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Historical tsunami and storm deposits during the last five centuries on the Sanriku coast, Japan

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ABSTRACT

Nine event deposits in a small alluvial valley along the Sanriku coast, Japan, were correlated with historical tsunamis and storms that have been recorded in this region since the 15th century. We identified nine sandy layers in 15 geo-slices collected at distances ranging from 140 to 260 m from the coast in a lowland back marsh protected from the sea by a high sandy ridge. Based on their sedimentary characteristics, grain-size distribution, and marine microfossil assemblages, namely *Coccoliths*, these event layers, which were well preserved in their order of deposition, were probably either tsunami or storm deposits. Diatom analysis revealed four stages of paleo-environmental change from tidal marsh to wetland. The uppermost event layer covering the ground surface is probably the deposit from the 2011 Tohoku-Oki tsunami. Ages for other event deposits were radiometrically dated using ^{14}C, ^{137}Cs and ^{210}Pb with Bayesian estimation. The second event layers can be correlated with the 1960 Chilean or 1968 Aomori-Oki earthquake tsunamis. The candidates for the third event layer are the 1947 Catherine and 1948 Ione typhoons as well as the candidates for the second event layer. The fourth and fifth event layers are likely associated with the 1933 and 1896 Sanriku-Oki earthquake tsunamis. Four lower event layers can be correlated with historical tsunamis and storms that occurred during the 15th to 18th centuries, such as the 1611 Sanriku-Oki earthquake tsunami.

1. Introduction

Studies of past tsunami deposits can be used to reconstruct the history, size or mechanism of past earthquakes. For example, the AD 869 Jogan earthquake, a predecessor of the 2011 Tohoku-Oki earthquake, is one of the most studied events in Japan by means of tsunami deposits. The inundation area and coastal deformation are estimated from geological data in both Miyagi and Fukushima prefectures, and the fault parameters were estimated using tsunami numerical simulation (Minoura and Nakaya, 1991; Sawai et al., 2012; Sugawara et al., 2012; Namegaya and Satake, 2014).

Tsunamis generated by modern large earthquakes have provided invaluable opportunities for understanding the characteristics of their deposits. The first modern study was conducted on deposits from the 1960 Chilean tsunami on the Sanriku coast in northeastern Japan (e.g., Kawamura and Mogi, 1961; Kon'no, 1961). Tsunami deposits from the 1993 SW Hokkaido earthquake (Nishimura and Miyaji, 1995; Nanayama et al., 2000) and the 1998 Papua New Guinea earthquake (Gelfenbaum and Jaffe, 2003) also provided opportunities to understand their characteristics. More recently, the 2004 Sumatra and 2011 Tohoku-Oki earthquakes and their associated tsunamis prompted numerous studies in sedimentology (e.g., Moore et al., 2006; Goto et al., 2011; Jaffe et al., 2012; Nakamura et al., 2012), microbiology (e.g., Sawai et al., 2009a), mineralogy (e.g., Jagodziński et al., 2012) and geochemistry (e.g., Chagué-Goff et al., 2012a; Szczuciński et al., 2012). The main sedimentary features of tsunami deposits identified by these studies include laminae, normal and/or inverse grading, erosional basal contacts and mud clasts (e.g., Nishimura and Miyaji, 1995; Moore et al., 2006; Morton et al., 2007; Takashimizu et al., 2012; Fujiwara and Tanigawa, 2014).

Tsunami and storm deposits sometimes have quite similar sedimentary features and the criteria to distinguish a tsunami deposit from a storm deposit are still controversial. Comparative studies of modern tsunami and storm deposits suggest criteria by which to distinguish tsunami deposits from storm deposits (Nanayama et al., 2000; Goff et al., 2004; Tuttle et al., 2004; Morton et al., 2007). For example, Morton et al. (2007) suggested that mud clasts and mud laminae are identified within tsunami deposits, whereas storm deposits are typically composed of numerous parallel laminae, do not contain internal mud laminae, and rarely contain mud clasts. On the other hand, Fujiwara and Tanigawa (2014) reported that parallel lamination is one of the typical sedimentary features of the 2011 tsunami deposit.

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Histories of past tsunamis and storms in the last five hundred years along the Sanriku coast have been well documented in historical literature. Tsunamis are caused by numerous large earthquakes (*M* 7–9) along the Japan Trench, where the Pacific plate subducts beneath northern Honshu at approximately 8 cm/year (Fig. 1a), as well as far-field earthquakes such as those across the Pacific Ocean. Large earthquakes that have generated near-field tsunamis along the Pacific coast of Honshu since the 15th century include the 1454 Tohoku-Oki earthquake (Namegaya and Yata, 2014), the 1611 Sanriku-Oki earthquake, the 1677 and 1763 Aomori-Oki earthquakes, the 1793 Miyagi-Oki earthquake, the 1856 Aomori-Oki earthquake, the 1896 and 1933 Sanriku-Oki earthquakes, the 1968 Aomori-Oki earthquake (Tokachi-Oki named by Japan Meteorological Agency, JMA), and the 2011 Tohoku-Oki earthquake (Table 1a). Documented far-field tsunamis include those from the 1700

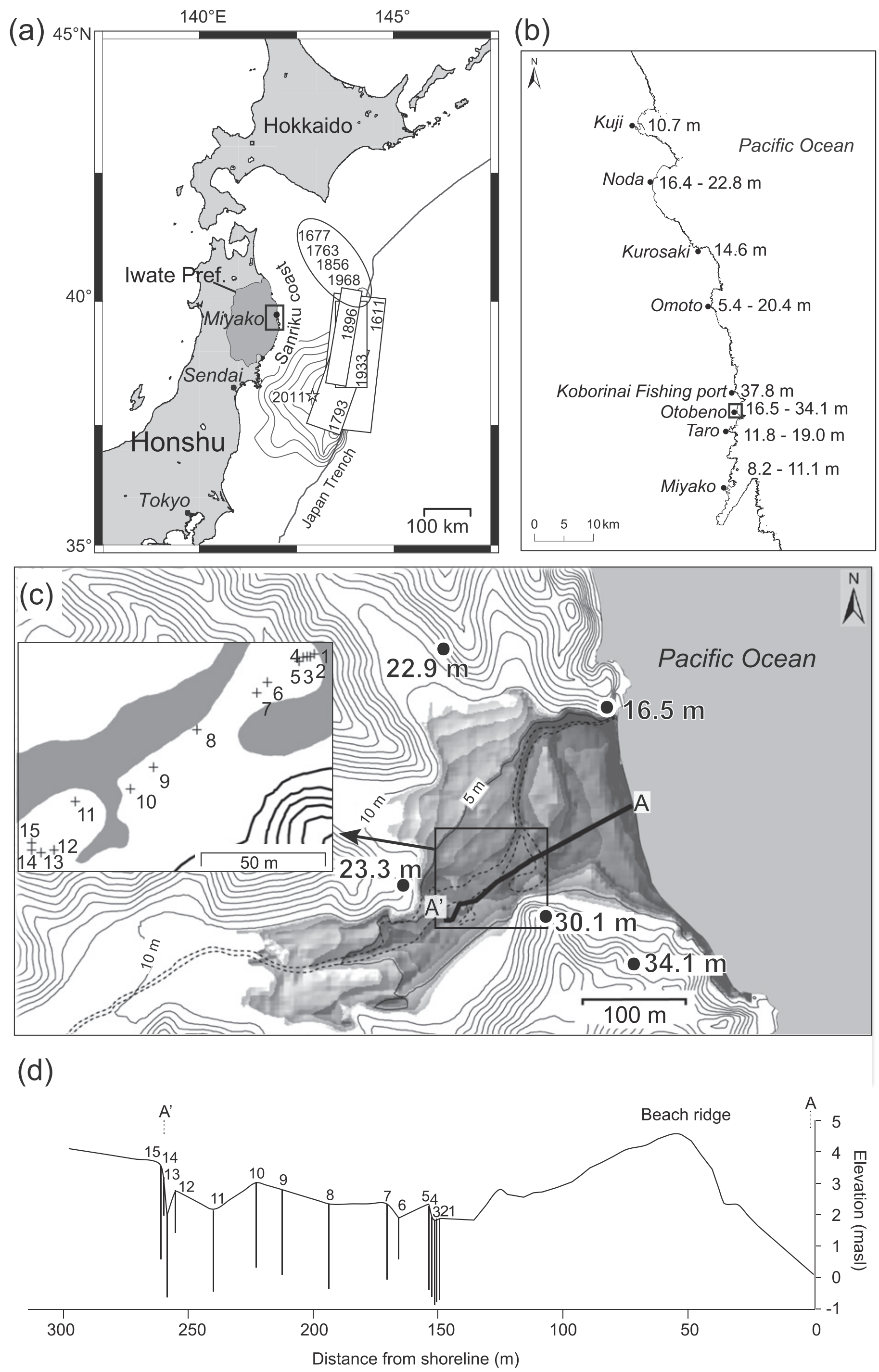

Fig. 1. (a) Map showing the Sanriku coast, Iwate Prefecture and the sources of past major earthquakes after the 15th century along the Japan Trench. Fault models are marked: the 1611 Sanriku-Oki earthquake, the 1677, 1763, 1856 and 1968 Aomori-Oki earthquakes, the 1793 Miyagi-Oki earthquake (Hatori, 1987), the 1896 (Tanioka and Satake, 1996) and 1933 Sanriku-Oki (Kanamori, 1971) earthquakes and the 2011 Tohoku-Oki earthquake (Satake et al., 2013). The contour interval of the 2011 Tohoku-Oki earthquake slip is 4 m. (b) Coastal area in Iwate prefecture. Numbers indicate the run-up heights of the 2011 Tohoku-Oki tsunami (Tsuji et al., 2011, 2014). The black rectangle indicates the location of the survey site shown in (c). (c) Topographic map of Numanohama Marsh. The transect (A-A′) is approximately perpendicular to the present-day coastline. The inset shows the locations along the transect at which geo-slice samples were collected using a geo-slicer. (d) Topographic cross section of line A-A′ in (c).