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ScienceDirect
Earth and Planetary Science Letters 259 (2007) 307–318
EPSL
www.elsevier.com/locate/epsl

Fluidization of granular material in a subduction thrust at seismogenic depths

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Received 10 August 2006; received in revised form 17 April 2007; accepted 29 April 2007
Available online 8 May 2007
Editor: R.D. van der Hilst

Abstract

Subduction thrusts exhumed from seismogenic depths may record the dynamic slip processes during subduction zone earthquakes. The thrust faults in the Shimanto accretionary complex of southwest Japan imbricate the mélange derived from sedimentary rocks and basalt, which represent a duplex underplating associated with the downward step of the subduction thrust at seismogenic depths (4–6 km in depth, temperature = 130–150 °C). One well-exposed duplex-fault zone consists mainly of foliated cataclasites and ultracataclasites derived from basalt. The fault zone structure suggests slip localization along the 2–20 cm thick ultracataclasite layer at the boundary between different lithologies. The common features observed along the ultracataclasite layer are the injection of granular material into the mélange without the sorting of fine-grained particles along with a small detection probability of the fragmented counterparts in the injected materials, which suggests a rapid injection of fluidized granular material during faulting. The ultracataclasite layer is marked by fluid-related processes, as indicated by the alteration and precipitation of amorphous silica gel along the ultracataclasite and the concentration of veins near the ultracataclasite. The fluidization during localized slip under fluid-infiltrated conditions could be due to thermal pressurization, which causes the fluid pressure to approach lithostatic values. The injection of fluidized granular material may result from hydraulic fracturing in response to an increase in the fluid pressure associated with thermal pressurization. The plate boundary subduction thrust could be lubricated when the granular material fluidizes due to thermal pressurization during earthquakes.

Keywords: accretionary complex; subduction thrust; ultracataclasite; fluidization; thermal pressurization

1. Introduction

Most of the global seismic moment release is achieved through earthquakes on subduction thrust faults (Scholz, 2002). The exhumed subduction thrusts in ancient accretionary complexes may provide an invaluable opportunity to understand the dynamic slip processes during subduction zone earthquakes. Pseudotachylytes (i.e., solidified frictional melts produced during a seismic slip) were recently found in several on-land accretionary complexes (Ikesawa et al., 2003; Kitamura et al., 2005), and the melt lubrication of faults can possibly occur during subduction zone earthquakes (Ujiie et al., 2007). However, pseudota-

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doi:10.1016/j.epsl.2007.04.049

chylytes are rarely observed in fault rocks of ancient accretionary complexes, which may indicate that melt lubrication is not a dominant dynamic weakening mechanism in subduction zones. Hence, other coiseismic lubrication mechanisms (Wibberley and Shimamoto, 2005) could be recorded in on-land analogs of subduction thrusts exhumed from seismogenic depths. Numerous fluid-related processes have been preserved in ancient subduction thrusts (Moore and Vrolijk, 1992; Meneghini and Moore, 2007). Hence, it is probable that the fluid-infiltrated subduction thrusts may cause low effective stress conditions and dynamic weakness due to fluid pressurization during a seismic slip. However, the role of fluid on the fault weakness remains poorly understood. In comparison to plate boundary faults in other tectonic settings such as the San Andreas Fault and its ancient analogs (Chester et al., 1993; Evans and Chester, 1995), detailed geological observations of plate boundary faults in subduction zones are lacking.

Here, we describe the structure of the fault zone and the fault rocks of a subduction thrust exhumed from seismogenic depths. Based on the interpretation of the structures found in ultracataclasites, we then discuss the possible deformation processes that could correspond to seismic slip in subduction zones.

2. Geological setting

The studied fault developed in the Late Cretaceous to early Tertiary Shimanto accretionary complex of eastern Shikoku, southwest Japan (Fig. 1A). Here, an argillaceous mélange (blocks of hemipelagic red shale, acidic tuff, and sandstone in a sheared black shale matrix) and basalt are repeated along the thrust faults (Fig. 1B). The fabric analysis indicated that the mélange was formed during the subduction, and its kinematics was consistent with the relative plate motion during the Late Cretaceous to early Tertiary (Onishi and Kimura, 1995). The imbrications of the mélange and basalt along the thrust faults after the subduction were interpreted to represent a duplex underplating (Ikesawa et al., 2005). The underplating-related deformations in the duplex faults were marked

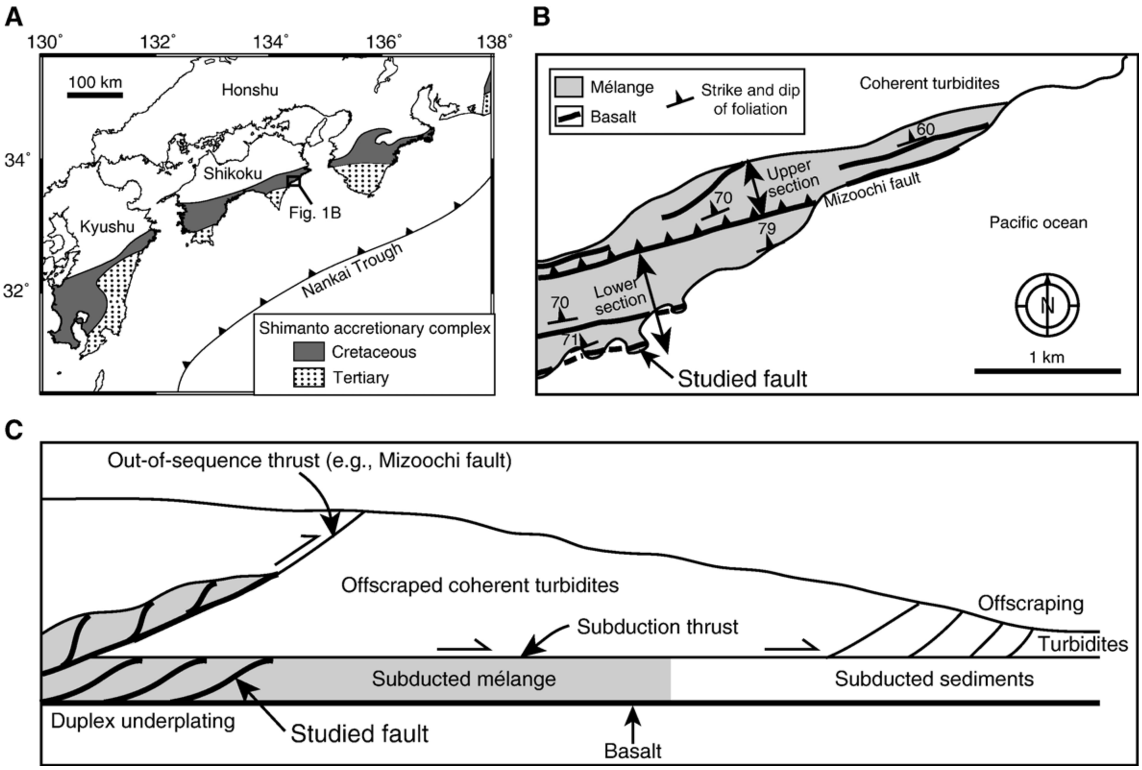

Fig. 1. Geological setting of the studied fault. (A) Distribution of the Shimanto accretionary complex in southwest Japan. (B) Geological map of the Late Cretaceous to early Tertiary Shimanto accretionary complex in eastern Shikoku showing the repetition of the mélange and basalt (modified from Ikesawa et al., 2005). The location of the site is shown in A. The studied fault corresponds to the duplex fault. There is a thermal gap across the Mizoochi fault (out-of-sequence thrust) dividing the mélange into the upper and lower sections. (C) Paleotectonic setting of the duplex faults in seismogenic depths. The duplex faults were formed in association with the downward step of the subduction thrust to the basalt.