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Reducing the age range of tsunami deposits by ^{14}C dating of rip-up clasts

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ABSTRACT

Erosion by tsunami waves represents an important issue when determining the age of a tsunami deposit, because the age is usually estimated using dating of sediments above and below the deposit. Dating of material within the tsunami deposit, if suitable material is obtainable, can be used to further constrain its age. Eroded sediments are sometimes incorporated within the tsunami deposits as rip-up clasts, which might therefore be used as minimum age dating material. However, the single calibrated ^{14}C age often shows a wide age range because of fluctuations in the calibration curve. Therefore, it remains uncertain whether rip-up clast measurements are useful to constrain the depositional age of tsunami deposits, or not. In this study, we carried out high-resolution ^{14}C dating of tsunami deposits, including rip-up clasts of peat, in Rikuzentakata, northeastern Japan, where numerous rip-up clasts were observed within a tsunami deposit. Sediments above and below the tsunami deposit and a 5 cm large rip-up clast were dated sequentially. Comparison of these dating results with the calibration curve revealed that the clast was inverted. Its age was better constrained based on the stratigraphic order, and we infer that the clast corresponds to approximately 100 years of sedimentation. The oldest age of the clast was consistent with the age of the peat immediately below the tsunami deposit, suggesting that surface sediments probably formed the rip-up clast at the time of the tsunami. Thus, the dating of the rip-up clast was useful to further constrain the depositional age of the tsunami deposit, as we narrowed the tsunami deposit age range by approximately 100 years. Results show that ignoring tsunami-related erosion might lead to overestimation of the tsunami deposit age. For this reason, an appropriate dating site, which is less affected by minor tsunami-related erosion with regards to the paleo-topography, should be explored. We therefore propose a more effective sampling strategy for better age estimation of tsunami deposits.

1. Introduction

Fine grained clasts of soft sediment (e.g., soil, peat) taken from bottom layers have been observed in various sedimentary situations (e.g., Knight, 1999, 2009; Richmond et al., 2012; Ghandour et al., 2013; Ito et al., 2014). High-energy current, bioturbation, and severe climate conditions can break up fine-grained layers to smaller clasts, which can then be transported and deposited as reworked clasts (Allen, 1987; Knight, 2005; Richmond et al., 2012). Although such fine-grained clasts are designated by various terms (Knight, 1999), in tsunami sedimentology, they are usually known as "rip-up clasts" (e.g., Kortekaas and Dawson, 2007; Goff et al., 2012).

Strong shear stress caused by the tsunami wave might erode and transport sediments as rip-up clasts (Richmond et al., 2012). For example, after the 2011 Tohoku-oki tsunami, many researchers described sedimentological and geomorphological features of erosion by the tsunami (e.g., Richmond et al., 2012; Takashimizu et al., 2012; Tappin et al., 2012; Fujiwara and Tanigawa, 2014; Tanaka and Sato, 2015), indicating that severe erosion did not occur uniformly but locally. Tappin et al. (2012) inspected aerial photographs of affected coastal areas before and after the 2011 event, and found that the landward side of an embankment was considerably scoured by accelerated flow and turbulence induced by the overtopping flow. Places where water dropped from great heights such as behind a wave breaker or road were markedly eroded by tsunami flows (Richmond et al., 2012). During and after the erosion, eroded soil was broken up and was sometimes transported as rip-up clasts. Field observations conducted after the 2011 tsunami revealed these rip-up clasts created by erosion of pre-tsunami soil during the run-up phase of the tsunami were transported landward from their initial position (Richmond et al., 2012; Fujiwara and Tanigawa, 2014). Takashimizu et al. (2012) described sedimentary features of the 2011 tsunami deposits along a ~4 km long survey line. Rip-up clasts were observed in lower areas such as behind beach ridges. Considering these facts, rip-up clasts

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seem to have been formed by overtopping flow from the seaside and might have been deposited nearby or in the eroded area.

Erosion due to tsunami flow complicates the dating of paleotsunami deposits because their age is commonly estimated from dating results obtained from sediments above and below the deposit (e.g., Atwater and Moore, 1992; Sawai et al., 2009). If underlying sediments are eroded to a considerable degree, then the age of the sediment beneath the tsunami deposit shows an older age than the actual timing of the tsunami. Sawai et al. (2015) observed a relict scour pond on the Sendai Plain in Japan, which might have been formed due to erosion by a paleotsunami. They found that severe erosion by the tsunami led to sediment beneath the scoured horizon to be markedly older than sediment above it. Because the degree of erosion cannot usually be estimated, the depositional age of the tsunami deposit often shows a large bracketing age range (Goto et al., 2014).

A possible means of correcting erosion effects is to date tsunami-transported material within the tsunami deposit, assuming that this material was initially close to the pre-tsunami surface. As a tsunami deposit comprises reworked allochthonous sediment, dating results obtained using material within the deposit do not necessarily indicate the depositional age (Komatsubara et al., 2006). However, we can use this age as a lower limit age (limiting maximum age; Sawai et al., 2009) if it is younger than the age of the sediment below the deposit. Attempts at dating material within a tsunami deposit have been conducted with shells, corals, and plant fragments (e.g., Bondevik et al., 1997a, 1997b; Clark et al., 2011; Fujino et al., 2014). However, ^{14}C dating results using this material often have large statistical errors because of fluctuations in the calibration curve. U—Th dating of coral can be used, as it is more precise than ^{14}C dating (Fujino et al., 2014; Rixhon et al., in press). However, only limited material (e.g., coral, speleothem) can be used for U—Th dating. Another way to directly date a tsunami deposit is to use the Optically Stimulated Luminescence (OSL) method on sediment grains (e.g., Murari et al., 2007; Tamura et al., 2015). However, there is a possibility of resulting variable ages due to a partial bleaching of grains, and as a result the OSL method has not always been a reliable dating method for coastal sediments (Goff et al., 2012). For these reasons, such techniques remain insufficient to constrain the depositional age of tsunami deposits.

Rip-up clasts might represent a means to better constrain the lower limit age of tsunami deposits because clasts are likely to be composed of the most recent sediments present when the tsunami occurred. Although so far, only a few attempts have been made to measure their age and because of the large statistical errors, these ages were not enough to constrain the tsunami age (e.g., Bondevik et al., 1997a; Goff et al., 2011). Rip-up clasts, if they are sufficiently large, can lead to better dating because sequential dating in the stratigraphic order becomes possible. Sequentially dated results would help to further constrain their age range by the stratigraphic order (Bronk Ramsey, 2008; Ishizawa et al., 2017).

This study applied high-resolution ^{14}C dating of peat below and above a tsunami deposit, together with a rip-up clast of peat within the deposit at Rikuzentakata, northeastern Japan, to constrain its depositional age. We also discuss appropriate sampling sites in relation to their topographic setting to allow better dating of tsunami deposits.

2. Study area

Rikuzentakata is located in the southeastern part of Iwate Prefecture in northeastern Japan, which faces the Japan Trench (Fig. 1a). Many studies of tsunami deposits have been conducted along the Japan Trench since the discovery of the CE 869 Jogan tsunami deposits (e.g., Abe et al., 1990; Minoura and Nakaya, 1991; Sawai et al., 2012), with deposits correlated with this event recently reported at several places along the Sanriku coast (e.g., Ishimura and Miyauchi, 2015; Takada et al., 2016).

During Japan's history, many tsunamis have been documented along the Sanriku coast, including at Rikuzentakata (Watanabe, 1995). Historical records suggest that the CE 1611 Keicho tsunami impacted Ofunato (Ebina and Imai, 2014), which is located approximately 10 km north from Rikuzentakata. Namegaya and Yada (2014) pointed out that the CE 1454 Kyotoku tsunami might have struck the northeastern part of Japan, although it is uncertain if this event also affected the Sanriku

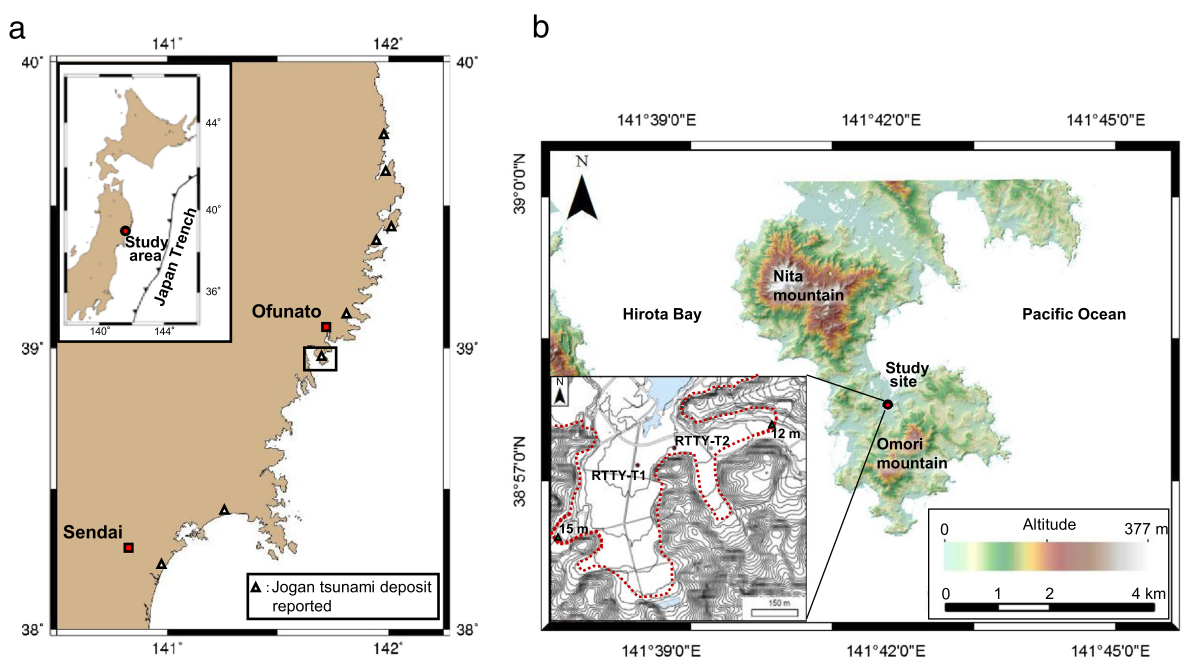

Fig. 1. (a) Location map showing the study area (red circle). Gray triangles: locations where CE 869 Jogan tsunami deposits were observed in earlier studies (Sawai et al., 2012; Ishimura and Miyauchi, 2015; Takada et al., 2016). Detail of the square zone is presented in Fig. 1(b). (b) Topographical map and contour map around the study site. The contour interval is 2 m. Base map is made with the 5 m mesh DEM data provided by the Geospatial Information Authority of Japan. The red dotted line in the contour map represents the inundation area (Haraguchi and Iwamatsu, 2011), while green triangles show the inundation height (The 2011 Tohoku Earthquake Joint Survey Group, 2011). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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