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Diatom assemblages within tsunami deposit from the 2011 Tohoku-oki earthquake along the Misawa coast, Aomori Prefecture, northern Japan

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ABSTRACT

This paper reports variations in the diatom assemblages within the deposit from the 2011 Tohoku-oki tsunami along the Misawa coast, Aomori Prefecture, northern Japan. The landward extent of the tsunami deposit was as much as 400 m inland. The deposit contained mixed assemblages of marine-brackish and freshwater diatoms. The mixed assemblages indicated that the tsunami deposit was composed of not only beach and dune sand but also soil from the coastal forest. Marine-brackish species were predominant in the seaward tsunami deposit. However, the relative abundance of marine-brackish species rapidly decreased in the samples about 150 to 250 m inland from the shoreline. A decrease in marine-brackish diatoms at inland locations suggests that the eroded terrestrial soil was incorporated into the tsunami deposit. The composition of marine-brackish species in the tsunami deposit was different from that of modern inter- to supra- tidal sediments. One possible interpretation for this discrepancy is that the 2011 tsunami deposit were sourced from multiple environments, including supra-, inter- and sub- tidal locations.

1. Introduction

A great earthquake (Mw 9.0) occurred off the Pacific coast of the Tohoku region of Japan on March 11, 2011. The 2011 Tohoku-oki earthquake generated a devastating tsunami that struck areas along the northeast coast of Japan. Along the Pacific coast of the Aomori Prefecture in northern Japan, the tsunami inundated the coastline up to elevations of 14 m (The 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group, 2011) and left deposits. The characteristics of the sediments deposited by the tsunami along the coastline of the Aomori Prefecture has been studied (Nakamura et al., 2012; Koiwa et al., 2014). However, the assemblages of the microfossils of organisms such as diatoms and foraminifera within the tsunami deposit have not yet been described. Information gained from microfossil analysis aids in identifying and interpreting paleotsunami deposits.

Diatoms are present in freshwater and marine environments. Because their silicified valves are usually well preserved in coastal deposits, diatom assemblages have often been used to identify the source of anomalous sandy deposits (e.g., Hemphill-Haley, 1996; Hutchinson et al., 2000; Kelsey et al., 2005; Nanayama et al., 2007) and coastal uplift and subsidence associated with subduction zone earthquakes (e.g., Atwater and Hemphill-Haley, 1997; Sawai et al., 2004, 2012a; Shennan and Hamilton, 2006). Many paleotsunami studies that use diatom assemblages have appeared in recent decades (Dura et al., 2016) and references therein. Descriptions of diatom assemblages in modern tsunami deposits have also increased as a result of the occurrence of major tsunamis in recent years (e.g. the 1998 Papua New Guinea tsunami: Dawson, 2007; the 2004 Indian Ocean tsunami: Sawai et al., 2009; the 2010 Chile tsunami: Garrett et al., 2013; the 2011 Tohoku-oki tsunami: Szczuciński et al., 2012; Takashimizu et al., 2012). However, there is a lack of studies that characterize the diatom assemblages contained within modern tsunami deposits. The lack of a modern analogue prevents the proper assessment of older tsunami deposits that are preserved in the geologic record.

Tsunami waves transport allochthonous diatoms inland from all coastal environments that are inundated by the tsunami. The diatom assemblages found in tsunami deposits are therefore a mixture of both planktonic and benthic species from marine, brackish, and freshwater environments (e.g., Tuttle et al., 2004; Dawson, 2007; Kokociński et al., 2009; Sawai et al., 2009; Szczuciński et al., 2012). In addition to providing an indication of the source of the sediments deposited by the tsunami, diatom assemblages in tsunami deposits can provide information about flow conditions based on vertical changes of the diatom assemblages within the tsunami deposit and selective breakage of diatom valves (Sawai et al., 2009). In addition, diatom assemblages have been used to delimit the landward extent of tsunami waves where overt signs of tsunami deposits are lacking (Hemphill-Haley, 1996; Chagué-Goff et al., 2015).

This paper describes diatom assemblages within the tsunami deposit associated with the 2011 Tohoku-oki tsunami along the Misawa coast of

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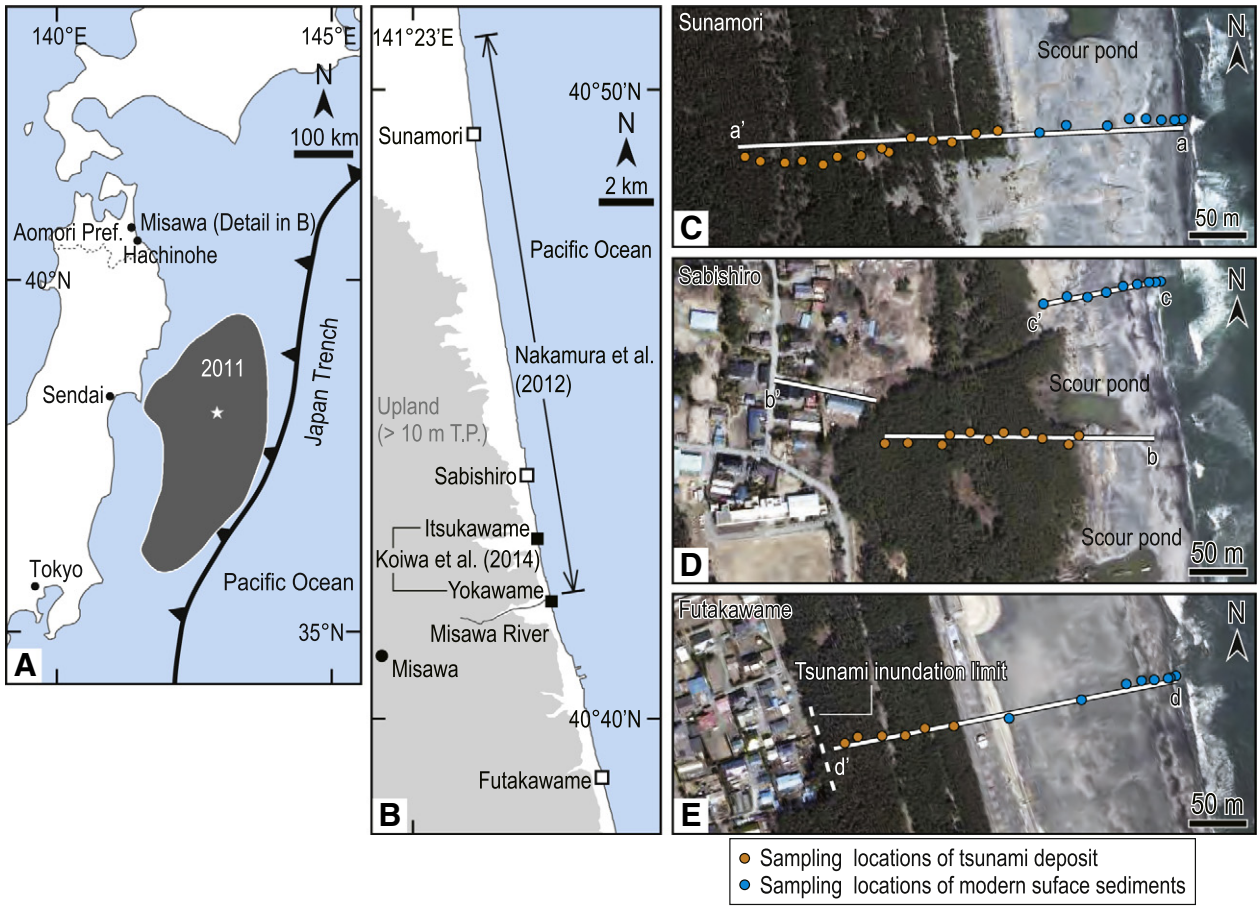

Fig. 1. A: Map of northeastern Japan showing the Misawa study site and the estimated rupture area of the 2011 Tohoku-oki earthquake (Ozawa et al., 2011). B: Locations of the Sunamori, Sabishiro and Futakawame study sites, indicating the locations of studies by Nakamura et al. (2012) and Koiwa et al. (2014). C, D, and E: Aerial photographs of the Sunamori, Sabishiro, and Futakawame sites showing the studied transects. Survey locations are indicated by circles. Orange and blue circles indicate the sampling locations of the tsunami deposit and modern surface sediments, respectively. The tsunami inundation limit indicated in E was inferred from the eyewitness account and the distribution of debris. Aerial photographs were taken by the Geospatial Authority of Japan on 5 April, 2011 (photograph numbers: CTO20111X-C2-10, CTO20111X-C2-19, and CTO20111X-C3-10, respectively). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

northern Japan (Fig. 1). We document the distinctive diatom assemblages and sediment sources of the 2011 tsunami deposit, providing information that will facilitate the identification and interpretation of geological evidence of past tsunamis.

2. Study sites

2.1. Geomorphology and vegetation

The Misawa coastal sites we studied included Sunamori and Sabishiro in Misawa City and Futakawame in Oirase Town, Aomori Prefecture, northern Japan (Fig. 1). The Misawa coast faces the Pacific Ocean and lies roughly along the 141.4°E meridian. The Misawa coastline is ~25 km long and consists of a 50–100-m-wide beach and a 100–300-m-wide coastal forest. The beach is characterized by natural foredunes and artificial dunes roughly 5 m high (Fig. 2A, B). A seawall roughly 6 m high separates the beach and the coastal forest at the Futakawame site (Fig. 2C). According to a local government signboard, the former coastal forest along the Misawa coast was heavily damaged by the tsunami associated with the 1933 Showa-Sanriku earthquake (M 8.1, Utsu, 2004). The modern coastal forest was planted after 1933 and is composed mainly of pine trees. The area landward of the coastal forest is used primarily for residential and agricultural purposes and consists of beach ridges, lowlands, and terraces.

2.2. The 2011 Tohoku-oki tsunami along the Misawa coast

The run-up heights of the 2011 Tohoku-oki tsunami ranged from 3 to 12 m above sea level along the Misawa coast (The 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group, 2011). According to the Port and Airport Research Institute of Japan, the Hachinohe tide station (~16 km south of the Futakawame site, Fig. 1A) recorded three tsunami waves before it was washed out. The second of the waves was the largest. Sequential digital photographs also show three waves, with the second wave being the largest (Koiwa et al., 2014). Aerial photographs and satellite images show that the tsunami waves overran the foredunes and penetrated up to 500 m inland along the Misawa coast (Geospatial Information Authority of Japan, 2011). At the study sites, the tsunami waves destroyed the artificial dunes and formed scour ponds perpendicular to the shoreline (Fig. 1C, D). At the Sabishiro site, the tsunami inundated landward up to the seaward part of the residential area. According to an eyewitness, the tsunami wave did not reach the residential area of the Futakawame site (Fig. 1E).

2.3. Previous study of the 2011 tsunami deposit on the Misawa coast

Two reports have been published concerning the 2011 tsunami deposit on the Misawa coast. Nakamura et al. (2012) documented the tsunami heights and sedimentary features of the tsunami deposit, such as local variations in thickness and grain size, sedimentary structures,