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# Frictional behavior and its seismological implications within thrusts in the shallow portion of an accretionary prism

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ABSTRACT

The Emi Group in the Boso accretionary complex is reported to have experienced a relatively shallow burial depth, approximately 1–4 km below the sea floor at low temperature (50–75 °C), indicating that the group passed through or around the upper portion of the seismogenic zone. Two representative thrusts in the group were recognized as products of deformations in the setting. Frictional experiments using the powder samples from the fault zones showed the frictional behavior of velocity hardening under the wet condition with 20 MPa and 40 MPa normal stresses. Microstructures within the thrusts exhibited pervasive deformation with composite planer fabrics. This results that the shallow portion of the thrust at the base of the accretionary prism is aseismic with stable sliding.

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## 1. Introduction

The great earthquakes occur frequently along subduction zone thrust faults such as the Nankai Trough, the Japan Trench, and the Sumatra Fault. Subduction plate boundaries are seismic to a limited depth range and can be divided into three main zones: a shallow aseismic updip zone, the seismogenic zone, and a deep downdip aseismic zone (e.g., Hyndman et al., 1997). The aseismic updip limit of the seismogenic zone is of particular importance in tsunami generation (e.g., Park et al., 2000). The coseismic slip distribution of the 1946 Nankai earthquake was estimated using tsunami and geodetic data (e.g., Ando, 1982; Satake, 1993). Park et al. (2000, 2002) considered that the out-of-sequence thrusts (splay faults) were related to the large interplate earthquake that occurred in the Tonankai region in 1944, and suggested that the thrusts could be responsible for tsunami generation. However, few studies have investigated the relationship between such possible thrusts and shallow coseismic slip for the purpose of better understanding slip behavior.

Earthquakes are thought to result from stick-slip frictional instability on existing faults (e.g., Scholz, 1998; Kanamori and Brodksy, 2001), and frictional properties of the materials at the interface largely control their behavior. Laboratory experiments have shown that seismogenic, or unstable, stick-slip behavior is linked to slip localization and velocity-weakening frictional behavior, whereas aseismic, or stably sliding, behavior is linked to distributed shear and velocity-strengthening frictional behavior (e.g., Dieterich, 1978; Ruina, 1983; Sammis and Biegel, 1989; Tullis, 1996; Marone, 1998; Scholz, 1998).

It is important to elucidate the frictional behavior of thrusts in the shallow portion of accretionary prism, because the trusts would probably generate tsunami. Therefore, we investigated the major thrusts developed in the Emi Group, one unit of the Boso accretionary wedge, which experienced at or around the shallow portion of the seismogenic zone. We also characterized the fabrics and textures of the deformation structures and performed laboratory-based experiments on the frictional behavior of materials in two typical thrusts.

## 2. Geology and tectonic setting of the Emi Group

### 2.1. Stratigraphy and sedimentary structures

The Emi Group, stratigraphically defined by Kawai (1957), is distributed in the coastal line south of the Mineoka Belt in the Boso Peninsula, Japan (Fig. 1). This group is composed dominantly of fine to

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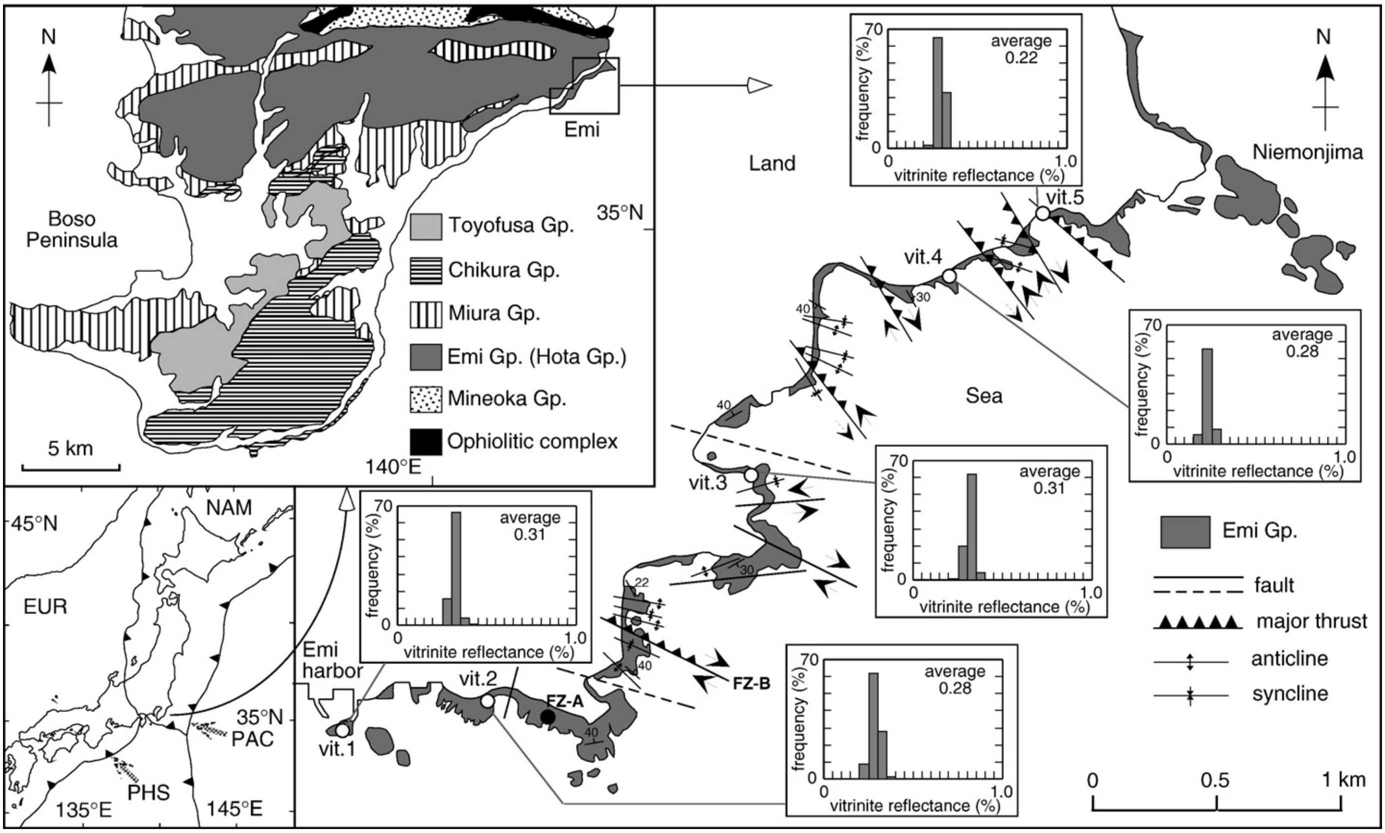


**Fig. 1.** Index map, simplified structural map, and lithologic map of the Emi Group, Boso Peninsula, Japan, with data of vitrinite reflectance. Plate; EUR-Eurasian, NAM-North American, PHS Philippine Sea, PAC-Pacific. vit; sampling point of vitrinite. Modified from Hirono (2005).

coarse acidic tuffaceous clastic sedimentary rocks interlayered with tuff layers (Ogawa and Ishimaru, 1991). The age of the sediments ranges from late Oligocene to middle Miocene (Sawamura and Nakajima, 1980; Suzuki et al., 1996). The clastic sediments are mostly turbidites and are thought to be entirely derived from the volcanic Izu island arc (Ogawa and Ishimaru, 1991). The sandy parts are largely liquefied and form dish structures, injections, and web structures. The sediments are porous and their grain contacts show face-to-face or face-to-ridge. Furthermore, early structures such as flame structure and convolute laminations, comprising "soft-sediment deformation" (Maltman, 1984), are well preserved.

### 2.2. Deformation structures

Strata of the Emi Group are disrupted by various stages of faulting into broken formations. Hirono (2005) identified six stages in the deformation history of the Emi Group based on superimposition relationships and different deformation styles. The early stage deformations are mainly characterized by layer-parallel faults and conjugate sets of thrusts accompanying liquefaction and fluidization, owing to layer-parallel compression. The microscopic deformation mechanism has been identified as independent particulate flow of Knipe's definition (Knipe, 1986), characterized by non-deformed grains, dimensional preferred orientations of sand grains parallel to seams, and fragmentation of carbonate cements within the pores (Hirono, 2005). The later stage deformations are also by thrusting, strike-slip faulting, or folding due to horizontal compression. Faulting at the latest stage appears as thrusts on the geological map (Fig. 1). The microscopic deformation mechanism of these stages is identified as cataclastic flow of Knipe's definition (Knipe, 1986), characterized by cataclasis of sand grains and fragmentation of carbonate cements (Hirono, 2005).

### 2.3. Experienced maximum temperature

The thermal maturity of organic matter is a useful indicator for understanding thermal history in low-temperature regimes (e.g., Middleton, 1982; Laughland and Underwood, 1993). Hirono (2005) collected some samples of organic matter from sandstone layers in the Emi Group, measured the vitrinite reflectance, and revealed that the maximum paleo-temperature ranged approximately from 50 °C to 75 °C. The representative data of the vitrinite reflectance, from Hirono (2005), are shown in Fig. 1.

Assuming the paleo-geothermal gradient is 20–50 °C/km, similar to the present value based on the heat flow (50–120 mW $m^{-2}$) in the Nankai trough (Ashi and Taira, 1993; Ashi et al., 2002), the maximum burial depth of the Emi Group obtains around 1–4 km, suggesting that the deformation occurred at such a shallow level.

### 2.4. Estimation of confining stress

We here estimate the confining stress from data of the burial depth.

$$\sigma'_v = \sigma_v - P_f \tag{1}$$

where $\sigma'_v$ is the effective vertical stress, $\sigma_v$ is the vertical stress, and $P_f$ is the pore fluid pressure.

$$\sigma_v = \rho_w g z_w + \rho_s g z_s \tag{2}$$

where $\rho_w$ and $\rho_s$ are the densities of seawater and sediment, respectively, $g$ is the gravitational acceleration, $z_w$ is the seawater depth, and $z_s$ is the sediment depth below sea floor. If the pore fluid pressure within strata is under hydrostatic condition, it, $P_{f\text{-Hydro}}$, is expressed as

$$P_{f-\mathrm{Hydro}} = \rho_w g (z_w + z_s) \tag{3}$$

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