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A 4500-year record of emergence events at Onnetoh, Hokkaido, northern Japan, reconstructed using plant macrofossils

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Abstract

Plant macrofossils (vascular plants and mosses) document six episodic emergence events during the late Holocene at Onnetoh, eastern Hokkaido, northern Japan. Four events were dated by the AMS radiocarbon method to 4240–3910, 3640–3360, 1520–1260, and 790–660 cal year BP, and another was dated by liquid scintillation spectrometry of radiocarbon to 2750–2430 cal year BP. We attribute the three most recent and the two oldest periods of emergence events identified in this study to uplift associated with unusually large interplate earthquakes along the southwestern part of the Kuril subduction zone.

Keywords: plant macrofossils; emergence events; Holocene; earthquake; Hokkaido; Kuril subduction zone

1. Introduction

Elastic deformation associated with strain accumulation and stress release near subduction zones can cause episodic emergence and submergence in coastal regions (e.g., Atwater et al., 1995; Long and Shennan, 1994; Nelson et al., 1996). Before an earthquake, the upper continental plate is locked against the seaward edge of the subducting plate. Under these conditions, interseismic stress accumulates, accompanied by downward motion of the upper plate. The accumulated stress released during and after an earthquake is associated with vertical and horizontal elastic deformations of the upper plate. This sequence is repeated and is recorded as cycles of submergence and emergence or of emergence and submergence at low-elevation sites (marshes and lakes) along coasts (Atwater and Hemphill-Haley, 1997; Shennan et al., 1998, 1999). Late Holocene relative sea-level changes along the Pacific coast of eastern Hokkaido have been attributed to such deformation of the convergent margin during interplate earthquake events (Sawai et al., 2004a). Here, we present new data on emergence

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events associated with the Kuril subduction zone, whose history we reconstructed using plant macrofossils from the Onnetoh site, southeastern Hokkaido.

Micro-and macrofossils have been successfully used for evaluating peat-over-mud sedimentary contacts in coastal areas (e.g., Gehrels et al., 2001; Horton et al., 2000; Sawai et al., 2002; Sherrod et al., 2000). Only a few reports on plant macrofossils (vascular plants and mosses), however, have been published (Donnelly et al., 2004; Freund et al., 2004; Sawai et al., 2002; Sherrod et al., 2000), whereas many papers report studies of microfossils (pollen, diatoms, foraminifera, and testate amoebae) (Charman et al., 1998; Gehrels et al., 2002; Hayward et al., 2004; Horton et al., 1999; Hughes et al., 2002; Sawai et al., 2004a; Zong et al., 2003). Salt marsh plants are well known to be sensitive to tidal and salinity levels in coastal environments (e.g., Chapman, 1974; Ito, 1963; MacDonald and Barbour, 1974), but because daily tides and wind can transport detached parts of plants, such as leaves and seeds, from their point of origin, plant macrofossils present a potential problem for coastal environmental reconstruction regarding distinguishing autochthonous and allochthonous components of an assemblage.

This study had two purposes: to further document late Holocene emergence events along the Pacific coast of eastern Hokkaido, where changes have been attributed to uplift related to the Kuril subduction zone, and to present a case study of reconstruction of coastal paleoenvironment on the basis of plant macrofossils.

2. Setting

2.1. Study site

The Onnetoh site is located on the southwestern edge of the Nemuro peninsula. The site is surrounded by Pleistocene marine terraces 30–50 m above sea level, and it is protected from the sea by a narrow entrance (Fig. 1d). The Onnetoh receives freshwater via a river, which flows in from the south. The spring tidal range is 1.2 m, and the neap tidal range is 0.9 m (Maritime Safety Agency, 1998, p. 386). As a result of tidal changes and the inflow of freshwater from the southern river, salinities of the Onnetoh water range from 10 to 20 psu.

2.2. Tectonics

Southeastern Hokkaido rests on a continental plate, beneath which the Pacific plate is being subducted at a rate of 4–6 cm/year (Fig. 1a). Global positioning satellite measurements show that the Pacific coast of Hokkaido is moving rapidly northwestward at a rate of 2–3 cm/year (Le Pichon et al., 1998; Mazzotti et al., 2000; Sawai, 2001a). Recent tide-gauge data from along the coast demonstrate subsidence of 0.8–0.9 cm/year in this region during the last century (Ozawa et al., 1997; Shimazaki, 1974a), suggesting that the coast is presently being deformed by interseismic stresses caused by the locked condition of the Kuril subduction zone (Fig. 1b, Le Pichon et al., 1998; Mazzotti et al., 2000).

2.3. Interplate earthquakes in Kuril subduction zone

Interplate earthquakes in the Kuril subduction zone have multiple modes of rupture; one is usually large earthquakes ($Mw \sim 8.0$) that have recurred approximately every 100 years in the past 200 years, and the other is unusually large earthquakes ($Mw > \sim 8.5$) that have recurred on average about every 500 years during the late Holocene. In the late 1990s, it was thought that plate boundary of which rupture was ~100 km repeatedly broke every ~100 years and that each rupture zones were independent (Hatori, 1971). Such usually large earthquakes caused tsunami waves but they do not leave tsunami deposits on the coast. For example, the tsunami caused by the 2003 Tokachi-oki earthquake (Mw 8.0) ran up in eastern Hokkaido 1–4 m (Tanioka et al., 2004), but 10 days later, rain washed away the onshore tsunami deposits. Nevertheless, extensive tsunami deposits have been identified by various studies along the Pacific coast of eastern Hokkaido (e.g., at Kiritappu, Nanayama, 1998; at Harutori-ko, Nanayama et al., 2003; and at Tokotan-numa, Sawai, 2002) (Fig. 1c). Nanayama et al. (2003) simulated the source of tsunami waves that would leave such deposits and concluded that only an unusually large earthquake with a rupture length of 200–300 km could account for the inundation areas indicated by the tsunami deposits preserved along the coast.