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Imaging the source area of the 1995 southern Hyogo (Kobe) earthquake (M7.3) using double-difference tomography

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Abstract

To understand the generation process of inland earthquake, we determined the seismic velocity structure in and around the source area of the 1995 southern Hyogo (Kobe) earthquake (M7.3) in SW Japan. We adopted the double-difference (DD) tomography method [Zhang, H. and C. Thurber. Double-Difference Tomography: the method and its application to the Hayward Fault,California. Bull Seism Soc Am 93 (2003) 1875–1889.]. We inverted arrival times recorded by a dense temporary seismic network for aftershocks and seismic networks routinely operated by Japanese Universities. Obtained results are summarized as follows: (1) Low-velocity zones of a few kilometers' width are distributed along the fault or along the aftershock alignment, suggesting that the fault of the 1995 earthquake is located primarily in a low-velocity zone. (2) Amount of velocity decrease within this low-velocity zone varies along the strike of the fault. Most of large slip areas (asperities) seem to correspond to higher velocity areas relative to the surroundings on the fault, rather than to lower velocity areas.

Keywords: fault; coseismic slip distribution; aftershock; asperity; tomography; the 1995 southern Hyogo (Kobe) earthquake

1. Introduction

The 1995 southern Hyogo earthquake occurred on 17 January 1995 in the upper crust of the southern part of Hyogo prefecture, its fault extending from Kobe city to the northern part of Awaji Island. The focal mechanism of this earthquake was of the right-lateral strike–slip fault type [1]. Aftershock distributions [2] and surface ruptures in the northern part of Awaji Island [3] showed that this shallow inland earthquake was generated by reactivation of the Rokko fault system (the Suma and Suwayama faults) and the Nojima fault (see Fig. 1). On Awaji Island, in the southern part of the focal area of the southern Hyogo earthquake, surface ruptures were found on the Nojima fault. [3]. Maximum offset was 1.5 m. Source process studies e.g. [4–9]showed that a large quantity of slip was distributed along the surface rupture of the fault. In the northern part, a small amount of slip was distributed in the shallower part of the fault

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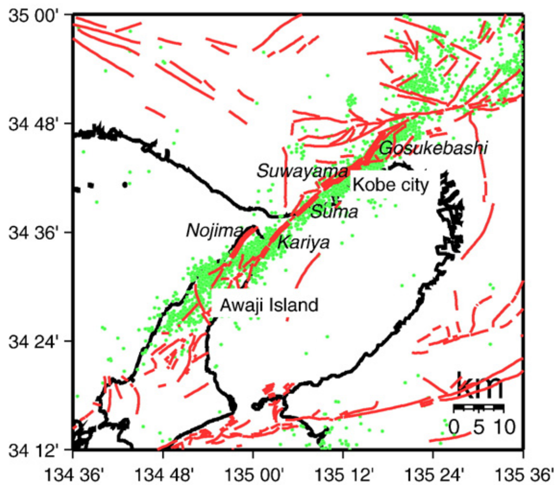

Fig. 1. Locations of major active faults. Small dots show events.

and a large amount of slip occurred at depths near the mainshock hypocenter which is located at the deepest and central part of the fault plane.

The nature of the large slip areas (asperities) of the fault is uncertain. It has become clear that asperities are common in several large or moderate-sized interplate recurrent earthquake pairs along the plate boundary in NE Japan [e.g. 10,11]. These observations possibly suggest that asperities are persistent features which reflect certain physical properties on the fault plane. Zhao et al. [12,13] have obtained three-dimensional seismic velocity structure in and around the 1995 southern Hyogo earthquake. They found low velocity zones in and around the hypocenter and the fault. However, the relation between the lateral coseismic slip distribution and the seismic velocity structure has not been discussed in their studies.

In this study, we performed seismic tomography by the double-difference tomography method [14] to obtain the detailed seismic velocity structure in and around the source area of the 1995 southern Hyogo (Kobe) M7.3 earthquake in Japan and discuss its relation with the rupture process.

2. Methods and data

For our analysis, we adopted the double-difference (DD) tomography method [14]. This method has the advantage of obtaining the seismic velocity structure at high spatial resolution for areas where hypocenters are densely distributed such as aftershock areas. For the DD tomography method, we used not only the absolute travel times, as in conventional tomography, but also the differential travel times between closely located events in a manner comparable to DD location [15]. When differential data are used, the DD tomography method cancels the equations corresponding to the common parts of the ray paths, so we can estimate the velocity structure only around the hypocenter. The velocity model is parameterized as a set of grids, and the velocity at any location is calculated by linear interpolation between the grids. We calculated the velocity models with a grid of a few km in and around the focal area. Ray tracing is done by the pseudo-bending method [16].

After the southern Hyogo (Kobe) earthquake, 27 temporary seismic stations were deployed around the focal area. The data sets (Fig. 2) used in this study were derived mainly from NET-HYOGO (Urgent Joint Observation Network for the 1995 southern Hyogo earthquake) [2]. The NET-HYOGO deployed three-component short-period seismometers and telephone telemetry system. The inversion uses 47770 P-wave and 38616 S-wave arrival times, which are picked manually from 2390 earthquakes (M=>1.5) recorded by this dense temporary seismic network for aftershocks and by the seismic networks routinely operated by Kyoto University, the University of Tokyo and Kochi University. Total number of the station used in this study is 113. Most of the events used are aftershocks of the Kobe earthquake. The analysis was carried out as follows. Hypocenters, one-dimensional velocity structure, and station correction values were first estimated simultaneously by the program VELEST [17]. This process yields a more suitable initial hypocenter locations and initial velocity structure. The three-dimensional velocity structure was then estimated by double difference tomography and used to refine the hypocenter locations. The grid points are set at intervals of 5–10 km NE–SW along the strike of the fault, 3–5 km NW–SE, and 3–5 km in depth. Initial hypocenter locations are from [13]. Initial 1D velocity structure is also the same as that used in [13].

3. Results

Overall distribution of the obtained velocity structure is similar with those by [13]; the low-velocity zone detected along and around the mainshock fault, although detailed distribution of the low-velocity zones are different. We can see many aftershock clusters clearly because we also relocated the aftershocks by the double-difference algorithm [15].

The obtained velocity structure shows complex patterns (Fig. 3); there are prominent low-velocity zones in and around much of the main shock fault. In the case of the 1995 southern Hyogo earthquake,