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# Structural evolution in accretionary prism toe revealed by magnetic fabric analysis from IODP NanTroSEIZE Expedition 316

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ABSTRACT

This paper presents magnetic fabric analysis to examine the internal structure of the accretionary prism toe in the Nankai Trough, off the east coast of Japan. Two sites (C0006 and C0007) drilled during Integrated Ocean Drilling Program (IODP) Expedition 316 penetrated the sediment section, including intra wedge thrusts and the frontal thrust. Anisotropy of magnetic susceptibility (AMS) measurements provides insight into recorded strain during sedimentary and tectonic processes. Results from the upper part of the wedge show sedimentary acquired compaction fabric in general. In the lower part, AMS fabrics occasionally rotate almost ninety degrees and suggest horizontal compression. In contrast, magnetic fabrics did not show any correspondence to the thrusts or minor normal faults, which implies that those faults develop with concentrated shear deformation without disturbing surrounding sediments. Two adjacent drilling sites and dense sampling demonstrated clearly the change in strain field which is reported by previous studies. Based on these results, we propose a model of structural evolution at the toe of the prism. Underthrusting sediments induce horizontal stress in the lower part of the wedge, which reduces the effective stress and forms a high pore pressure anomaly and zones of fracturing. The frontal thrust is bent geometrically and terminates its activity in response to an increase of friction that triggers initiation of the next-generation frontal thrust. The upper part of the wedge tilts accordingly, resulting in an unstable slope.


## 1. Introduction

The Nankai Trough seismogenic zone experiment (NanTroSEIZE) is a multidisciplinary project with the goal of documenting the fault mechanics in a subduction zone. A key component of NanTroSEIZE is logging and sampling by the D/V *Chikyu*, as part of the Integrated Ocean Drilling Program (IODP). Stage 1 of NanTroSEIZE consisted of three continuous expeditions from 314 to 316 aimed at understanding the shallow parts of two major faults in the accretionary prism, the megasplay fault and the frontal thrust. During Expedition 316, fault rock samples from these two targets were successfully recovered (Kinoshita et al., 2009).

The strength of a material is a fundamental question in terms of its absolute value and special variation for faulting process in subduction zones. The key hypotheses on catastrophic faulting at the updip limit of seismogenic zone are; a change in thermal condition (e.g. Hyndman and Wang, 1993) and following change in frictional behavior (e.g. Saffer and Marone, 2003), a change in shear strength controlled by fluid pressure (e.g. Moore and Saffer, 2001), and a change in strength due to lithification (e.g. Kimura and Ludden, 1995; Matsumura et al., 2003). The Nankai Trough has lateral variation of prism taper angle which may induce different condition of basal friction on the décollement (Kimura et al., 2007a). To evaluate these hypotheses, we need to constrain stress, strain and strength variation in the accretionary prism. Recent observations of very low frequency (VLF) earthquake swarms in accretionary prisms near Kii Peninsula (Obara and Ito, 2005) reflect a poorly known dynamic process of the accretionary prisms. Those small events occur, interestingly, between the updip limit of the seismogenic zone and trench, which indicate that the shallow accretionary prism is still active during the interseismic period. However, structural studies on the evolution of shallow accretionary prism have mainly focused on in relation to long term tectonics but not to plate boundary earthquake or even VLF events. Further knowledge about the strain/stress condition in the shallow accretionary prism is necessary for us to understand the variation of such plate boundary processes. Here we performed anisotropy of magnetic susceptibility (AMS) analysis to evaluate the strain recorded in the prism toe material and to reveal the strain variation at initial deformation stage, which allow us to discuss strength variation. AMS is used as a strain indicator and is a unique technique especially for the rocks without any other strain marker or for limited volume of samples.

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Measurement of AMS provides a rapid and precise description of the average preferred mineral orientation (fabric) of a rock. Ever since the pioneering work by Graham over 50 years ago (Graham, 1953), numerous studies have shown that AMS is a powerful petrofabric tool and can be related to mineral and tectonic fabrics in the analysis of structural geology (e.g., Stacey, 1960; Khan, 1962; Kligfield et al., 1983; Knight and Walker, 1988; Jackson and Tauxe, 1991; Rochette et al., 1991; Tarling and Hrouda, 1993; Borradaile and Henry, 1997; Kanamatsu et al., 2001; Housen and Kanamatsu, 2003). For magnetite, AMS primarily defines grain-shape anisotropy; for other minerals, AMS expresses crystallographic control on magnetic properties. Thus, the orientation-distribution of a dominant mineral from the AMS of a rock can be inferred. AMS principal directions can record current directions from sediment, flow-directions from magma, finite-strain directions from tectonized rocks and stress-directions from low-strain, low-temperature, neotectonic environments. In particular, AMS fabric seems to be a reliable strain indicator in geological settings where conventional strain markers are scarce or absent at the outcrop scale (e.g., Kissel et al., 1986; Pares et al., 1999; Cifelli et al., 2004). Several studies have also pointed out that AMS method is unique to investigate subtle tectonic related fabrics in clay sedimentary rocks at the early stages of deformation (Mattei et al., 1997). This method has successfully performed to provide strain information in various types of accretionary prism material; e.g. ocean drilling (Owens, 1993; Housen et al., 1996; Housen and Kanamatsu, 2003; Ujiie et al., 2003), ancient accretionary prisms (Kanamatsu et al., 1996; Kanamatsu et al., 2001; Yamamoto, 2006) and even highly deformed plate boundary rocks (Ujiie et al., 2000; Kitamura et al., 2005). In this paper, we present initial results of an AMS study of samples from the accretionary prism toe taken during Expedition 316.

## 2. Geological overview of Expedition 316

During Expedition 316, cores were collected from four sites along a transect lying almost perpendicular to the Nankai Trough offshore of Kii Peninsula, central Japan (Figs. 1 and 2) (Kinoshita et al., 2009). Here the Philippine Sea plate is being subducted beneath the Eurasian continental plate, with a convergent rate of ~4 cm/yr (Seno et al., 1993). Drilling was focused on two regions, the shallow part of the megasplay fault (Sites C0004 and C0008) and the frontal thrust (Sites C0006 and C0007). We highlight the latter region in this paper.

Site C0006 targeted the main frontal thrust at the prism toe. However, coring was terminated at 603 m core depth below seafloor (CSF) before the frontal thrust (885.5 m LWD (Logging While Drilling) depth below seafloor) was reached. Lithologic Unit I (0–27.23 m CSF) is Pleistocene in age and consists of a fining-upward succession of silty clay, sand, silty sand, and rare volcanic ash layers (Fig. 3). Dominant lithology is greenish gray silty clay. A 1.25 m thick layer of volcanic ash with abundant pumice fragments occurs near the base of the unit, while most of the ash layers forms less than 10 cm throughout the site. Lithologic Unit II (27.23–449.67 m CSF) is also Pleistocene, with an age gap from Lithologic Unit I, and is interpreted as having been deposited in a trench setting. Lithologic Unit II contains thick sand beds (~1–7 m thick) grading into silt in Subunit IIA. Lower Subunits IIC and IID are composed of less coarse material. Silty clay-dominant Lithologic Unit III is similar to the Upper Shikoku Basin facies documented at Ocean Drilling Program (ODP) Sites 1173 and 1174. A series of thrusts are observed in these cores (Fig. 3). Ash layers rarely occur in Unit IIC and above, but are relatively abundant in Unit IID. Unit III contains interbedded volcanic tuff layers in dominant silty clay, as expected in the Upper Shikoku Basin which is formed by hemipelagic setting along with accumulation of volcanic ash during major volcanic eruptions.

Site C0007 was aimed at recovering the frontal thrust that was not recovered in Site C0006. Lithology of Site C0007 is basically comparable to that of Site C0006. Lithologic Unit I (0–33.94 m CSF) consists mainly of hemipelagic silty clay and slump-related disaggregated or chaotically mixed bedding (Fig. 4). Lithologic Unit II consists of a repetition of coarser and finer grained subunits, which is interpreted as being due to either thrust faulting or switching of the position of the trench channel. Pliocene hemipelagic sediments in Lithologic Unit III are similar to those in Site C0006, and resemble the Shikoku Basin facies sampled during ODP Legs 131 and 190 (Taira et al., 1991; Moore et al., 2001). Lithologic Unit IV is possibly Pleistocene in age, however, unconsolidated sand suggested by drilling monitoring caused very incomplete recovery. Three major fault zones were observed in Site C0007 (Fig. 4) and the lowermost one (399–446 m CSF) is considered to be the frontal thrust.

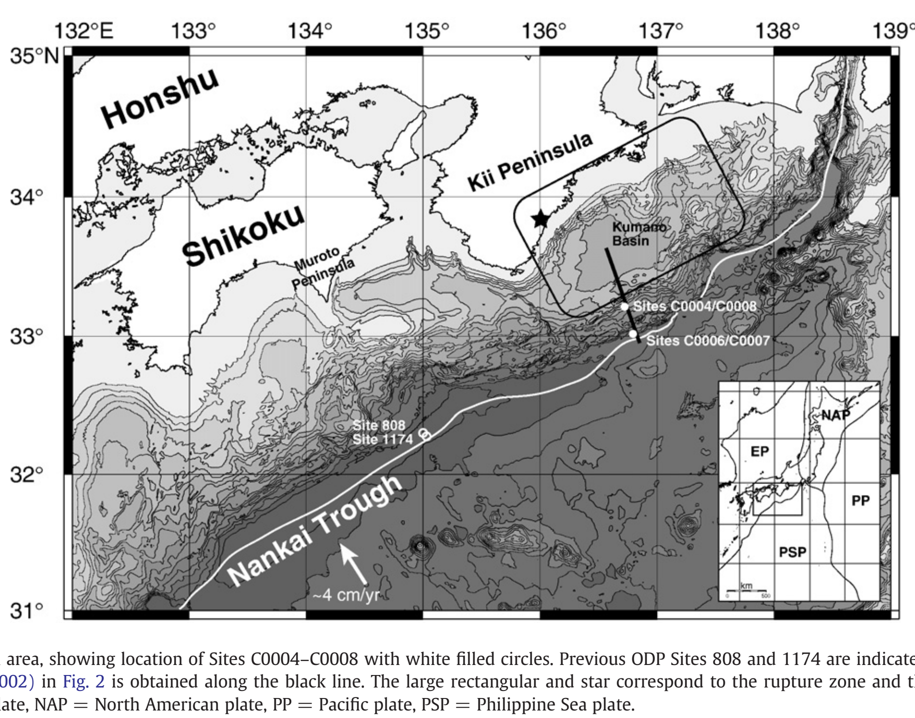


**Fig. 1.** Map of Nankai Trough area, showing location of Sites C0004–C0008 with white filled circles. Previous ODP Sites 808 and 1174 are indicated with opened circles. Seismic reflection from Park et al. (2002) in Fig. 2 is obtained along the black line. The large rectangular and star correspond to the rupture zone and the epicenter of 1944 Tonankai earthquake. EP = Eurasian plate, NAP = North American plate, PP = Pacific plate, PSP = Philippine Sea plate.