Verification of the asperity model using seismogenic fault materials

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Abstract

The asperity model is an important conceptual framework for comprehensible understanding of a variety (heterogeneity in slip and moment) of earthquakes located in subduction zones. A significant advantage of the asperity model is that slip behavior in both the asperity area (strong coupling dominated by stick slip behavior) and the non-asperity area (weak coupling dominated by stable sliding) can be described by a single constitutive friction law with a few parameters (i.e., a-b, D_c). Therefore many numerical simulations for reproducing cycle and slip distribution of subduction earthquakes have been attempted based on the asperity model, resulting in several recent significant advances in understanding the origin of a variety of subduction zone earthquakes.

However, whether the constitutive parameters used in such simulations represent realistic values determined from seismogenic fault materials by laboratory experiments have not been verified up until now. For instance, an asperity region is often described by the constitutive parameter, $a-b<0$ or larger D_c, in numerical simulations, although we have not yet confirmed these mechanical properties in natural faults in seismogenic zones at depth. Moreover, we still do not fully understand what materials compose the asperity/non-asperity regions and what physical properties of the materials characterize the asperity/non-asperity. Detailed analyses of core materials collected from seismogenic fault drilling by the Chikyu in such actively deforming regions are essential, if we wish to (1) produce realistic constitutive parameters that can be incorporated into earthquake numerical simulations, and to (2) resolve the important question like what the asperity/non-asperity area is in terms of material sciences.

Introduction

The slip heterogeneity revealed by recent geophysical studies is often characterized by terms such as 'asperities'and 'non-asperities (barriers)'which demonstrates the spatial diversity of seismic slip (Kanamori, 2008). Asperities are the portions on a fault at which large slip occurs, and non-asperities are patches where fault motion is impeded. Asperities and barriers reflect the heterogeneities of stress, the frictional properties of faults and geometries, and have a key role in the nucleation, growth and cessation of slip motion. Thus, the asperity/non-asperity model is an important conceptual framework for explaining regional variation of rupture patterns in subduction zone earthquakes by numerical simulations. However, it has not been verified up until now whether the constitutive parameters used in such simulations represent realistic values determined from seismogenic fault materials by laboratory experiments. In addition, it is not still poorly known what materials and their physical properties characterize an asperity and non-asperity. Here we propose three hypotheses that will be possibly confirmed by detailed analyses of core materials collected from seismogenic fault drilling by the Chikyu and by borehole monitoring in such actively deforming regions.

(1) Depth variation of constitutive parameters in the framework of a rate and state friction law:

Figure 1 shows a synoptic model for fault stability as a function of depth for subduction zones, summarized by Scholz (1998). This model implies that fault zone materials at asperity regions could show the velocity weakening behavior (one of the constitutive parameter, a-b, indicates negative value) at in-situ conditions. A critical slip weakening distance, D_c, which is the slip over which fault strength breaks down during earthquake nucleation, is often used to define the asperity/non-asperity; shorter D_c for asperity and longer D_c for non-asperity. These hypotheses can be verified by determining the parameter by laboratory friction experiments on seismogenic fault materials collected from the asperity/non-asperity regions.

(2) Strength profile along subducting plate boundaries:

Figure 2 shows a conceptual model for the strength profile along subducting plate boundaries (Shimamoto et al., 1993). The diagram implies that intermediate seismogenic zone (region AB in the figure) could correspond to the asperity where earthquake ruptures nucleate and that the rocks in the region are possibly composed of strong materials which are able to accumulate the stress. The strength in the shallow and deep zone (region TA and BC) is low due to the massive solution-transfer processes and to the fully-plastic deformation mechanisms operated. Thus the materials from non-asperity regions could show the characteristic microstructures formed by these deformation mechanisms. The strength of rocks along subduction plate boundaries is perhaps much weaker than the frictional strength of common rocks (i.e., Byerlee’s law) due to the weakening effects of abundant H_2O and chemical reactions on the strength of rocks. Core samples collected by ultra-deep drilling are required to verify these hypotheses and the model of strength profile along subducting plate boundaries.

(3) Fluid pressure distribution along subduction fault zones:

Evolution of pore-fluid pressure around fault zones is crucial for earthquake nucleation and recurrence intervals (i.e., a fault-valve model, proposed by Sibson, 1994). Elevated pore pressure reduces the effective normal stress on faults, leading to the initiation of failure or earthquake slip. On the other hand, a stable slip (fault creep) may be also enhanced by the existence of fluid. It is still unclear whether the distribution of fluid along faults could characterize the asperity/non-asperity. The distribution of fluid pressure within subduction zones can be estimated from 3D seismic reflection data (i.e., Tsuji et al., 2008, Figure 3) and should be calibrated by in-situ measurements. Establishing a correlation between distribution of microseismicity and fluid (or fluid pressure) along fault plane may help to understand the role of fluid to define the asperity/non-asperity

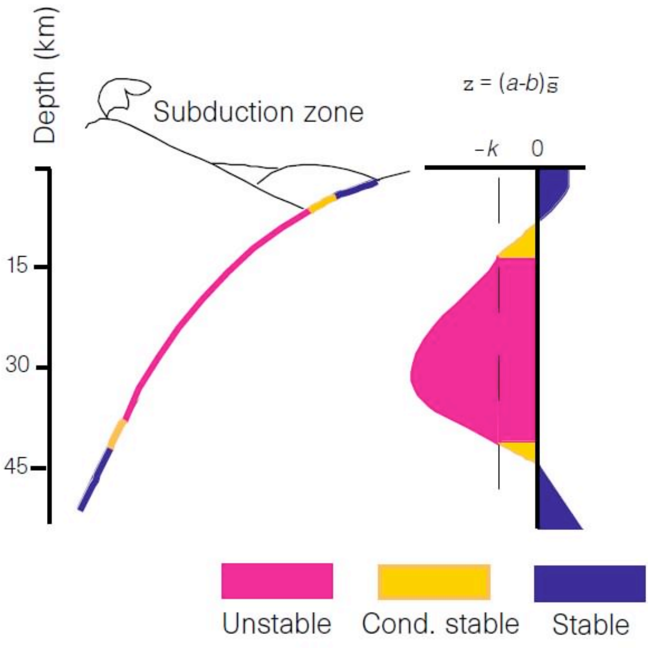

Figure 1. A conceptual model for fault stability as a function of depth for subduction zones (Scholz, 1998). The model implies that an asperity can be described as a constitutive parameter, $a-b<0$, in the framework of the rate and state friction law.

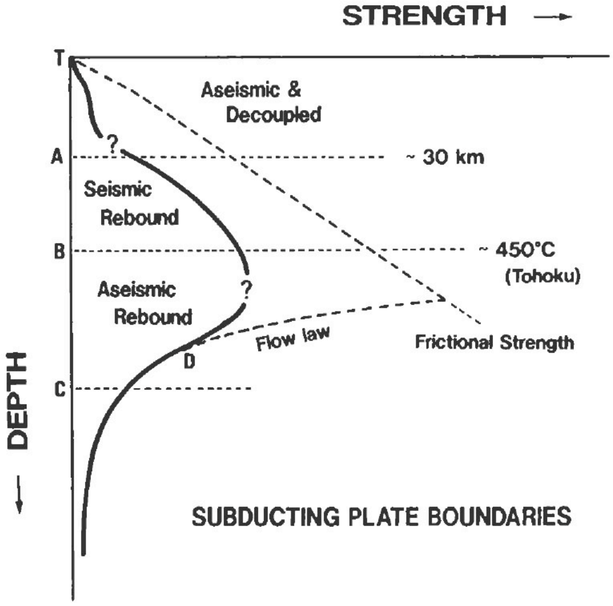

Figure 2. A conceptual model for the strength profile along subducting plate boundaries (Shimamoto et al., 1993). AB, intermediate seismogenic zone, which could correspond to an asperity region. TA and BC, shallow and deep aseismic zones (non-asperity zones). Heavy dashed line indicates the frictional strength of many brittle rocks and the flow stress in the fully plastic regime. The strength of rocks along subduction plate boundaries is perhaps much weaker than the frictional strength due to the weakening effects of abundant H_2O and chemical reactions on the strength of rocks.

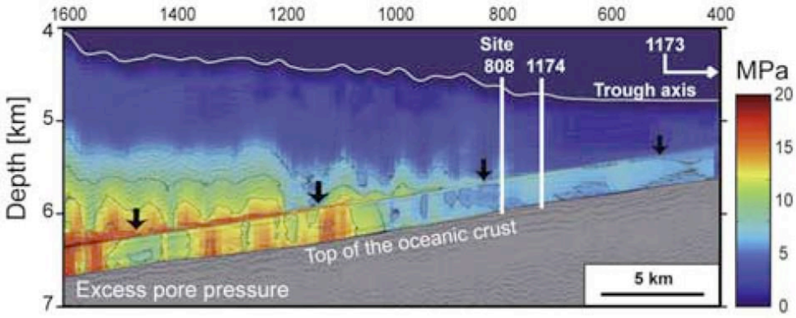

Figure 3. Pore pressure distribution at Nankai trough area estimated using a single

relationship between elastic property and porosity (Tsuji et al., 2008). Asperity or non-asperity at the plate boundary may be related with the pore pressure distribution.

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