サンアンドレアス断層および周辺活断層の深部不均質構造と地震発生メカニズム

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Deep crustal heterogeneity along and around the San Andreas fault system in central California and its relation to the generating process of M6-7 earthquakes – An inversion analysis of coda envelopes from local earthquakes –

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We have estimated 3D distribution of coda scatterers in the crust in central California by using an inversion analysis of coda envelopes from local earthquakes. From the well-developed strike-slip active faults, high seismicity, and also the dense seismographic network, this area is considered to be one of the most suitable areas in the world for this kind of scattering analysis. Through the analysis we will try to estimate the crustal heterogeneity and deep structure along and around the San Andreas and several other faults, and also earthquake generating mechanism related to those heterogeneous structure.

We analyzed 3801 wave traces from 157 events recorded at 140 stations of the Northern California Seismic Network, NCSN. The deviation of observed coda energy from expected smooth decay was evaluated as a function of lapse times of coda waves and then inverted to estimate spatial distribution of scattering strength in the crust and uppermost mantle under the assumption of single isotropic scattering. The obtained scatterer distribution is shown in **Fig. 1**. The block size is 5km in both horizontal and depth and relative scattering intensity at the shallowest depth, 0-5 km, is indicated by a circle. The diagonal elements of the resolution matrix are greater than 0.5 at the central and about 0.2 at the outer part of the analysis area. The variance reduction of observed data is about 12-14% for the solution shown in **Fig. 1**, and roughly speaking, about 12-14% of observed coda deviation can be explained by the single isotropic scattering model.

Fig. 1 represents strong scatterers are distributed along the San Andreas and San Gregorio faults. Scattering is also strong along some parts of the Hayward and Calaveras faults. These scatterers are distributed continuously at depth ranges from 0 to about 15km (see **Fig. 2**). Other strong scatterers also exist about 10-20 km east off the Calaveras fault. These scatterers are located only at the shallowest depth, 0-5 km, and therefore considered to be generated by a surface topography of Diablo Range. Scatterer distribution also seems to be correlated with a surface geology, the micro-seismicity, and the location of high velocity anomalies estimated by the 3D tomography studies.

Fig. 2 shows a cross section of scatterers in the rectangular area shown in **Fig. 1**, plotted onto the X-Y vertical plane. Scattering is stronger below all the active faults for the shallowest three blocks and this suggests the San Gregorio, San Andreas (SAF), Hayward-Calaveras (HCF), and Greenville faults are almost vertical from surface to about 15km depth. The next two blocks, 15-25 km depths, corresponds to the lower crust in this area as shown by Brocher et al. (1998). Strong scatterers below the SAF and the HCF in the lower crust tend to lie in horizontal between the two faults. This may suggest a sub-horizontal detachment structure connecting the SAF and the HCF. Brocher et al. (1994) also found the lower crustal reflectors between the SAF and the Hayward fault and interpreted them as a detachment surface. We can see far deeper scatterers at 30-40 km depths between the SAF and the HCF. One possible interpretation is that the heterogeneous structure may suggest a deeper boundary between the Pacific and North American plates, although the resolution of those solutions is poor. Continuous slip across the deep plate boundary encounters the sub-horizontal detachment in the lower crust and the shear stress is transferred to the bottom of the SAF and the HCF and then brittle fracture should occur along these faults. Further analyses, for example, to detect coherent wave trains from deeper scatterers by using station or event arrays will be necessary.

In **Fig. 1**, we can find several clusters of scatterers located along the SAF with 25-30 km intervals from south of San Francisco to the intersection with the Calaveras fault. Similar pattern of scatterer distribution is also recognized at 5-10 km depth. This suggests some segmentation structure may exist along the SAF in the seismogenic zone of the crust. Moderate to large earthquakes with M6-7 frequently occur in and around the San Francisco Bay area. The area ruptured by the 1989 Loma Prieta earthquake (M7.0) almost corresponds to one of the segments between strong scatterers shown in **Fig. 1**. Bakun (1999) estimated source areas of 13 events with magnitude greater than 6.2 that occurred in this area from 1836 to 1997 by analyzing the seismic intensity data. According to this, the M6.3 event in 1890 ruptured the southeastern neighboring segment of the Loma Prieta eq. The micro-seismicity in this area has a character of clustering along the SAF. The location of earthquake clusters and the strong scatterers stated above has almost good agreement and the fault segments between strong scatterers show extremely low micro-seismicity. From these, a model of segmentation structure along the SAF is proposed as schematically illustrated in **Fig. 3**. Along the SAF from south of San Francisco to the intersection with the Calaveras fault, we can estimate four partially locked segments with each horizontal length of 25-30 km. These locked segments are considered to be ruptured during respective M6-7 events. The segment boundaries are characterized by the active micro-seismicity and stronger scattering, and therefore considered to be weak zones. This segmentation structure along the SAF may be interpreted as a transition from the southeastern creeping zone to the northwestern completely locked zone. Fault segments along the SAF is also estimated by the Working Group on California Earthquake Probabilities (1990) through the analyses of a surface fault geometry, the micro-seismicity, the slip distribution of 1906 great earthquake, and also the ruptured area of the 1989 Loma Prieta eq. The segment boundaries thus obtained almost agree with those estimated in the present scattering analysis.

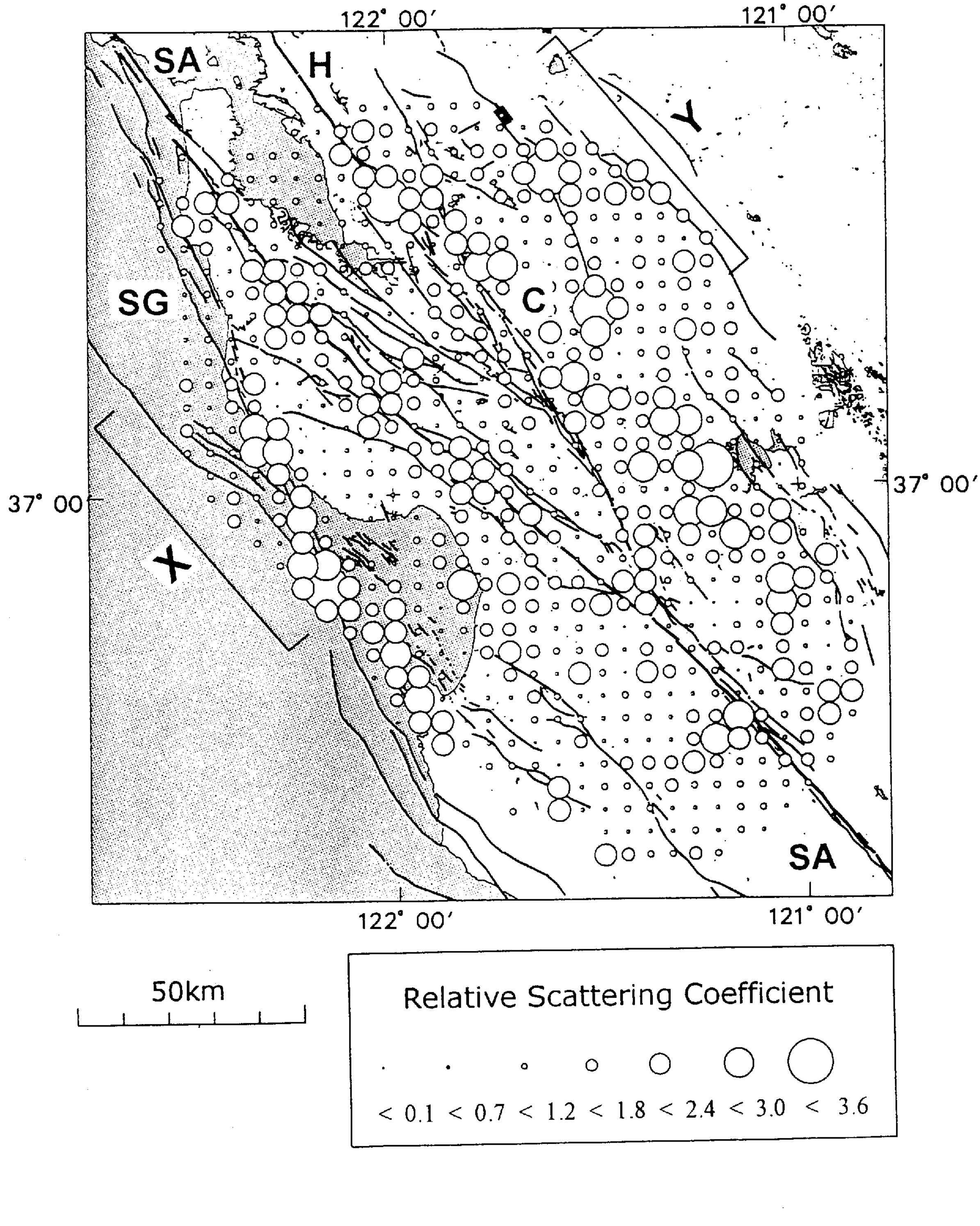

Fig. 1 Distribution of relative scattering intensity estimated at a depth of 0-5 km. Larger symbols show stronger scattering. Thick solid lines represent the historical and other solid lines the Holocene and Quaternary active faults; **SG**, San Gregorio; **SA**, San Andreas; **H**, Hayward; **C**, Calaveras faults. Cross section of scatterers along the X-Y line is shown in **Fig.2**.

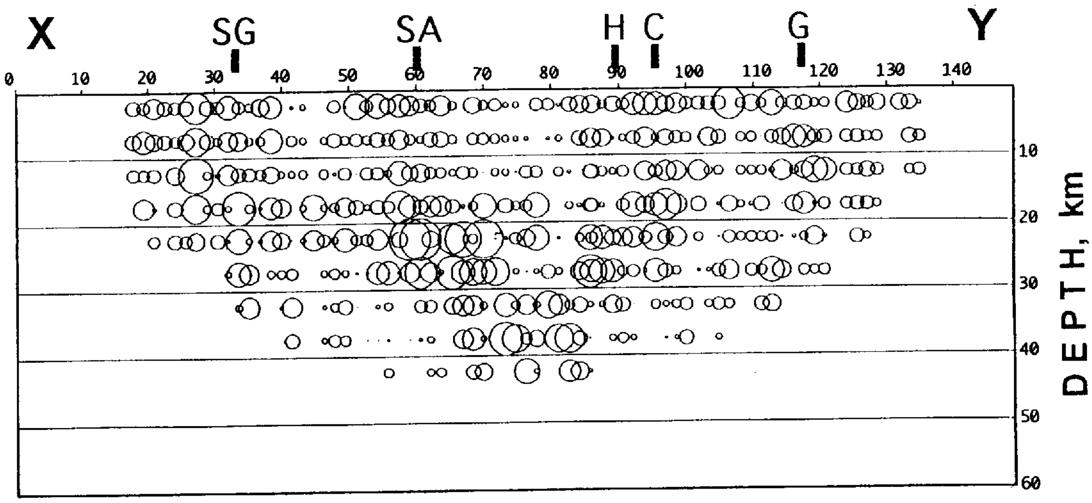

Fig. 2 A vertical cross section of scatterers plotted for the rectangular area shown in **Fig. 1**. Surface location of active faults are indicated by the thick bars.

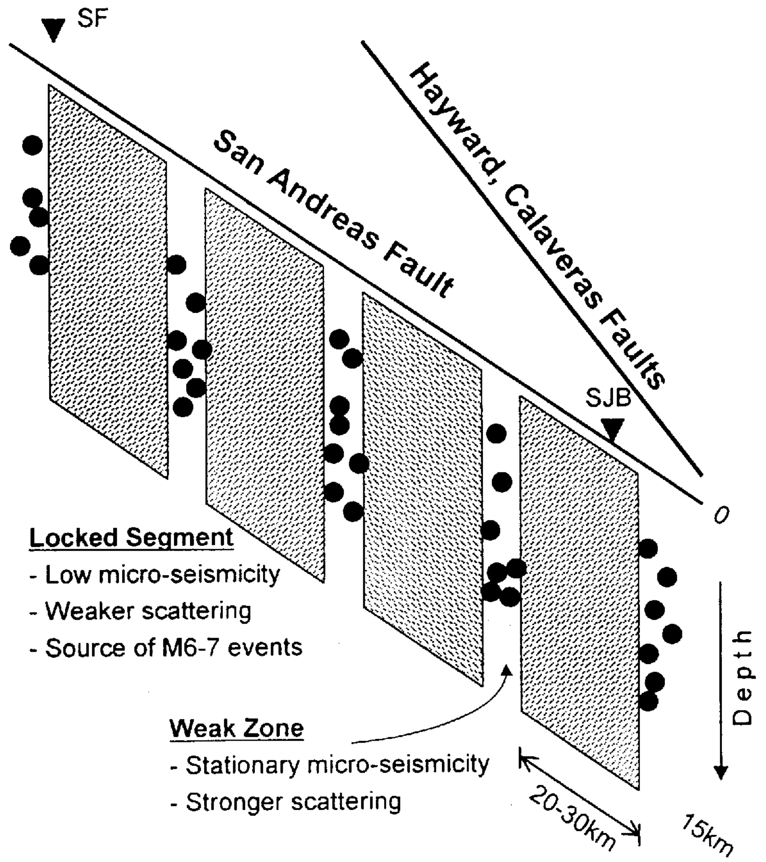

Fig. 3 Schematic illustration of a segmentation structure along the San Andreas fault, from San Francisco to the intersection with the Calaveras fault. Partially locked segments (shaded rectangles) with horizontal lengths of 25-30 km are ruptured during respective M6-7 events, and the segment boundaries are estimated to be weak zones characterized by stronger scattering and higher micro-seismicity.