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Paleoecological evidence for coastal subsidence during five great earthquakes in the past 1500 years along the northern onshore continuation of the Nankai subduction zone

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ABSTRACT

During the last 1500 years, a marsh on the north coast of Suruga Bay, central Japan, has experienced as many as five rapid submergence events. This conclusion is supported by analyses of depositional facies and pollen and diatom assemblages in sediment cores from the Ukishimagahara lowland, on the footwall side of the Fujikawa-kako fault zone (FKZ), the northern extension of the Nankai and Suruga Troughs. Light-colored silt or clay beds, ~30–50 cm thick, deposited as the result of submergence events that drowned the marshland, cover terrestrial peat or humic soils produced by the marshland vegetation. Radiocarbon ages and dated tephras suggest that in this lowland submergence events have occurred at aperiodic intervals of 100–400 years. Atmospheric phenomena can cause increased precipitation and flooding by rivers and typhoons, but they cannot explain the cyclic submergence events at centennial timescales. During the late Holocene, sea levels have been declining relative to land around the Japanese Islands, so high sea levels cannot explain the periodic submergence of the lowland. The most likely cause of these events, therefore, is coseismic subsidence of the lowland related to great earthquakes (~M8.0) occurring in the FKZ or the Suruga Trough. Coseismic coastal deformation around the study area during the 1854 Ansei Tokai earthquake supports this hypothesis.

1. Introduction

The Fujikawa-kako fault zone (FKZ) is at the northeastern end of the Nankai and Suruga Troughs (Fig. 1A). It consists of an area of active thrust faulting with over 26 km long, which extends north from the west bank of the Fujikawa River mouth on the northern coast of Suruga Bay. The western side of the fault zone is uplifted (Research Group for Active Faults of Japan, 1991), and the estimated vertical displacement rate is ~7 m/1000 years (Yamazaki, 1979, 1984, 1992), which means the FKZ is among the most active fault zones in Japan. The FKZ is close to the Tokyo and Tokai metropolitan areas and underlies major traffic networks, including the Shinkansen (Bullet train), the national railway, and highways. Thus, fault activity along the FKZ can lead to severe traffic disruption and devastation in the urban areas. To assess the seismic risk of the FKZ to the central Japan area, it is critical to determine when great earthquakes are likely to occur there.

Long-term evaluation of seismicity and disaster prediction in the Nankai and Suruga Trough region is also concerned with possible great earthquakes in the FKZ. As part of the response to the 2011 off the Pacific coast of Tohoku earthquake and tsunami, the cabinet office of the Japanese government proposed new guidelines for assessing the risk of similar earthquakes and tsunamis affecting the Nankai and Suruga Trough region. Following these new guidelines, the Committee for Evaluation of Mega-Earthquake Modeling along the Nankai Trough (2011) announced that this region should be considered at risk for the largest possible class of earthquake (~Mw 9.0) and tsunami, even though no such a mega-earthquake has yet been recorded in the region. The potential seismogenic rupture zone includes almost the entire length of the Nankai and Suruga Troughs, and the FKZ corresponds to the eastern margin of this hypothetical mega-fault zone. It has been estimated

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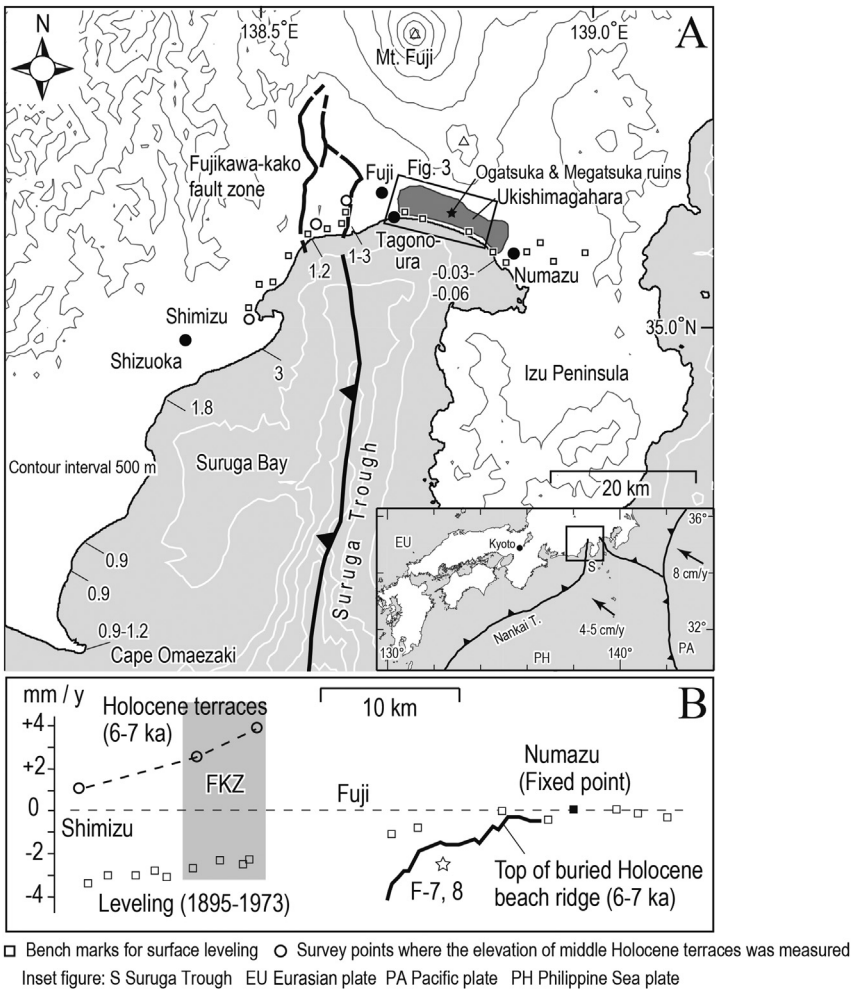

Fig. 1. Location map of the study area. **A: Topography and tectonic setting**. The Fujikawa-kako fault zone (FKZ) trace is modified from Shimokawa et al. (1996). Numerals denote vertical surface displacement (in meters) during the 1854 Ansei Tokai earthquake of M8.4 (Hatori, 1976; Ishibashi, 1984). Arrows in the inset show the plate motion of the Philippine Sea and Pacific plates relative to the Eurasian plate (e.g. Seno et al., 1993). B: **Vertical tectonic movement along the northern coast of Suruga Bay**. Data on surface leveling, Holocene terraces, and beach ridges are from Hatano et al. (1979). This graph has been projected onto a profile that curves around the north shore of Suruga Bay. The vertical axis shows uplift and subsidence rate, using the elevation at Numazu as the zero datum. Subsidence rates at sites F-7 and F-8 (Fig. 3B) are those estimated by Fujiwara et al. (2008).

that rupture along the length of this seismogenic zone would result in an Mw 9.1 earthquake. This estimated magnitude is much larger than the previous estimates (Mw 8.7) that have been used in disaster planning.

Analyses of historical documents and archaeological data, such as traces of liquefaction (mainly sand dykes) and ground cracking suggesting the occurrence of intense ground shaking revealed the history of great interplate earthquakes (M ~8) that have occurred along the Nankai and Suruga Troughs (Fig. 2). Earthquakes generated in rupture zones C, D, and E are known as Tokai or Tonankai earthquakes, and those generated in rupture zones A and B are known as Nankai earthquakes. This history suggests that Tokai and Nankai earthquakes have occurred at intervals of 90–250 years during the last 1300 years.

The faults making up the FKZ were first reported by Inoue (1934). Even though systematic geological research has been conducted since the 1970s (e.g., Yamazaki, 1979; Shimokawa et al., 1996, 1998; Maruyama and Saito, 2007), the rupture history of the FKZ is still unclear. The last rupture event along the FKZ possibly occurred in its southern part concurrently with the 1854 Ansei Tokai earthquake. The local occurrence of uplift and subsidence on the northern coast of Suruga Bay during the 1854 event (Hatori, 1976; Tsuneishi and Shiosaka, 1981; Ishibashi, 1984) supports this hypothesis (Fig. 1A). However, no pre-1854 events along the FKZ are reported in historical documents. Because of the thick covering of sandy and gravelly Holocene deposits, derived mainly from the Fujikawa River, and intense land use around the FKZ, it is difficult to "directory" investigate fault movements by trench and drilling surveys along the fault traces in the FKZ. Researchers then have mainly investigated the FKZ's rupture history by using "indirect" geological evidence related to faulting events around the FKZ, such as the formation of Holocene terraces and the subsidence of marsh deposits (e.g., Yamazaki et al., 2002).

The Headquarters for Earthquake Research Promotion (1998) has used the results of such studies to evaluate the long-term seismic activity of the FKZ. In a recent reappraisal of this evaluation (Headquarters for Earthquake Research Promotion, 2010), two different scenarios denoted as cases a (great earthquakes at short recurrence intervals with relatively small ground surface displacement) and b (greater earthquakes with a long recurrence interval and large ground surface displacement) were proposed for seismic activity in the FKZ, according to the data used for reconstruction of paleoearthquake events. In both scenarios, the expected magnitude of an earthquake occurring along the FKZ is