Tectonophysics 568–569 (2012) 39–52

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Dynamic role of tectonic mélange during interseismic process of plate boundary mega earthquakes

Yujin Kitamura [a,*], Gaku Kimura [b,c]

[a] Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan
[b] Department of Earth and Planetary Science, Faculty of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
[c] Institute for Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Kanagawa 236-0001, Japan

ARTICLE INFO

Article history:
Received 15 February 2011
Received in revised form 30 June 2011
Accepted 12 July 2011
Available online 23 July 2011

Keywords:
Tectonic mélange formation process
Accretionary prism
Shimanto Belt
Seismogenic zone
Nankai Trough
Slow earthquake

ABSTRACT

Tectonic mélange has a key role in subduction zones because its thick pile forms the plate boundary itself; therefore, the plate boundary process is nearly identical to the mélange-forming process. We examined three tectonic mélanges in the Shimanto Belt in southwest Japan to decipher their progressive deformation process with subduction, especially within the seismogenic zone. Here we report detailed observation of sandstone blocks and the strain history of the shale matrix of a sediment-dominated tectonic mélange. The necessity of tectonic mélange accompanying fossil seismogenic décollement is unveiled. Several deformation processes continue by turn until the depth of the down-dip limit of the seismogenic zone is reached. The results support the space–time partition of deformation in terms of seismic behavior and suggest a possible candidate for a geological consequence of recently observed slow earthquakes.

1. Introduction

Is tectonic mélange a passive product of plate convergence? This question arises because recent research has enabled us to reestablish a framework of subduction process in more detailed point of view. In this sense, we focused on the formation process of tectonic mélanges and consider an active and dynamic role for them.

In the earliest days of plate tectonic theory, mélanges were thought to be fossil rocks of the “Wadati–Benioff zone” (Ernst, 1970). After many reports on mélanges involving thorough observation, they were classified based on their origin: tectonic, sedimentary and diapiric (Cowan, 1985; Raymond, 1983). A thick pile of tectonic mélanges has been interpreted as a plate boundary rock because it is a fault-related chaotic rock with strain hardening of the underthrusted sediments that is associated with peeled oceanic crust (Kimura and Ludden, 1995; Moore and Silver, 1987).

Seismic records have revealed that the seismic events in a subduction zone can be classified into several different portions and depths (Byrne et al., 1988; Hasegawa et al., 1978; Isacks et al., 1968; Yoshii, 1979). The shallowest portion of a seismic event, which coincides with the plate boundary between the underthrusting lower oceanic plate and the upper plate, is characterized by the thrust-type focal mechanisms of an earthquake. This portion is currently called the seismogenic zone (Byrne et al., 1988). The key hypotheses to explain the catastrophic faulting at the updip limit of the seismogenic zone are as follows: a change in the thermal condition (e.g. Hyndman and Wang, 1993) and a 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). A pore fluid-induced process such as the fault-valve or seismic pumping hypothesis (Sibson, 1975) may also be an important mechanism in the seismogenic behavior of plate boundary faults. Seismic reflection studies that have high amplitude negative polarity reflectors may indicate a low-velocity zone beneath the plate boundary reflector, possibly suggesting high fluid pressure (Park et al., 2000, 2002b).

From the on-land studies, it can be inferred that the deformation mechanisms that contribute to mélange formation include independent particulate flow, shallow cataclasis, and pressure solution creep with micro-Riedel shear and plastic flow (e.g. Byrne, 1979; Hashimoto and Kimura, 1999; Kimura and Mukai, 1991; Onishi and Kimura, 1995; Onishi et al., 2001; Ujiie, 2002; Ujiie et al., 2000). The ductile behavior of the tectonic mélanges during their formation process has been well studied with good examples of the flow mélange model (Cloos, 1982) or heterogeneous rheology model (Fagereng and Sibson, 2010). All these studies suggest the presence of some relationship between mélange formation and the seismic process; however, no direct evidence has been demonstrated for a long time. The finding of a pseudotachylyte in a tectonic mélange in an accretionary subduction zone in the Shimanto Belt (Ikesawa et al., 2003) prompted further study on the mechanism of

---

* Corresponding author. Tel.: +81 46 867 9748; fax: +81 867 9315.
E-mail address: ykitamura@jamstec.go.jp (Y. Kitamura).

0040-1951/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.tecto.2011.07.008

the fast slip. Since the previous studies on mélange formation have concerned only slow processes, a new model that integrates all the static and dynamic processes is awaited. The space–time relationships among these deformation mechanisms are quite important for understanding the onset of seismogenesis in subduction zones.

The tectonic mélange intrinsically consists of competent blocks in an incompetent matrix: in our studied area, they are sandstone blocks in a shale matrix. The physical properties of sandstone have been well studied (e.g. Bryant et al., 1974; Hoshino et al., 2001; Nafe and Drake, 1957). Deformation studies of porous rocks (e.g. Edmond and Paterson, 1972; Jones, 1980; Zhang et al., 1990) indicate that the porosity is an important parameter in affecting the micromechanical process of the brittle–ductile transition. The mechanics of the accretionary wedge (e.g. Davis et al., 1983; Zhao et al., 1986) are strongly affected by the strength, which is controlled by the porosity of sedimentary rocks. Regarding the deformation of underthrusting sediments, sandstone is believed to have a limited role, because it is thought that lithification by cementation in the early stage makes sandstone rigid and relatively strong, so that deformation concentrates in the weaker shaley matrix with pressure solution creep (e.g. Kawabata et al., 2007, 2009). Previous studies of sandstone in the ancient accretionary prism emphasized their shallow deformation (Byrne, 1984; Cowan, 1982; Hashimoto et al., 2006). Our target is the much deeper deformation that occurs in the subduction zone corresponding to the depth of the seismogenic zone.

To examine the relationship between deformation and the seismogenic process, we investigated three tectonic mélanges in the Shimanto Belt which are buried down to the depths of the upper, middle and lower seismogenic zones at their maximum. Comparing the different mélanges allows us to isolate progressive deformation within the seismogenic zone. Here we describe the deformation styles of the sandstone blocks and the shale matrix in the tectonic mélanges in detail and discuss the dynamic plate boundary process in relation to mega seismogenesis.

2. Geological settings

The Shimanto Belt is an ancient accretionary complex that lies along the Pacific coast of southwest Japan. It runs over 1500 km from the Kanto District through the Kii Peninsula, Shikoku and Kyushu to the Ryukyu Islands, and it parallels the axes of the Nankai Trough and the Ryukyu Trench (Fig. 1). The Shimanto Belt is subdivided into the Cretaceous Northern Belt and the Paleogene and Neogene Southern Belt, while the Kula, Pacific and Philippine Sea Plates were subducted beneath the Amurian (Eurasian) Plate in each age, respectively (Isozaki, 1996). Each sub-belt is composed of several formations of coherent units and mélange units. Most of the mélanges in the Shimanto Belt are tectonic, although there are minor sedimentary and diapiric ones. Those tectonic mélanges have systematic deformation fabrics throughout the pile that

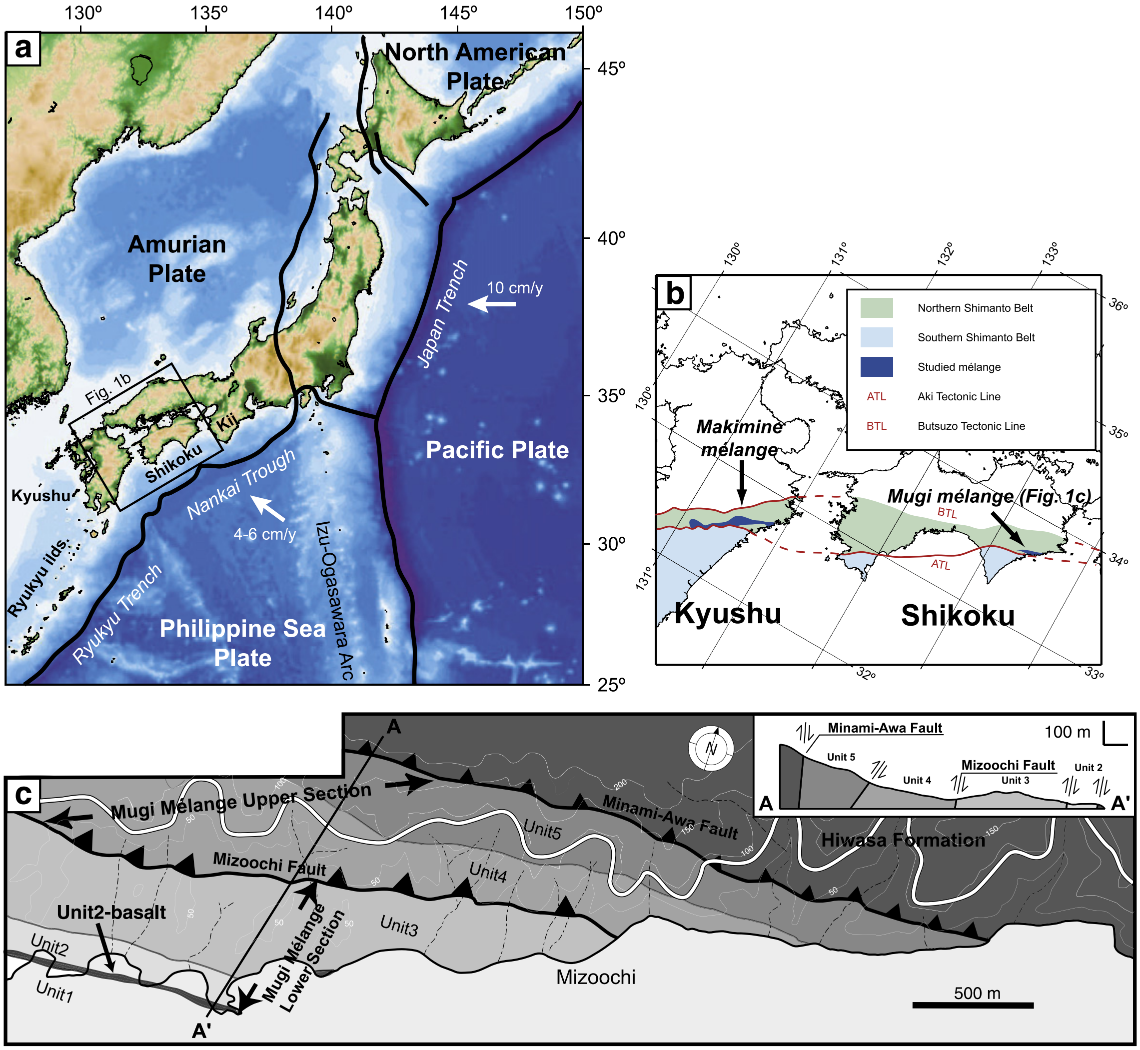

Fig. 1. (a) Tectonic setting around southwest Japan. (b) Geological map of the Shimanto Belt. (c) Tectonic map of the Mugi Mélange. The lower Mugi mélange consists of two thrust sheets: Units 1 to 3 and the upper section of Units 4 and 5. The upper boundary fault (roof fault) is called Minami–Awa fault, and the bounding fault between the upper and lower sections is the out-of-sequence thrust, Mizoochi fault.