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Geological evidence of tsunamis in the past 3800 years at a coastal lowland in the Central Fukushima Prefecture, Japan

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ABSTRACT

We found seven event deposits during the past 3800 years in a total of 16 geological core samples from a coastal lowland in Fukushima Prefecture, about 12 km north of the Fukushima Daiichi Nuclear Power Station. The event deposits consisted of well-sorted and rounded fine to coarse sand with single normal grading structures, parallel laminae, mud drapes, rip-up clasts, and erosional basal contacts. They were distributed about 2 km inland from the current shoreline and commonly became thinner landward. The third and fifth sand layers were characterized by many climbing ripples and parallel and trough-cross bedding that were probably caused by storm surges or some other events during the period of absent beach ridges. The other deposits were characterized by sedimentological features common to tsunami deposits. The top layer appeared to have been deposited by the 2011 Tohoku tsunami, and the second layer might have been resulted from the AD 869 Jogan Tohoku tsunami. The other three tsunami deposits corresponded to tsunami events between the second and fourth centuries AD, the sixth and fourth centuries BC, and the twelfth and ninth centuries BC. The average recurrence interval of the paleo-tsunamis was estimated to be 560–950 years. These dates are mostly consistent with previous studies of the Sendai plain, suggesting that paleo-tsunamis that reached the Sendai plain also reached the coast of Fukushima Prefecture. However, no trace was found from an earthquake around the 15th century, which had been considered as a predecessor of the 2011 Tohoku earthquake (Mw 9.0) in the tsunami deposit surveys in Sendai plain.

1. Introduction

The 2011 Tohoku earthquake (Mw 9.0), which occurred on 11 March 2011, was the largest interplate earthquake in Japanese history. The tsunami generated by the earthquake, with the heights of 11.5–15.5 m above mean sea level, caused catastrophic damage to the Fukushima Daiichi Nuclear Power Station (NPS). The tsunami damage to the emergency diesel generator resulted in a core melt-down and hydrogen explosions. The tsunami design height of the facility was just 5.4–6.1 m, much lower than the 2011 tsunami. One of the reasons for this inadequate design height was that the tsunami assessment was based on the historical tsunami records during the last century (Tokyo Electric Power Company, 2012). The need for a geological survey in Fukushima Prefecture was pointed out before the 2011 Tohoku earthquake because tsunami deposits from the 869 Jogan Tohoku earthquake had been found on the Sendai plain. However, only a few tsunami deposit surveys had been performed in the northern and central regions of the Fukushima Prefecture (e.g., Satake et al., 2008; The Headquarters for Earthquake Research Promotion, 2010; Sugawara et al., 2012).

Large interplate earthquakes and tsunamis occur repeatedly along the Japan Trench (e.g., Utsu, 1990; Usami, 2003). The tsunami caused by the AD 869 Tohoku earthquake was recorded in a historical document during the Jogan era, and the tsunami deposits are widely distributed from the Aomori to Fukushima Prefectures (Fig. 1a; e.g., Abe et al., 1990; Minoura and Nakaya, 1991;Minoura et al., 2001; Sawai et al., 2008; The Headquarters for Earthquake Research Promotion, 2006, 2007, 2008, 2009, 2010; Sugawara et al., 2012; Sawai et al., 2012; Ishimura and Miyauchi, 2015; Takada et al., 2016). The tsunami deposit distribution of the 869 Tohoku earthquake suggests that the associated tsunami was similar in size to the 2011 Tohoku earthquake tsunami (Sugawara et al., 2012; Sawai et al., 2012), and more recent work in the Sendai plain has indicated that a similar tsunami was also generated by either the 1454 or 1611 Tohoku earthquake (Sawai et al.,

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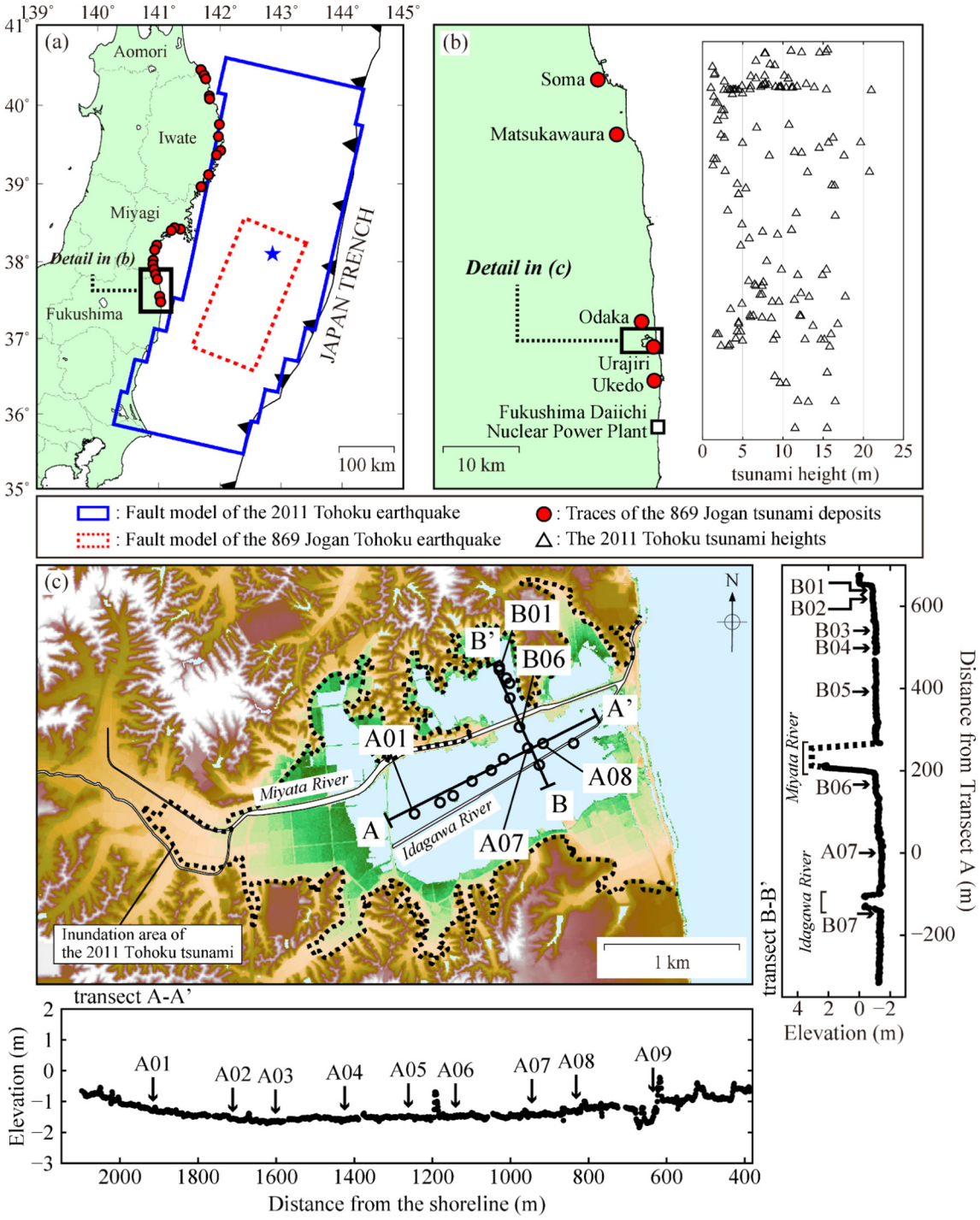

Fig. 1. Index of map. (a) Overview of northeastern Japan along the Japan Trench. The red and blue rectangles show fault areas of the 2011 Tohoku earthquake estimated from tsunami waveforms (Satake et al., 2013) and the 869 Jogan Tohoku earthquake inferred from the distribution of tsunami deposits (Sawai et al., 2012; Namegaya and Satake, 2014), respectively. The blue star is the epicenter of the 2011 Tohoku earthquake. Red circles indicate traces of the Jogan Tohoku tsunami deposit (Minoura et al., 2001; Sawai et al., 2008; Sugawara et al., 2012; Sawai et al., 2012; Ishimura and Miyauchi, 2015; Goto et al., 2015; Takada et al., 2016). (b) Paleo-tsunami deposit survey locations in the Fukushima Prefecture. Triangles indicate the observed 2011 Tohoku tsunami heights (Mori et al., 2012; Sato et al., 2014). (c) Sampling sites in Idagawa lowland. The dotted line shows the inundation limit of the 2011 Tohoku tsunami from the Tsunami Damage Mapping Team, Association of Japanese Geographers (2011). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2015).

In this paper, we report the results of tsunami deposit surveys in the Idagawa lowland, Minami-soma City, in Fukushima Prefecture. Several studies have been made on the tsunami deposit in this lowland, before and after the 2011 tsunami, and the tsunami recurrence interval has been estimated to be approximately 600 years (Goto and Aoyama, 2005a, 2005b; Oikawa et al., 2011; Kakubari et al., 2017). However, they relied on a small number of cores and samples. In this study, we used a total of 16 geological core samples widely distributed in the lowland and analyzed their sedimentary facies, structures, and grain