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Fossil tubeworms link coastal uplift of the northern Noto Peninsula to rupture of the Wajima-oki fault in AD 1729

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ABSTRACT

The active fault zone on the seafloor off the northern coast of the Noto Peninsula of central Japan is divided into four segments from west to east: Monzen-oki, Saruyama-oki, Wajima-oki, and Suzu-oki. To examine the latest event that occurred in these segments, we investigated the dates and elevations of fossilized intertidal tubeworms along the northern coast of the Noto Peninsula, located on the hanging-wall sides of the faults, using radioactive carbon dating and global positioning measurements. For each fossil, we calculated the difference between the past and present elevation, thereby estimating the elevation of the sea level at the date of the fossil, using a curve for sea level change. This calculation provided us with the elevation change at each site. The vertical changes estimated from the elevations and ages of the intertidal tubeworms revealed that the coastal emergence probably occurred between 1600 and 1800 AD. This area of coastal emergence lies adjacent to active faults within the Wajima-oki segment. A model for rectangular faults with three fault planes and a moment magnitude of 6.6 for the Wajima-oki segment reproduced the observed pattern of coastal emergence well. Only one damaging earthquake, that in 1729, is known to have occurred in this part of the northern Noto Peninsula between 1600 and 1800 AD, and there has not been one since 1800 AD. The slip distribution of the fault predicted by the model is consistent with the distribution of shaking-related damage documented in 1729. We conclude that rupture of the Wajima-oki segment caused the 1729 earthquake.

1. Introduction

The faulting history of active faults is one of the key types of information needed to explain regional tectonics and geomorphological evolution. Geophysical and geological survey data, including paleogeodetic data, examined along with historical documents, can reveal details of the faulting history, such as the date of the latest event, the recurrence interval, and the crustal deformation. For a large fault system with several segments, it is important to examine the faulting history of each segment and the interactions between the segments. However, there are several problems to be addressed in comparing geophysical and geological observations with historical data. For example, a historical document may describe severe seismic damage in an area, but there may be no source location and/or source fault that has been identified as the cause of that damage, even though there are active faults in or around the area. Therefore, to achieve a comprehensive understanding of regional tectonics, it is important to obtain geophysical and geological evidence of historical earthquakes and construct a fault model that is consistent with geophysical and geological observations and historical data.

Holocene marine terraces, intertidal organisms, and wave-cut benches are useful markers of the faulting history of marine active faults (e.g., Yamaguchi and Ota, 2004; Hsieh and Rau, 2009; Ramos and Tsutsumi, 2010). Many studies have been conducted on tectonic uplift using *Pomatoleios kraussii* (hereinafter termed *P. kraussii*) assemblages in Japan (Kayanne et al., 1987; Nishihata et al., 1988; Maemoku, 1988; Shishikura et al., 2008). *P. kraussii* forms colonial zonation or patches of calcareous tubes that can only survive within a narrow range of the mid-tidal zone on rocky coasts, and the upper limit of the range corresponds to the mean sea level (Imajima, 1979; Miura and Kajihara, 1983, 1984; Kayanne et al., 1987). The emerged *P. kraussii* assemblages are therefore excellent indicators of historical mean sea levels. Sampling of *P. kraussii* along coastlines can reveal pseudo-two-dimensional coseismic crustal deformation associated with a particular paleoearthquake, in contrast to one-dimensional or point-based paleoseismic trench investigation across a fault.

The Noto Peninsula, located in the backarc region of the Japanese islands, is an area with developed marine terraces (Ota and Hirakawa,

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1979). The Noto Peninsula is one of Japan's foremost areas of marine fault activity, with an uplift rate of more than 1 mm/yr. However, the relationship between this fault activity and the earthquake history of the area has not been established, even though historical documents show that a damaging earthquake occurred in 1729 in the area of the Noto Peninsula (Usami, 2003). Recently, an active fault zone with several segments has been identified on the seafloor off the Noto Peninsula (Inoue and Okamura, 2010), but little is known about the activity of these active faults.

In this paper, we present estimates of the vertical displacements along the northern coast of the Noto Peninsula, obtained using the elevations and ages of intertidal sessile organisms. We also identify the latest active marine fault event, based on vertical displacement data, and we present a source model of the latest event. Finally, we discuss the relationship between the latest event, historical records, and the marine fault activity along the coast through the Late Pleistocene.

2. Tectonic and geologic setting

2.1. Geology and geomorphology

Jurassic granites, Oligocene igneous rocks, Miocene volcanic rocks, and sedimentary rocks, and Pleistocene terrace deposits are distributed along the northern part of the Noto Peninsula (Ozaki, 2010). Around the Noto Peninsula, normal faults were formed by extension tectonics during the expansion of the Sea of Japan in the Early Miocene, and these normal faults were converted into reverse faults as a result of north–south compressive stress during the Late Miocene (Okamura, 2002; Sato et al., 2007). Normal faults trending NE–SW, reverse faults trending ENE–WSW to E–W, and reverse faults trending NNE–SSW to NE–SW developed (Ozaki, 2010) (Fig. 1).

Pleistocene marine terraces along the coast, which are located on the uplift areas of these segments, indicate the upheaval in the coastal area

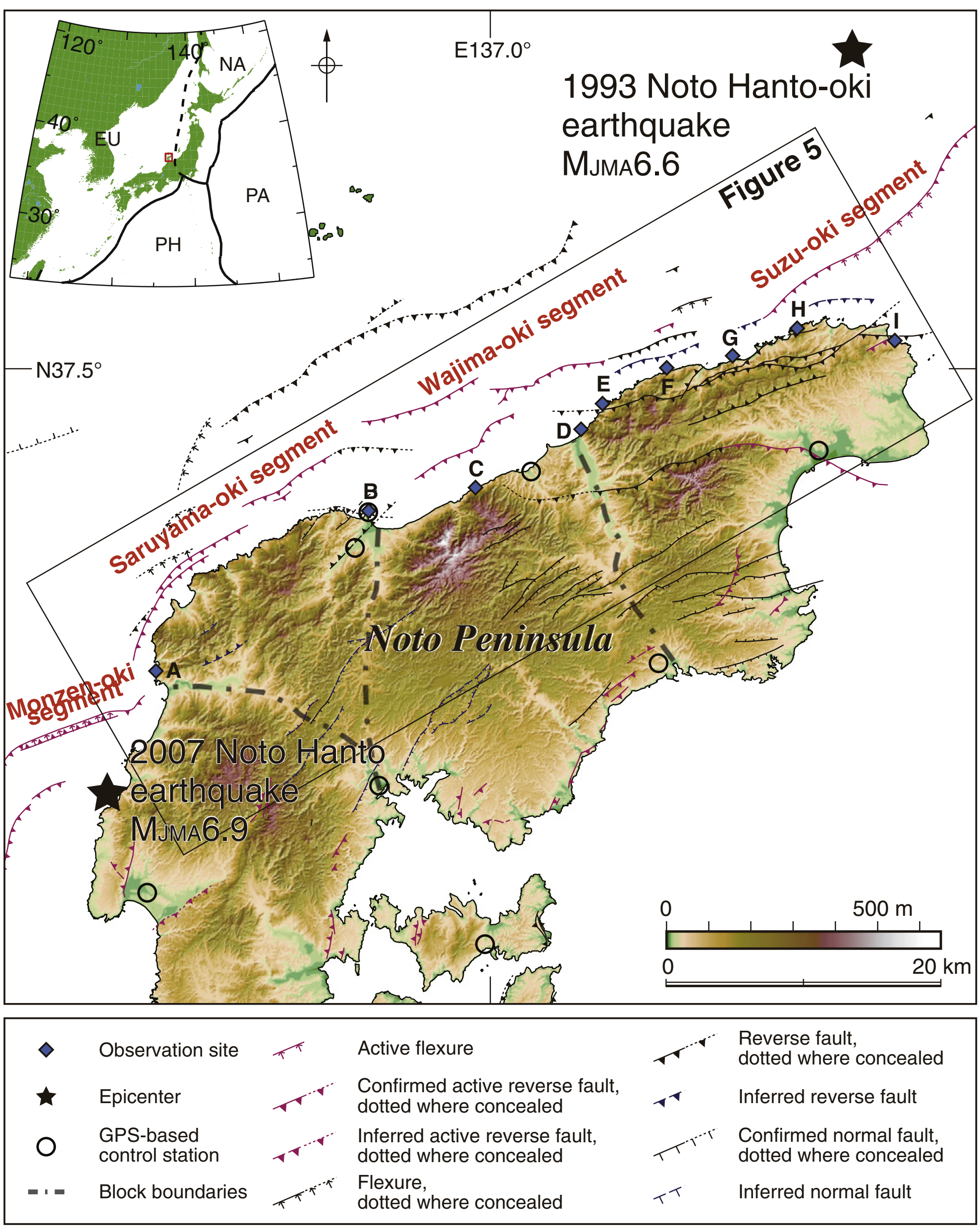

Fig. 1. Topographic map of the Noto Peninsula, showing locations of survey sites considered in this study (diamonds) and active reverse faults (barbs pointing downward) located offshore (Inoue and Okamura, 2010) and on land of the northern Noto Peninsula. Dotted-and-dashed lines indicate the block boundaries reported by Ota and Hirakawa (1979). The rectangle indicates the area shown in Fig. 5. (Inset map) EU: Eurasian plate, NA: North American plate, PH: Philippine plate, PA: Pacific plate.