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Geometry and lithofacies of coarse-grained injectites and extrudites in a late Pliocene trench-slope basin on the southern Boso Peninsula, Japan

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ABSTRACT

This study investigates the geometry and internal structures of coarse- to very coarse-grained volcanic sandstones and volcanic breccias with many siltstone clasts (interpreted to be sill-like injectites and extrudites) occurring in an upper Pliocene trench-slope basin succession on the southern Boso Peninsula, Japan. The injectites occur in the uppermost Shiramazu Formation, and pinch out laterally into siltstone-dominated deposits of the Mera Formation. Their thicknesses vary from a few centimeters to ~2 m. The basal and upper contacts of the injectites with host muddy deposits are sharp and/or erosional, and are locally discordant with the bedding of the host deposits. Siltstone clasts, which were ripped up or ripped down from the host muddy deposits, are commonly incorporated into the injectites, although some siltstone clasts have geological ages older than those of the host deposits. Seven lithofacies have been identified in the injectites based on the internal structures. The combinations of internal structures are different from those of high-density turbidity current deposits and debrites, and suggest that injection was promoted by a combination of turbulent and laminar flow conditions.

The extrudites show an overall convex-up geometry and possess lithological features similar to those of the injectites. They have been identified in the Rendaiji Conglomerate Member, which is encased in the Mera Formation, and which rests on the uppermost Shiramazu Formation. The extrudites are characterized by gently undulating waveforms that show upstream migration and climbing stacking patterns similar to the cross-sectional geometry of cyclic steps or upstream-migrating antidunes. The active eruption of solid–liquid mixtures onto the seafloor and sedimentary piles may have subsequently collapsed to produce supercritical high-density gravity currents down the flanks of a neptunian volcano.

The injectites and extrudites locally contain *Calyptogena* shells and shell fragments, as well as fragments of carbonate concretions that exhibit low carbon isotopic ratios, suggesting that fluidization of the source sediments was triggered by a combination of seepage of cold methane-bearing water into the source sediments and seismic shaking. Volcaniclastic deposits older than the host muddy deposits are present in the trench-slope basin deposits and these are the likely source of the injectites and extrudites.

1. Introduction

Injectites and extrudites are clastic deposits that form in response to soft-sediment deformation processes, when fluidized sediments intrude the host sediments as dikes, sills, and/or pipes (i.e., injectites), or are extruded onto the seafloor as neptunian volcanoes (i.e., extrudites) (Hurst et al., 2006, 2011). Injectites vary from a few millimeters to kilometers in thickness and length. They can be identified in cores and at outcrop scales, as well as in seismic imaging data; locally they show conical and saucer-shaped geometries with wings (Duranti, 2007; Hurst and Cartwright, 2007; Vigorito et al., 2008; Cartwright, 2010; Jackson et al., 2011). Injectites are commonly represented by fine- to medium-grained sandstones, although some injectites consist of much coarser grained sediments (Hubbard et al., 2007; Hurst and Cartwright, 2007; Hurst et al., 2011; Ross et al., 2014). They have recently received considerable attention as hydrocarbon reservoirs and as potential breaches of hydrocarbon seals (Lonergan et al., 2000; Hurst et al., 2003, 2011; Huuse et al., 2007; Cartwright, 2010). Consequently, the identification of injectites in stratigraphic successions, in particular those that form in deep-water environments and that are characterized by mudstones interbedded with various types of sediment-gravity-flow deposits, is critical for improving the predictability of the architecture, properties, connectivity, and volumes of reservoir rocks (e.g., Hiscott, 1979; Lonergan et al., 2000). Various types of internal structures within injectites, in particular those within sandstone injectites, have been documented, and some erosional and depositional structures of injectites have been used for estimating flow processes, such as laminar versus turbulent flow and the flow velocities responsible for sand injection (Dott, 1966; Peterson, 1968; Kawakami

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and Kawamura, 2002; Duranti and Hurst, 2004; Scott et al., 2009; Hurst et al., 2011; Ross et al., 2014; Cobain et al., 2015). Although erosional and depositional structures of coarse-grained injectites have been investigated to examine flow processes occurring during injection (Hubbard et al., 2007; Ross et al., 2014), detailed descriptions and interpretations of the geometries and internal structures of coarse-grained injectites remain limited as compared with those of sandstone injectites. Detailed descriptions and interpretations of lithofacies features and the geometry of coarse-grained injectites and extrudites likely provide criteria for the appropriate identification of injectites and extrudites in coarse-grained deep-water sedimentary successions.

Here, we describe the geometries and lithofacies features of coarse-grained injectites and extrudites intercalated in a deep-water succession deposited in a trench-slope basin in the Sagami Trough, which developed in response to northward subduction of the Philippine Sea plate beneath the central part of the Japanese Islands at ca. 3 Ma (Figs. 1, 2, and 3). In particular, the present study clarifies similarities and differences in the geometries and internal structures of coarse-grained injectites and extrudites, as compared with those of sediment-gravity-flow deposits, and examines flow processes involved in injection and extrusion of coarse-grained sediments in a convergent margin setting. We present detailed observations on the geometries and lithofacies organization of injectites in the uppermost part of the Shiramazu Formation and of extrudites in the Rendaiji Conglomerate Member on the southern Boso Peninsula, central Japan (Figs. 2 and 3).

2. Geological setting

The present study focuses on coarse-grained sediments intercalated in deep-water muddy deposits of the Shiramazu and Mera formations, which occur in the lower part of the Chikura Group on the southern part of the Boso Peninsula (Figs. 3 and 4A, B). On the basis of structural settings, sediment types, and paleowater depths, the formations are interpreted to have been deposited on the landward slope of a shallow trench (the Sagami Trough) at 3.1–2.8 Ma (Kotake, 1988; Kotake et al., 1995; Kawakami and Shishikura, 2006; Okada et al., 2012). The deep-water successions in the Shiramazu and Mera formations were deposited at paleowater depths of up to 2000 m, and in a basin with an average subsidence rate estimated at ~0.8 m/1000 yr. (Kotake, 1988) (Fig. 3). The two formations had been formerly defined as the Hata Formation and its southern part was redefined as these two formations. The Shiramazu Formation consists of siltstones interbedded with sandstones, tephras, and coarse- to very coarse-grained volcanic sandstones and volcanic breccias, while the Mera Formation consists predominantly of siltstones with local intercalations of very thin- to thin-bedded tephras and sandstones (Kotake, 1988) (Fig. 4A, B). Locally, the siltstone-dominated Mera Formation is intercalated with volcanic sandstones and volcanic breccias that contain abundant siltstone clasts, which are assigned to the Rendaiji Conglomerate Member. This member exhibits a convex-up geometry and is underlain by the uppermost part of the Shiramazu Formation (Fig. 2).

The lower part of the Shiramazu Formation consists of interbedded siltstones and sandstones that exhibit a locally developed anticlinal structure; the formation is characterized by intercalated coarse- to very coarse-grained volcanic sandstones and volcanic breccias that contain numerous siltstone clasts and articulated and fragmented *Calyptogena* shells (Majima et al., 1992) (Fig. 4C, D). These intercalated coarse-grained deposits show discordant and/or irregular contacts with host sediments; some calcareous nannofossils from siltstone clasts indicate an age of 4.8–3.8 Ma, which is older than that of the host

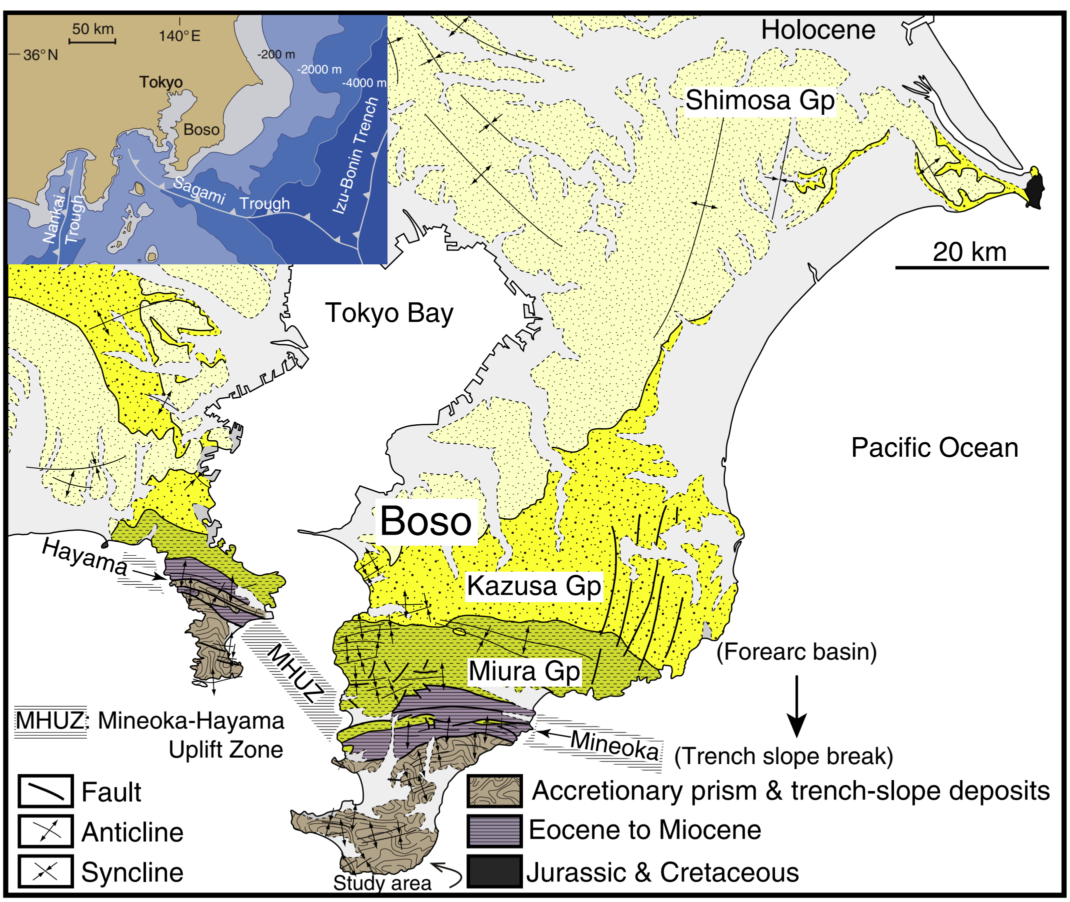

Fig. 1. Geological sketch map of the Boso Peninsula, Japan, and adjacent areas (modified from Ito et al. (2016)). The southern Boso Peninsula consists of accretionary prism and trench-slope deposits. Inset map shows a modern plate-tectonic framework of the Boso Peninsula and adjacent areas (after Fukuda et al. (2015)).