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Seismic Reflection Profiling in the Kanto and Kinki Metropolitan Areas, Japan

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Abstract

Deep seismic profiling was performed in the Kanto and Kinki areas to obtain a better estimation of strong ground motions. In the Kanto area, we identify the seismogenic source fault on the upper surface of the Philippine Sea plate. The depth to the top of this plate, 4 to 26 km, is much shallower than previously estimated from the distribution of seismicity. This shallower plate geometry changes the location of the maximum finite slip of the 1923 Kanto earthquake, and its location corresponds to a zone of poor reflection on the mega-thrust, namely, a strong reflectivity zone along the mega-thrust coincidences with aseismic slip zone. In the Kinki area, 120-km-long seismic reflection profiling was carried out from Osaka to Suzuka across the Osaka and Ise basins and several active faults. Deep sub-horizontal reflectors are found at 26 and 16 km in depth. The shallower reflectors correspond to the base of the seismogenic zone. Dipping reflectors, probably deeper extensions of active faults, merge into the mid-crustal reflectors.

Key words: Seismic reflection profiling, source fault, strong ground motion, metropolitan areas, Kanto and Kinki

1. Introduction

"Seismic hazard mitigation in urban areas" was started in 2002 as a special five-year project. As a major part of this project, deep seismic profiling was undertaken in the Kanto and Kinki areas. The main purpose of seismic profiling is to obtain a regional characterization of the crust, and to better estimate strong ground motions.

In this paper, we briefly summarize seismic profiling in the Kanto area, which was carried out in 2002 to 2003 (Sato *et al.,* 2005), and introduce the preliminary results of the 2004 Osaka-Suzuka seismic survey in the Kinki area, southwestern Japan.

2. Results of seismic profiling in Kanto area

In the Kanto region, the Philippine Sea plate (PHS) subducts northwestward under the Honshu arc at about 30–40 mm/yr (Seno *et al.,* 1993). The earthquakes of the subducting PHS identify a shallow and antiformally plunging surface from the Izu peninsula, southwest of Tokyo (Fig. 1, Kasahara, 1985; Ishida, 1992; Noguchi, 1998). High-resolution seismic velocity tomography (Matsubara *et al.,* 2005) resolves both the high-velocity core of the slab and its associated overlying low velocity lid, and confirms that the PHS lies under Tokyo. The presence of the Izu-Bonin arc within the PHS creates two styles of forearc

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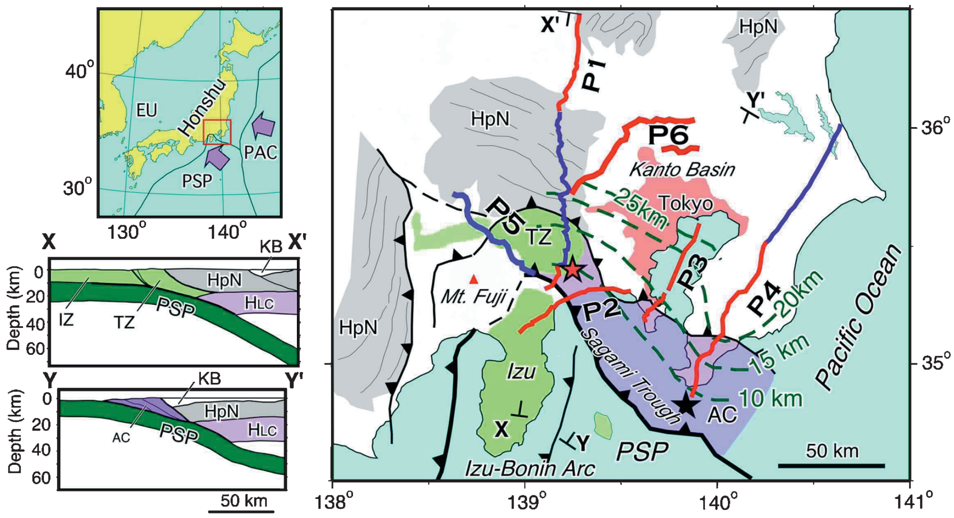

Fig. 1. Tectonic region of Metropolitan Tokyo (Kanto) area after Sato *et al.* (2005). (Upper left) Plate geometry of Honshu island. PAC: Pacific plate, EP: Eurasian plate, PHS: Philippine Sea plate. Arrows denote plate convergence directions relative to Honshu. Red box is the study area. (Right) Tectonic map of Kanto region and locations of seismic profiles P1-P6. Contours represent depths in km to the upper surface of the Philippine Sea plate (PHS) from a previous study (Ishida, 1992). Tectonic elements include: HpN: Pre-Neogene rocks belong to Honshu arc, HLC: lower crust of Honshu arc, KB: Neogene to Quaternary sediments of Kanto Basin, TZ: Tanzawa block (arc fragment of Miocene Izu-Bonin arc), IZ: Izu block, (volcanic Izu-Bonin arc crust), AC: primarily Neogene accretionary complex. Stars are epicenters of 1703 Genroku (black) and 1923 Kanto earthquakes (red). Red and blue profile segments indicate multi-channel vibroseis and explosion refraction/wide-angle reflection acquisition methods, respectively. X-X′ and Y-Y′ denote locations of schematic cross-sections. (Lower left) Lithospheric schematic cross-sections across Kanto. X-X′ represents arc-arc forearc collision; Y-Y′ illustrates the accumulation of a standard forearc accretionary complex. P5: Odawara-Kofu seismic line in 2005, P6: Northern Kanto seismic line in 2006.

accretion and deformation. In eastern Kanto an accretionary prism composed of late Cenozoic sediments overlies the downgoing PHS (Y-Y′ and AC in Fig. 1). In western Kanto, the Izu-Bonin arc has collided into the Honshu crust during the past 15 million years; remnants such as the Tanzawa block were transferred to the Honshu crust (X-X′ and TZ in Fig. 1). A mega-thrust separates the downgoing PHS from the overlying fore-arc and Honshu crust, which is composed of Mesozoic to early Cenozoic accretionary sediments and granitic intrusions (e.g. Taira *et al.*, 1989; HpN in Fig. 1).

Common mid-point seismic reflection data were acquired from profiles P2, P3, southern part of P4, and northern part of P1 (red in Fig. 1) using four vibroseis trucks or air-guns with a capacity of 9700 cm^3. In addition, profiles P1 and P4 were supplemented with refraction/wide-angle reflection profiling using widely spaced explosive sources of up to 300 kg, as well as sets of 100 stationary vibroseis sweeps at several sites per seismic line (blue in Fig. 1). All seismic signals were recorded by profile arrays of up to 2500 channels consisting of digital telemetry cable, off-line portable recorders, and ocean bottom cables when necessary. The seismic data were processed using conventional common-midpoint reflection methods including bandpass filtering, waveform deconvolution, common-midpoint sort, normal moveout correction, and variable fold stacking. The seismic sections were converted from two-way traveltime to vertical depths using velocity information derived from first-arrival travel times, reflection moveout analysis, and regional seismicity first-arrival velocity tomography (Matsubara *et al.*, 2005).

Seismic reflections from the top of the PHS are visible in all four profiles (Fig. 2). The Neogene-Tertiary accretionary prism is identified in the three eastern profiles (AC in P2, P3, P4). A portion of the Izu-Bonin island arc (TZ in profile P1) is accreted into the Honshu middle crust via wedge-thrust tectonics. The large-scale fore-arc Kanto basin (KB) is present in profiles P1, P3, and P4, and overlies the upper

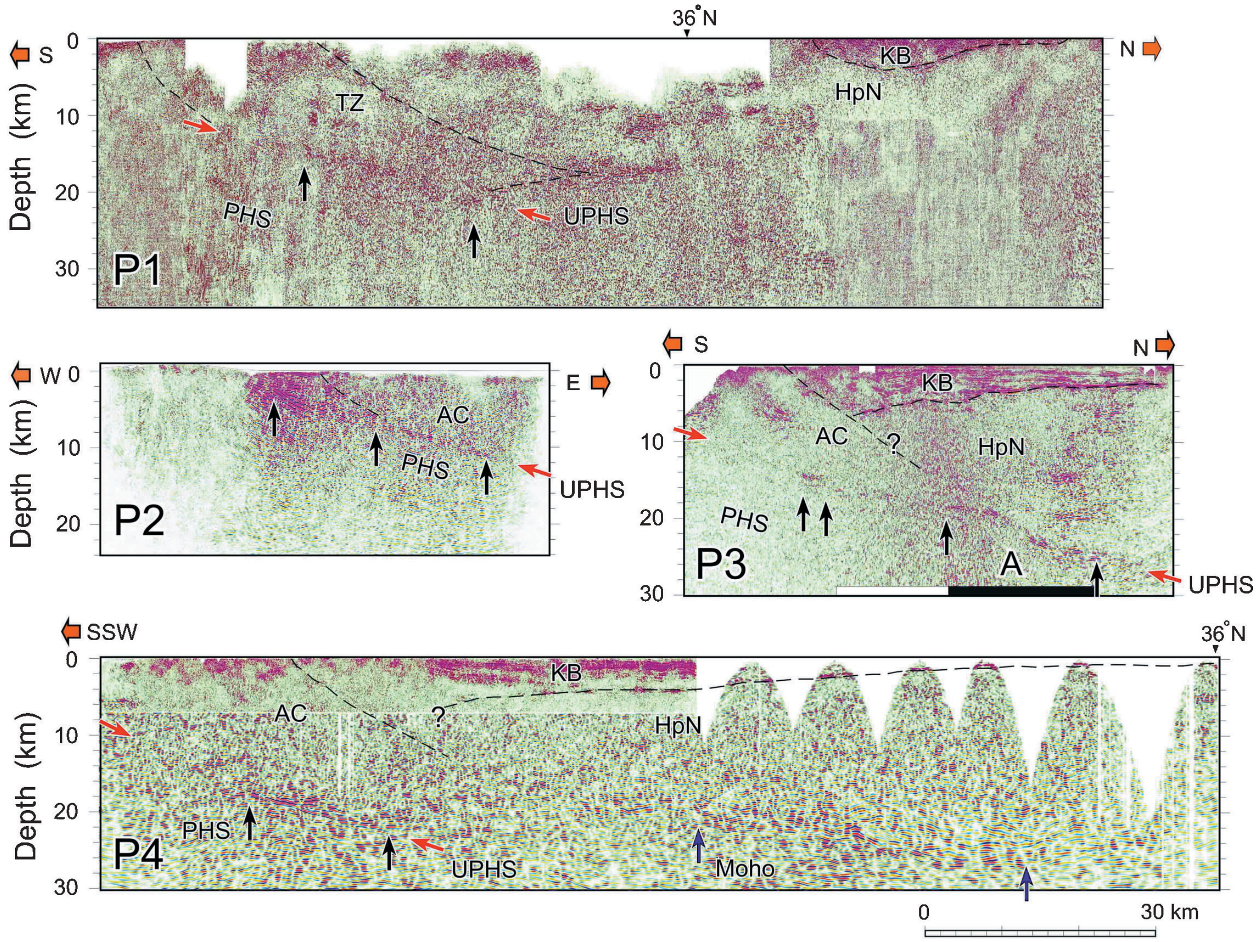

Fig. 2. Seismic reflection profiles P1-P4 in the Tokyo metropolitan area after Sato *et al.* (2005). These profiles are post-stack migrated and depth converted. Symbols for tectonic elements are defined in Fig. 1. Red arrows denote positions of seismic reflections produced at the upper surface of the Philippine Sea plate (UPHS). Black arrows delineate clearly visible UPHS reflections. Bars at the bottom of profile P3 indicate the lateral presence of strong amplitude (black and 'A'), weak-to no amplitude (white) reflections evaluated by relative amplitude processing.

crustal Honshu pre-Neogene basement (HpN). These profiles image the primary structural features of the overall subduction and two forearc systems within the Kanto region (e.g., schematic cross-sections in Fig. 1).

Seismic reflections of the upper surface of the subducted PHS are observed on all of the seismic sections (UPHS in Fig. 2). These reflections are found at 5 to 24 km depths in profile P1, 4 to 11 km depths in profile P2, and 6 to 25 km depths in profile P3. In the southern portion of profile P4, the mega-thrust dips at ～30° from 5 to 20 km depths. Sato *et al.* (2005) interpreted the reflections at 22–26 km in depth in the northern portion of profile P4 as the upper surface of the PHS. However, based on the newly obtained first-arrival velocity tomography using earthquakes observed by the dense array along P4 and explosive sources of seismic survey of P4 (Hagiwara *et al.*, 2006), the reflections in the northern portion correlate to the reflections near the base of the crust.

These seismic profiles show that the top of the PHS is at depths of 4 to 26 km beneath the region, which is shallower than has been commonly assumed (Fig. 3). While there is good agreement in southern Kanto between our estimate and previous ones where the slab is shallow, and in eastern Kanto (profile P1); there are large downdip differences in central and western Kanto of up to a ～18-km mismatch. Our shallower PHS geometry might lead to significantly larger estimates of strong ground motions, simply because the region of the mega-thrust earthquake rupture is closer to the earth's surface.

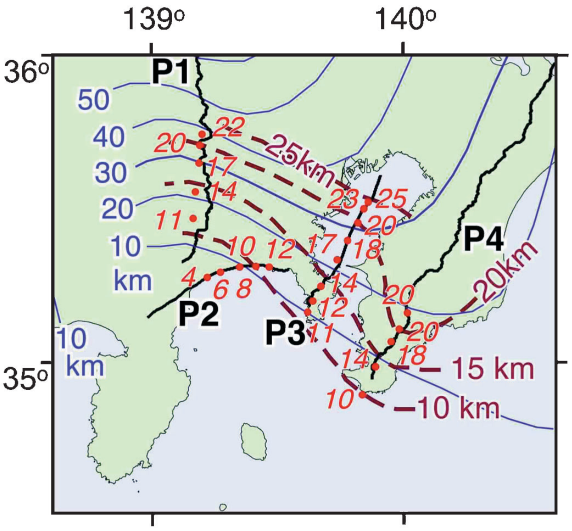

Fig. 3. Depth to the upper surface of the Philippine Sea Plate in km after Sato *et al.* (2005). Blue contours are from a previously published study (Ishida, 1992). Depths from seismic profiles are annotated (red) at marked locations (red dots).

The co-seismic displacement in the 1923 Kanto earthquake (Kobayashi and Koketsu, 2004) was recalculated using our revised PHS geometry (Sato *et al.*, 2005). The change of interpretation of the upper surface of the PHS along profile P4 does not affect the geometry of the source fault, which was used in Sato *et al.* (2005). The majority of profile P3 was acquired using one marine seismic acquisition method, and was amenable to relative amplitude seismic processing. The updip termination of UPHS reflection "A" in profile P3 (Fig. 2) correlates with the transition from low to high slip bounding the asperity region. The asperity zone is characterized by poor reflection and low reflectivity, whereas the down-dip aseismic zone is marked by a highly reflective zone.

Seismic profiling along Odawara-Kofu (P5) and Northern Kanto seismic lines (P6) was carried out in October 2005 and in January and February 2006 (Fig. 1). The Odawara-Kofu seismic survey portrays the existence of an aseismic slab in the northwest part of the Izu collision zone (Sato *et al.*, 2006). The Northern Kanto seismic survey reveals the detailed geometry of the base of the Neogene fill and its velocity structure.

3. 2004 Osaka-Suzuka seismic profiling

The Kinki metropolitan area is marked by a dense distribution of active faults (Active Fault Research Group, 1991). Deep seismic reflection profiling was undertaken from Osaka to Suzuka along a-120 km-long seismic line (Fig. 4). The major target was to obtain the deep geometry of the active fault and the velocity structure. The main seismic sources were four vibroseis trucks and dynamite shots. In addition, refraction/wide-angle reflection profiling was carried out using widely spaced explosive sources of up to 300 kg, as well as sets of 100 stationary vibroseis sweeps at several sites per seismic line.

Shallow coherent reflections beneath the Osaka and Ise plains represent mainly Pliocene sediments. Beneath the mountain range between these sedimentary basins, horizontal coherent reflectors at 16 km and 26 km are recognized (Fig. 5). The mid-crustal reflectors at 16 km in depth correspond to the base of the seismogenic zone. In the seismogenic zone, dipping reflectors, which are possibly deeper extensions of active faults, are recognized (Fig. 5). The dipping reflectors do not extend beneath the base of the seismogenic layer, and merge into the mid-crustal reflectors, as suggested by the schematic diagram shown in Fig. 6.

Conclusions

1. The seismogenic source fault on the upper surface of the Philippine Sea plate was detected by seismic reflection profiling in the Kanto area. The geometry obtained is shallower than that of previous estimations.
2. On the seismic profile, the zone of asperity, which suggests large co-seismic displacement, has poor reflection from the fault plane. Its downdip extension shows strong reflections.
3. In the Kinki area, dipping reflectors, probably deeper extensions of active faults, merge into the mid-crustal reflectors at the bottom of the seismogenic layer.

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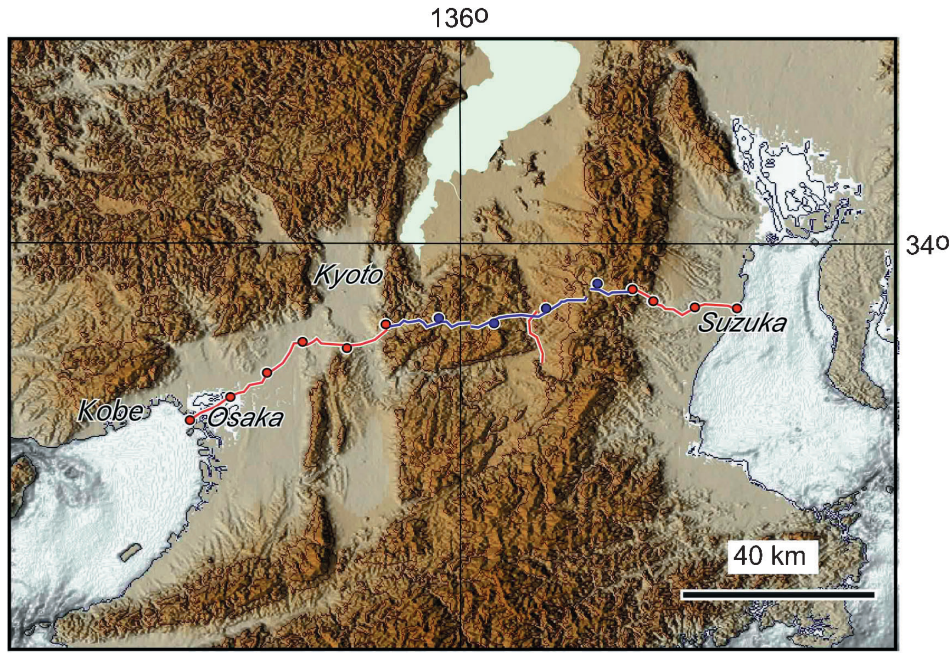

Fig. 4. Location map of the Osaka-Suzuka seismic line. Red and blue profile segments indicate dense and sparse vibroseis shooting in reflection data acquisition, respectively. Red and blue circles are the locations of 100 stationary sweeps and explosive shots, respectively. Topographic map is after Kimoto (2000).

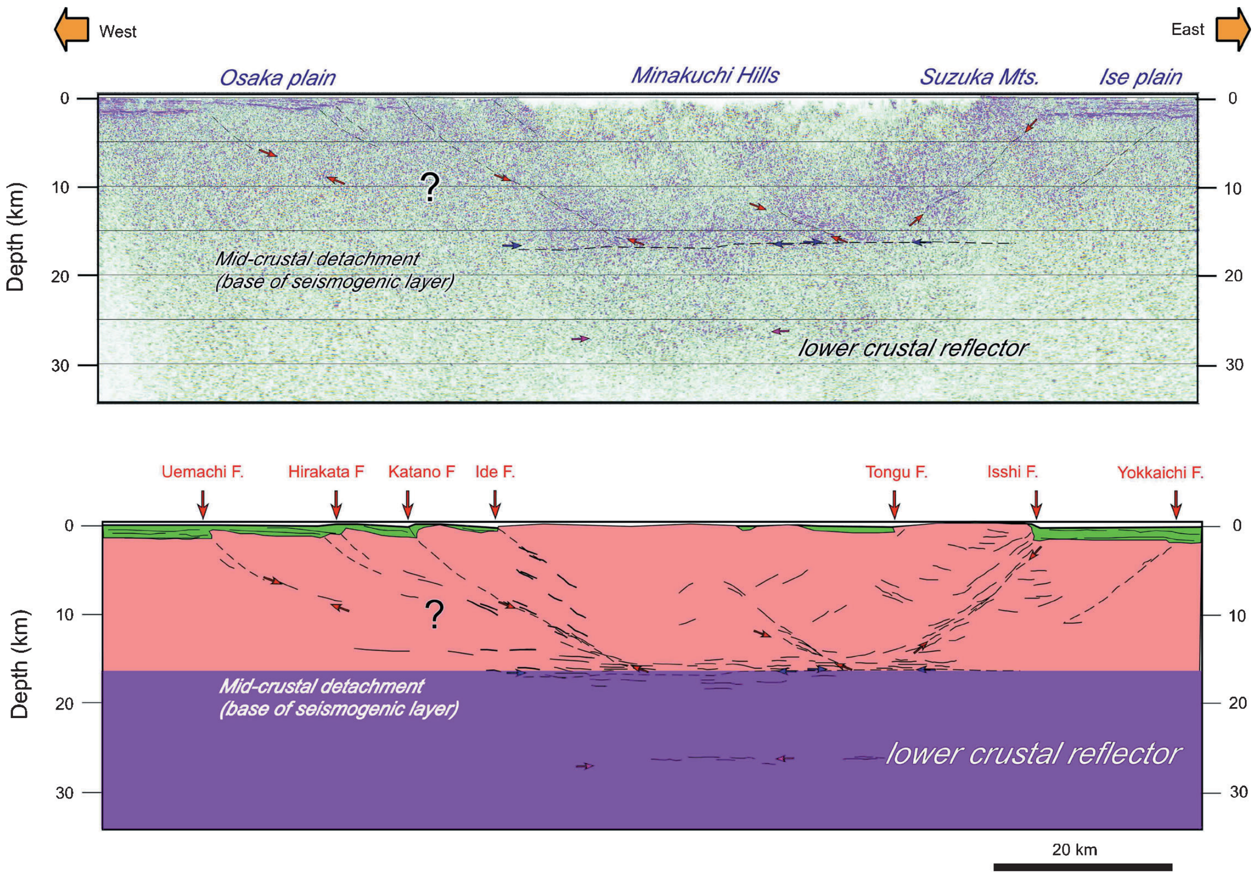

Fig. 5. Depth converted seismic section along the Osaka-Suzuka seismic line.

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