Elucidation of locking state at the shallower plate boundary after the Tohoku Earthquake based on seafloor acoustic ranging

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Several geodetic studies reported that postseismic deformation continuously occurs along the Japan Trench after the 2011 Tohoku Earthquake. In particular, GNSS-Acoustic (GNSS-A) observations successfully revealed landward motion off Miyagi due to visco-elastic relaxation. On the other hand, direct evidences for the postseismic slip at the shallowest part of the plate boundary have not been presented. In this study, we curried out seafloor acoustic ranging measurements across the Japan Trench off Miyagi and Fukushima, aiming to measure shallow postseismic slip. Seafloor acoustic ranging periodically transmits and receives sound waves between two instruments (PXP: precision transponder) installed on the seafloor or a moored buoy (IPN: indirect path node). This method can detect local deformation such as fault movement or land slide by calculating baseline length from two-way travel time and sound velocity in the sea. The measurement between two PXPs is called direct path ranging (DPR) and between PXP and IPN is called indirect path ranging (IPR). In DPR, the key to improving measurement accuracy is to estimate the appropriate sound velocity near the seafloor by using the temperature and pressure data measured at the same time of the ranging and to correct time series of the instrumental attitude. In IPR, in addition to those corrections, it is necessary to estimate the position of IPN that moves arbitrarily. In contrast to the previous IPR studies that can move the IPN as needed under the control of hanging from the vessel, this study attempted to extended it to the new formulation that can handle the case of a small IPN movements moored from the seafloor.

Off Miyagi, three DPR observations were conducted from 2013 to 2016, and measurements were successfully made five across-trench paths. We estimated the rate of plate convergence using all the available benchmark pairs data acquired across the trench axis during the entire period as 0.02 ±0.17 mm/yr indicating no significant after slip happened during this period. As the previous work of the post-2011 deformation using the GNSS-A data suggested, the shallow plate boundary does not move at all and the deformation should be explained by the viscoelastic deformation and the slip-deficit on the fault off Miyagi Prefecture. In plate boundary drilling and seismic reflection surveys near the DPR observation site, the coseismic slip occurred all the way to the trench axis because of the dynamic weakening and no stress concentration at the edge of the dynamic fault slip did not occur. That is why we do not have evident postseismic slip near the trench axis.

Off Fukushima, we performed the DPR/IPR combined observation for one year from 2017 to 2018. DPR observations crossed the trench axis at one baseline, and IPR observations passed at all baselines. A convergence rate of 3.8 ±0.8 cm/yr was obtained from one baseline of the DPR observation. In the IPR observation, the convergence rate of 3.7 ±1.1 cm/yr was obtained by applying the analysis method developed in this study. Off Fukushima, the GNSS-A observation site closest to (~ 20 km landward of) our observation location shows a seaward motion of ~ 12 cm/yr relative to the incoming Pacific plate. The difference in the deformation rate between the GNSS-A result and our acoustic ranging near the trench suggest extremely large rate of internal deformation of overriding plate. It is considered that the reverse faulting on shallow faults branching from the plate boundary contribute as well as the megathrust itself to cause the observed fast postseismic at the toe of the hanging wall crust. In addition, through our

observation, it was demonstrated that the deformation of the plate boundary can be captured with an accuracy of about ~1 cm/yr by IPR observation. Moored IPR is a very promising method that can perform long-term continuous observation and can extend the observation network to a wide area without being restricted by the direct conditions of the acoustic path.

Keywords: Tohoku Earthquake, Seafloor geodesy, Seafloor acoustic ranging, postseismic slip

