

Drilling into shallow interplate thrust zone for understanding of irregular rupturing of megathrust

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abstract

It is generally conceived that the shallowest portion of the megathrust fault is completely aseismic and allow stable sliding during the interseismic period. However, anomalous tsunami earthquakes sporadically happen in this area, causing disproportionally large tsunami as compared to the radiated seismic energy, release large displacement at the plate boundary. It has not been well understood why and how such the anomalous earthquake occurs irregularly. Also in the rupture propagation of gigantic ($M > 9$) earthquakes involving simultaneous rupturing of multiple asperities, the aseismic plate boundary seems to play an important role. Therefore, the mechanical properties of the most trenchward zone of the subduction plate boundary are very important for understanding mechanisms generating catastrophic earthquakes. I propose here to make long-term monitoring in deep boreholes drilled the shallowest portion of the megathrust fault to clarify how deform this area in the interseismic period. Downhole logging and seismic profiling will provide the answer to the cause of the anomalous rupture process by revealing the internal structure of the fault zone.

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1. Introduction

The occurrence of the 2004 Sumatra-Andaman earthquake (M9.1) showed that an interplate earthquake which ruptures almost entire part of a subduction system can occur, although we only know recurrence history of thrust earthquakes with sizes of M~8 in the system. Recent paleoseismological studies have revealed the occurrence of gigathrust earthquakes, much larger than M8 class megathrust earthquakes, in other subduction zones where only megathrust earthquakes have been known to occur. Gigathrust earthquake potentially causes global-scale catastrophic damage by its hard shaking and tremendously large tsunami. Therefore, it is very important to evaluate potential of the occurrence of gigathrust earthquakes both in space and in time. Although the understanding of the mechanism how ruptures along plate boundary developed to gigathrust earthquakes is essential, we have just been aware of the existence of the earthquakes of that kind.

From a tsunami hazard of point of view, understanding of the process of tsunami earthquakes is another important issue. Tsunami earthquakes are anomalous earthquakes accompanied with disproportionally large tsunami as compared to the earthquake size expected from the radiated seismic energy. Tall tsunamis induced by the anomalous earthquakes of this kind may hit coastal regions before any cautions are arisen because of lack of hard shaking by seismic motions.

This proposal describes a research program based on deep sea drilling to gain knowledge about frictional properties along the plate boundary, which is critical to understand the generation of these irregular earthquakes.

2. Importance of aseismic portion of the plate boundary

In general, interplate earthquakes are considered to be a series of repetition of sticks and slips along a plate boundary. In the first approximation, the location of the rupture area of a certain series of earthquake does not vary in the recurrence cycle (characteristic earthquake model). Usually, a subduction zone is partitioned into several segments each of which has an independent recurrence cycle and ruptured as a megathrust earthquakes with M~8. Gigathrust earthquakes of M>9 are considered to be simultaneous ruptures of several neighboring segments. Recurrence intervals of the giga-earthquakes estimated from the paleoseismological studies are much larger (10 times or more) than those of the M~8 earthquakes usually occur. The existence of multi-segment ruptures with longer recurrence cycles suggest that the segments of the megathrust earthquake influence one another and rare occurrence of giga-earthquake is interpreted as resultant of complex interaction among the segments. In order to

understand the interaction of the segments of megathrust earthquakes, behavior of regions outside of these segments of seismic ruptures as well as that within the segments. Although the stick-and-slip behaviors of the segments have become known well owing to the detailed analyses of seismic and geodetic data, it is not well clarified how the remaining aseismic portions are deformed.

Tsunami earthquakes are occasional ruptures of aseismic plate boundary near to the trench axis accompanying the failure of the seismic portion, which is located downdip side of the aseismic region. If the relative plate motion is consumed by stable sliding in the interseismic period along the aseismic portion of the plate boundary, it is difficult to explain why large coseismic displacement released at the occurrence of the tsunami earthquakes. It is probable that significant amount of slip deficit is accumulated over a long time in the most trenchward aseismic portion of the plate boundary and it is released occasionally to cause the anomalous tsunami earthquakes. In the occurrence of "regular" megathrust earthquakes, however, spatial extent of tsunami sources match to the area of coseismic slip and no significant amount of fault motion along the aseismic plate boundary is required to explain tsunami data. This means that the behavior at the most trenchward area is not in accordance with the recurrence cycle of the regular interplate earthquakes.

One of the important characteristics of the tsunami earthquake, other than anomalously tall tsunami generation, is long duration of fault rupture. Rupture duration time is usually in proportion to the magnitude, and thus to the rupture area. But tsunami earthquakes tend to have much longer source duration than the ordinary earthquake with the similar magnitude. It is notable that the 2004 Sumatra-Andaman earthquake had considerably long source duration. This may indicate that the rupture propagation in the megathrust earthquake involving multiple asperities has similar mechanism of the rupture process of the tsunami earthquakes. Therefore, the behavior of the shallowest aseismic plate boundary is the most important issue for understanding the generation process of the tsunami earthquakes as well as the megathrust earthquakes.

3. Research plan

I propose here to make long-term geodetic monitoring in the boreholes drilled into the shallowest portion of the megathrust fault to clarify how deform this area in the interseismic period. According to the above proposition, relative plate motion is not completely consumed as aseismic sliding. However, coupling coefficient should be much smaller than unity, because the recurrence intervals of the tsunami earthquakes are presumed to be larger than the ordinary earthquakes regularly occur. This situation

requires detecting very small rate of dislocation across the plate boundary.

Longer source duration time suggests that the tsunami earthquakes have slow rupture speed as compared to the ordinary earthquakes. Smaller radiation of seismic energy means low seismic efficiency and it is plausible that the rupture propagation consumes large high fracture energy. Since the fracture energy is considered to be proportional to the thickness of the shear zone, drilling into the source of the tsunami earthquakes can provide the answer to the cause of the anomalous rupture process by revealing the internal structure of the fault zone. Full suits of downhole logging and vertical seismic profiling will considerably important to define the detailed structure and required to be performed prior to installing the observatories.

Since the fault zone structure can account for the irregularity of the rupture process, we may not assume that the fault displacement is concentrated into a fault plane or a thin layer as in the normal earthquakes. Therefore, building a dense vertical array across the fault zone is particularly important. The deformation data obtained by this array observation will reveal rate of deformation during the interseismic period in the aseismic zone. It is also important to clarify how the relative plate motion is consumed in the aseismic plate boundary, slip along the plane or deformation of shear zone with finite thickness.

These downhole measurements have to be made in tight collaboration with large scale survey to construct an earth model on which computer simulations are made. Both gigathrust and tsunami earthquakes are rare phenomena, simulation studies are inevitable for understanding the generation mechanisms of these anomalous earthquakes. The multiple borehole observatories have to be built. Deployment of ocean bottom geodetic network, i.e. GPS/A for horizontal motions, pressure gauges for vertical movements, covering the downhole sites is essential as well as network of seismic observations to detect microseismicity, which may be involved in deformation of the fault zone.

The aseismic plate boundary just landward of the trench axis is the shallowest portion of the interface and drilling into 1 to 2 km below seafloor is required to reach the fault plane. Shallow holes may provide enough information of fault zone structure but reliable deformation measurements seem to be difficult because of low rigidity of hanging wall materials.

The most preferable sites for this drilling research are the source area of past tsunami earthquakes whose source have been well studied, e.g. the 1896 Sanriku earthquake, the 1992 Nicaragua earthquake, the 2006 Java earthquake. The source area of the 2004 Sumatra-Andaman earthquake should be included for understanding the

correlation between the slow rupture propagation and growing to the multi-asperities failure. The water depth exceeds 4,000 m in the source area of these earthquakes and it is strongly desired deep drilling under ultra deep water environment to be realized soon.