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Deep Plate Structure, Slow Slip, and Small Repeating Earthquakes off the Kanto Region, central Japan: Active Underplating below the Megathrust Earthquake Zone

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Determining the fine structure at the subduction zones is essential to reveal the generation mechanisms of interplate phenomena, including megathrust earthquakes. The peeling off of the uppermost layer from a subducting plate and accretion to the bottom of the overlying plate is called underplating. Underplating at deep region has been inferred based on exhumed high-pressure/low-temperature metamorphic rocks and deep seismic imaging, but both of these provide indirect evidence of underplating. Hence, its details, such as behavior at shorter time scale than the geologic time scale, remain unresolved. In this study, we succeed to detect active deep underplating based on the detailed relation between small repeating earthquakes, which can be considered as an indicator of plate motion, and the deep seismic imaging. It is generally difficult to do such comparisons with high accuracy, however, we resolved this problem by a series of relative comparisons.

Off the Kanto region, central Japan, the Philippine Sea plate (PHS) subducts causing various interplate phenomena, including megathrust earthquakes (e.g., the largest aftershock (Mw7.5) of the 1923 Kanto earthquake (Mw7.9)), slow slip events (SSEs), and small repeating earthquakes. The uppermost layer of the PHS consists of soft sediments and the underlying volcaniclastic and volcanic rock layer (hereinafter, VCR layer). While the sediments are fully scraped off at the entrance of subduction, the VCR layer subducts.

Processing of seismic reflection data just above the small repeating earthquake region provided clear imaging of the VCR layer of 3.1 – 3.6 km thickness, on the top of the PHS. Strong reflectors at the top and bottom of the VCR layer show large velocity contrasts. At such boundaries, seismic waves from natural earthquakes are likely to be converted. We studied seismograms of ~2000 earthquakes that occurred from 1979 to 2003, based on the seismic database maintained by the National Research Institute for Earth Science and Disaster Prevention, and found clear phases between the direct P and S waves in the radial components for earthquakes occurring below the small repeating earthquakes. Analyses of traveltime and polarity reveal that this phase was converted from P to S at the bottom of the VCR layer.

Traveltime of converted waves can be used to determine the relative location between earthquake hypocenters and the conversion plane. We used traveltime differences between the P-to-S converted wave and the direct S wave to cancel out the effects of paths through complex surface structures. Combination of traveltime analyses and high-precision hypocenters determined by the Double Difference method incorporating waveform cross-correlations revealed that small repeating earthquakes are distributed along the bottom of the VCR layer with 1.6 km depth uncertainty.

Because small repeating earthquakes are indicators of the plate motion, our result indicates that the active plate boundary corresponds to the bottom of the VCR layer, and not to its top, showing that the VCR layer is now being peeled off from the subducting PHS and accreted to the overlying plate. This is an active, deep underplating process. Off the Kanto region, source regions of the megathrust earthquakes, the SSE, and small repeating earthquakes are distributed in order from the trench axis to deeper regions, with the underplating region coinciding with the SSE. The SSE off the Kanto region repeats every ~6 years with almost the same size. This SSE activity indicates that deep underplating occurs intermittently. In such case, SSE may serve as a proxy for monitoring active underplating.