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Extension of Three Dimensional Velocity Model into Santa Barbara Basin, Western Transverse Ranges

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Seismic Hazard to Santa Barbara Basin area

The risk due to potential damaging earthquakes on Santa Barbara and Ventura has been estimated to be third behind San Francisco and Los Angeles in the United States (U. S. Geological Survey, 1998). The seismic hazards to the study area are indicated by the abundance of moderate to large historical earthquakes that have originated on nearby faults. A large (M>7) earthquake occurred in the Santa Barbara Channel in 1812. The 1927 M 7.5 Lompoc earthquake occurred some 130 km offshore west of SB. A number of large events are located in or near the Santa Barbara Channel, such as the 1925 M 6.3, 1941 M 6.0, and 1978 M 5.9, Santa Barbara earthquakes, and the 1973 M 6.0 Point Mugu earthquake. Fault-plane solutions for several of these events can be associated with segments of east-trending north-dipping reverse faults (the Red Mountain, Pitas Point-Venture, Mid-channel, and Anacapa faults (Yerkes and Lee, 1979). Recent hazards studies have focused primarily on the onshore faults such as the Arroyo Parida, More Ranch, Mission Ridge, etc. i.e. (Gurrola et al., 1998). However, these faults are subsidiary hanging wall faults to the much larger Red Mountain, Pitas Point, and North Channel faults which dip north and lie beneath the population centers along the coast.

Implications for improved velocity model

Current 1D velocity models for the Santa Barbara basin are not adequate for precise hypocenter locations (Figure 3 and 4) or ground motion modeling. For example two studies of the 1978 Santa Barbara earthquake dramatically show the potential problems associated with using poorly constrained 1D velocity models. The epicenter locations from (Corbett and Johnson, 1982) compared to those determined by Bogaert (1984) are systematically (Figure 3, 4) and the same aftershocks located by Lee et al. 1978 are shifted by 4.5 km to the north. This difference between the two determinations based on different velocity models highlights the importance of having a well constrained three dimensional velocity model. Without better hypocenter solutions there is no hope of understanding the relationship between the seismicity and the faulting in the area. Fault mapping will also greatly benefit by this velocity model in allowing time structure maps of (Hornafius et al., 1996) and Kamerling and Sorlien (2000) to be converted more accurately into depth. The geometry of these faults and the velocity structure of the overlying rocks are crucial for ground motion simulation studies which have been hampered by lack of accurate 3D fault maps and poorly constrained velocity models (Archuleta personal communication). The existing 3D velocity models (Hauksson and Haase, 1997; Magistrale et al., 1996), do not adequately cover the Santa Barbara basin.

Progress

The SB and Ventura basins have been explored extensively for hydrocarbon accumulations by the oil industry during the past 100 years. A major part of these data are available to assemble well-constrained subsurface structural, velocity and density models. Thus far 38 seismic velocity “check-shot” surveys have been analyzed for the eastern part of the Santa Barbara Channel (Figure 1). These surveys are given in travel time and depth and typically used to calibrate downhole sonic logs which yields a detailed picture of the velocity profile in the well. Additional integrated sonic logs were used to examine velocities where no check shot surveys existed. In wells with both check-shot surveys and integrated sonic logs the two survey types were compared. The integrated sonic logs were found to be fairly close to the check-shot surveys after corrections for sea water depth and the upper part of the hole above the start of the sonic log were applied. These time depth data were then converted to interval velocity data. The refinement of the interval velocity data depended to a large degree on the length of intervals between shots. As a first step in the analysis Santa Barbara Channel was divided into 4 major parts which are:

the northern shelf area of folded, faulted, and uplifted rock,
the deep relatively undeformed basin just to the south
the mid channel anticline
the southern basin and island shelf (very sparse data available)

Velocity data were divided by these areas. In particular the uplifted and deformed areas of the northern shelf and mid-channel anticline were compared to the relatively undeformed basin (Figure 2). Unfortunately not many wells were drilled in the basin part except at the Pitas Point gas field. There are several velocity surveys from these wells. However they may not be completely characteristic of other basin areas due to the presence of the gas reservoirs and possibly dissolved gas reducing seismic velocities. These data will be compared to wells drilled in the basin area of the western part of the Santa Barbara Channel in order evaluate this effect. The presence of gas can be detected in the wells directly and this can be used to remove potential gas effects for areas where gas is not present but this was beyond the scope of this project.

The velocity data clearly reflect the effects of uplift. The uplifted areas show higher velocities than the data from the undeformed basin areas. Where a lot of detail exist, the depths and magnitudes of vertical displacements can be estimated from the velocity curves (Figure 2). In the mid-channel anticline several wells penetrated schist basement below a fairly continuous sequence of sedimentary and volcanic rock from middle Miocene to Cretaceous age. These data allow for estimation of the velocities of these rocks in the deep basin area where they are not reached by drilling. These data are shown on Figure 2. The effects of erosion of the anticline as it grows can also be seen in the abrupt velocity increase at shallow levels. This represents Pliocene and Miocene rock below a thin veneer of Holocene sediment or in some cases exposed at the sea floor.

Initially the method of Magistrale, et al., (1996) was to be used to create the three-dimensional velocity model. However, the Santa Barbara basin has a thick sequence of Eocene through Cretaceous sedimentary rock which is not generally present in the Los Angeles basin where the Magistrale, et al., (1996) model was created. Due to budget cuts it was not feasible to create the additional surface maps in the time allotted. For now the velocity data will be input directly into a 3D geologic program which can output a 3D model suitable for modeling, converting time surfaces from seismic reflection mapping to depth, locations of earthquakes, and other purposes. As additional deep stratigraphic horizons are mapped Magistrale's method may be used.

Magistrale, et al., (1996) used p wave velocities and the relationship of Ludwig to calculate densities which they then used with Poisson's ratio to calculate shear wave velocities. Density data in the form of density logs and direct measurements on core have been collected to use this with the P wave data to calculate shear wave velocities using the relationship of (Ludwig et al., 1970). Vp/Vs ratios determined will be compared to results from (Hauksson and Haase, 1997) and (Nicholson and Simpson, 1985). (Bogaert, 1984) found Vp/Vs ratio of 1.78 yielded the smallest residuals for aftershocks of the 1978 Santa Barbara Earthquake.

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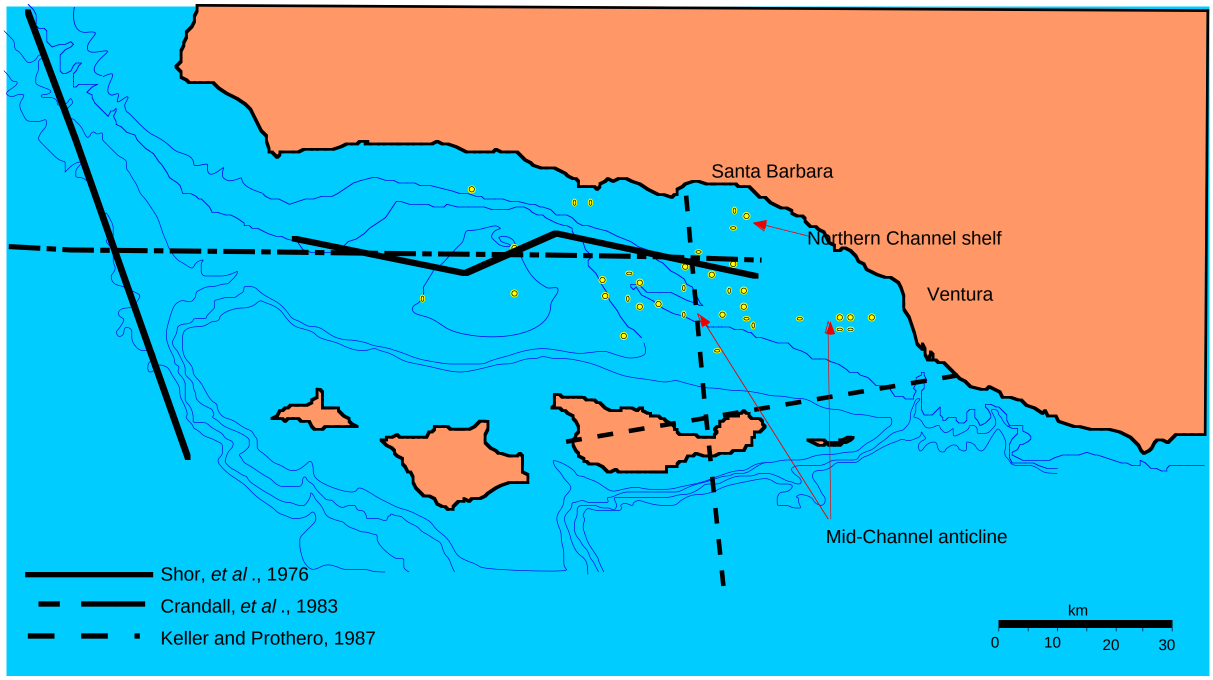

Figure 1. Map of the Santa Barbara Channel showing wells with "check-shot" velocity surveys used in this study, and velocity control from seismic refraction experiments.

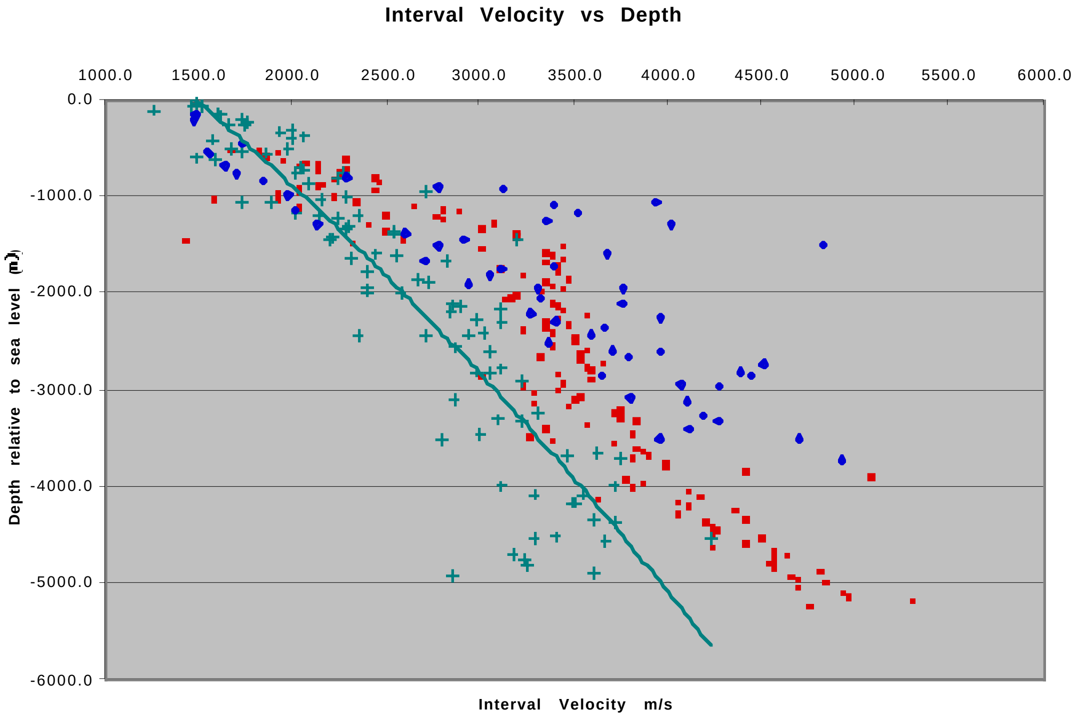

Figure 2. Interval velocity (m/s) profiles for three areas of the Santa Barbara Chanel. The green (crosses) represent velocities from the relatively undeformed basin. The red (squares) are from a detailed velocity profile from a well on the northern uplifted and deformed shelf. The blue (diamonds) are from wells along the uplifted and eroded mid-channel anticline. Depth below sea level in meters.

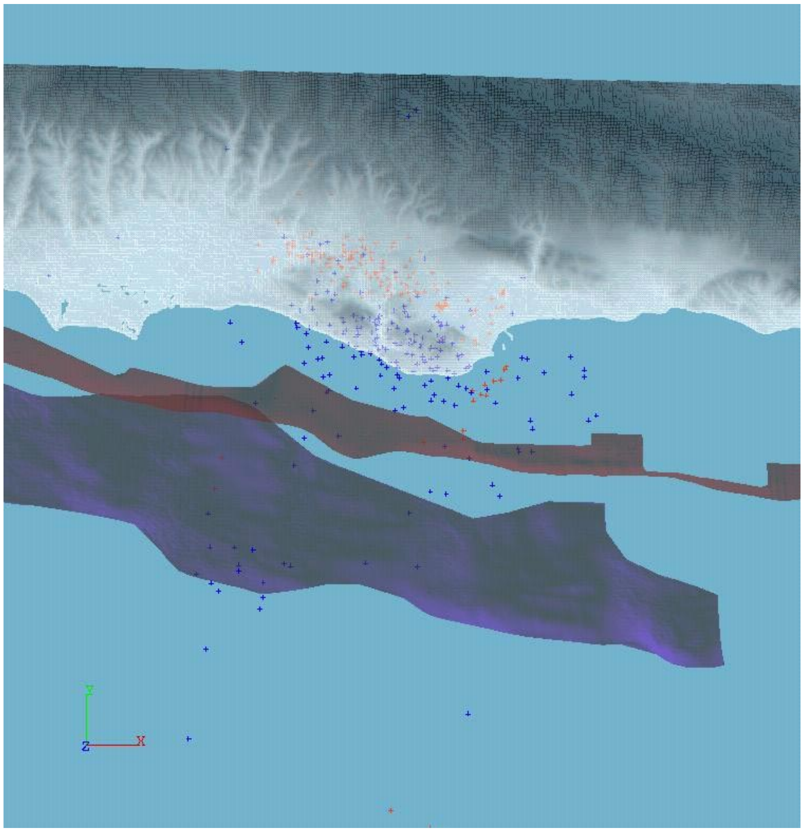

Figure 3. View looking down onto Santa Barbara-Goleta coastal area. The surfaces are the Red Mountain fault in red and the Pitas Point fault in purple. Earthquake hypocenters are shown in crosses for aftershocks of the 1978 Santa Barbara Earthquake which have the highest quality locations "A". Red are from Corbett and Johnson (1982) and blue are from Bogaert (1984). The topography in gray is slightly transparent to show the hypocenter locations. The axis bar is ~3 km.

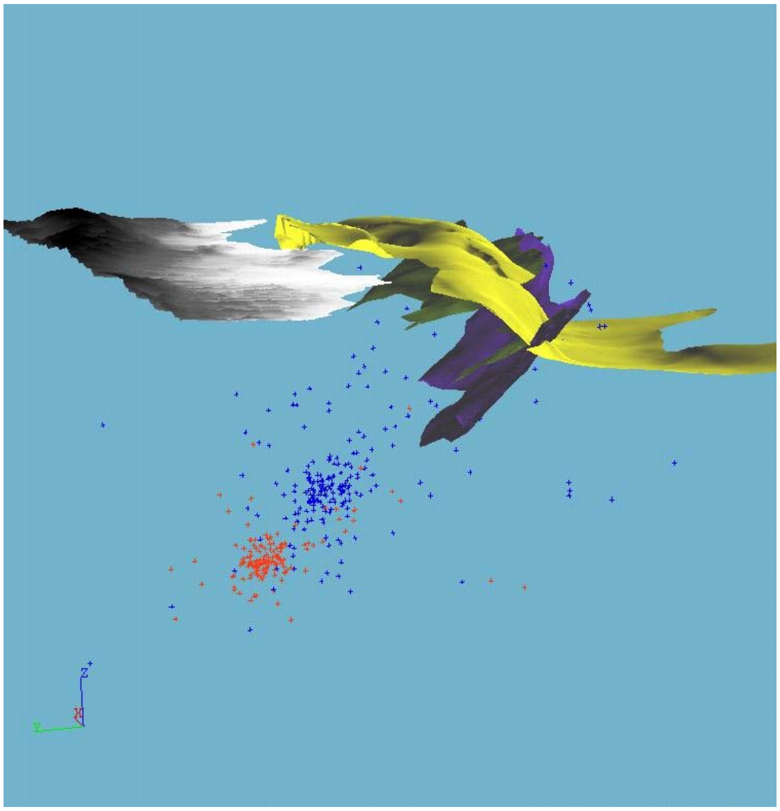

Figure 4. View to the east-southeast from the northern margin of the Santa Barbara Channel slightly above. Hypocenter data is the same as Figure 3. Even though the two sets of earthquake locations used different velocity models the plot show that either one still fits the steeper dipping Pitas Point fault and thus makes selecting one model over the other impossible. The axis bar is ~3km.