 g/cm3, the standard deviation is 0.092 and the variance is 0.0085. The correlation coefficient of the two parameters is 0.395, a reasonably good value, and the equation of the best fit line (shown in red) gives {rhob = (0.0827 * velocity) + 2.07}. There is also some correlation between sp and velocity, with lower sp corresponding to lower velocity, but not a good correlation between sp and density. The relations shown are consistent with previous studies of velocity vs. density in sedimentary rocks at low pressures (Birch, 1960; Nafe and Drake, 1960; Stewart and Peselnick, 1977).

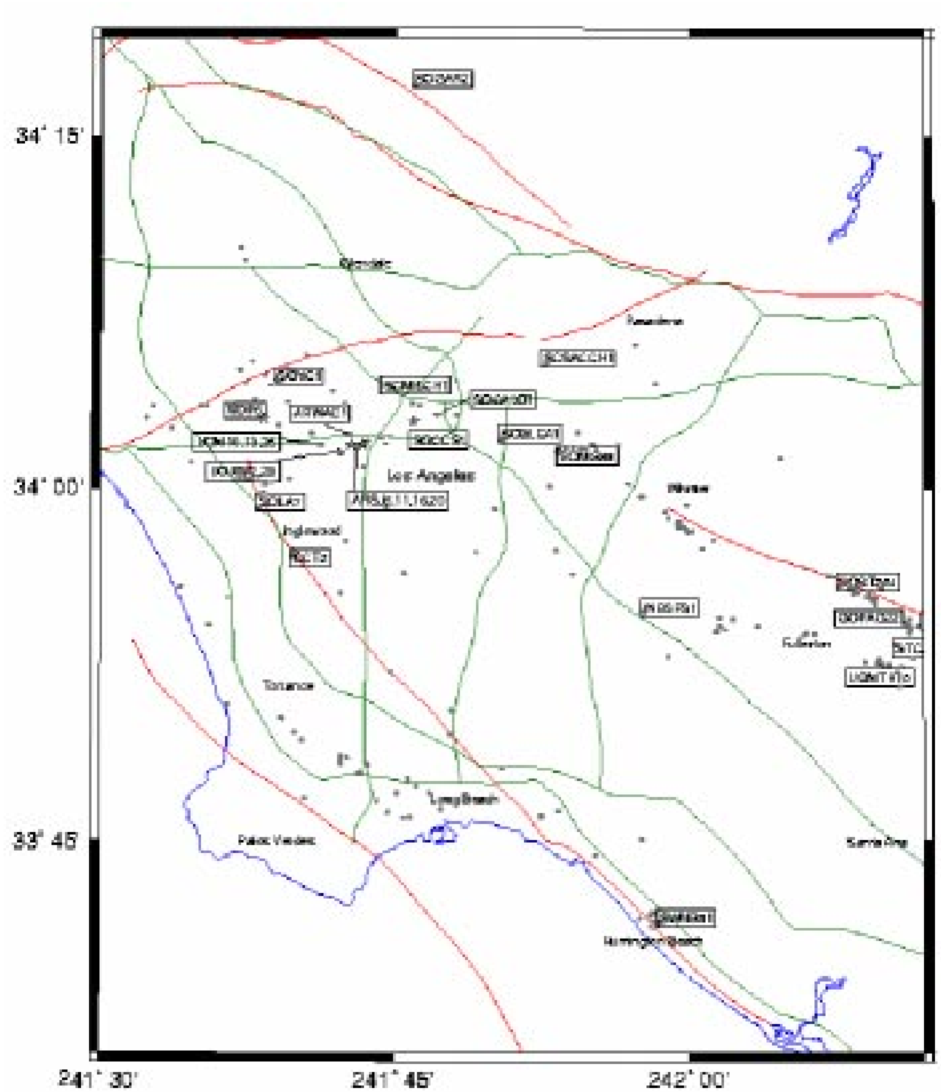

Figure 1. Locations of undigitized wells (grey circles), digitized density wells (black circles) and digitized density and sonic wells (black stars.) Some symbols represent more than one well (eg. UOM10,13,26 are three co-located wells.) A higher resolution map will be posted on our webpage (http://structure.harvard.edu).

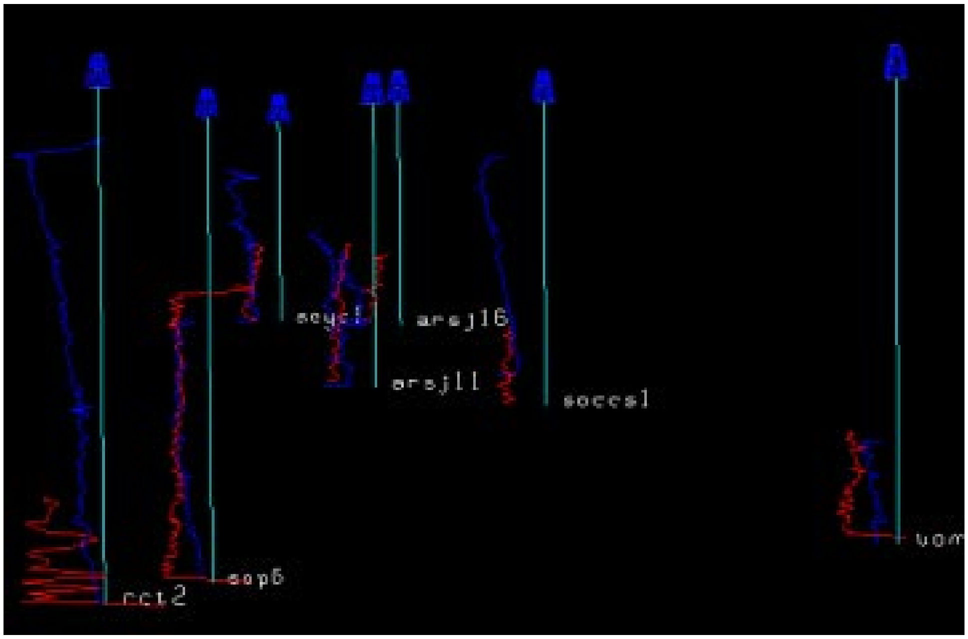

Figure 2. Density and sonic traces at seven of the wells. View is across the LA Basin looking to the northwest, and deepest well extends to 3 km.

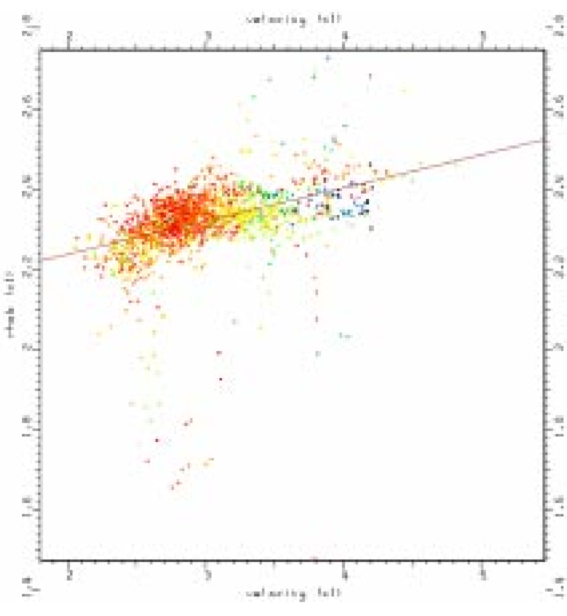

Figure 3. Velocity vs. rhob for a subset of the digitized wells. The color of the points gives sp, where red is 25 millivolts and black is –60 millivolts.

The relationship of density to depth can also be a useful one. Figure 4 shows a plot of the densities against depth, and shows a fairly good correlation. The 600 points shown give a correlation coefficient of –0.3877, with a mean of 2.324, a standard deviation of 0.1098 and a variance of 0.01205. Except for the four points with unusually low densities at approximately 1 km depth, the variation of rhob with depth is fairly constant and fairly minor. Below 2.5 km depth, there is considerably more scatter in rhob, but these points come primarily from the well CCT2, which may be shown to be anomalous after analysis of additional deep wells. Again there is some correlation of sp to depth, with the highest values for sp at greater depths, but not a good correlation of sp to density. It appears at this stage, not surprisingly, that velocity provides a better indicator of density than does depth. Work with the correlation of density to stratigraphy and rock type is underway and hopefully will provide a better correlation.

The density-Vp relation may guide a direct conversion between SCEC modeled velocity values and density and can be readily merged with the SCEC rule-based velocity model to develop a co-registered density volume. With analysis of additional wells and stratigraphy, it may be possible to use the density-depth relation to provide independent rules that can be employed to define density structure in the same manner that velocity is defined in the current SCEC model. Moreover, we expect to be able to use information from density logs in subsequent efforts as a proxy for seismic velocities. This will increase our borehole velocity constraints by more than 300%, as we have more than 600 density logs in wells where corresponding sonic logs are not available.

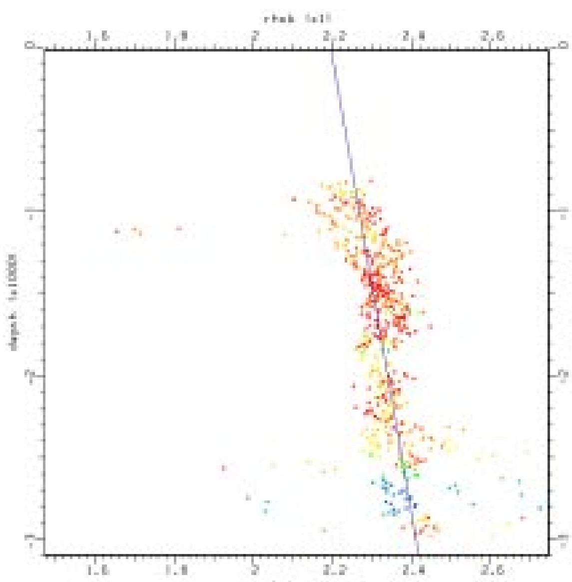

Figure 4. Density (g/cm3) with depth in meters. Color of points indicates sp, with red corresponding to 25 millivolts and black to –60 millivolts.

Distribution of Results

Density-vp and -depth relations will be provided to the SCEC Velocity model working group (R. Clayton). Relations and supporting density log data from a selection of the wells with both density and sonic measurements will be added to our Data Resources webpage (http://structure.harvard.edu). Sonic logs from these wells are currently available on the webpage.

References

Birch, Francis (1960). The Velocity of Compressional Waves in Rocks to 10 Kilobars, Part I, Journal of Geophysical Research, 65, 1083.
Nafe, J.E. and C.L. Drake (1960). Physical Properties of Marine Sediments, Lamont Geological Observatory Contribution No. 598, 794.
Stewart, R. and L. Peselnick (1977). Velocity of Compressional Waves in Dry Franciscan Rocks to 8 kbar and 300°C, Journal of Geophysical Research, 82, 14, 2027.