Reappraisal of the maximum runup of the 1771 Meiwa tsunami on Ishigakijima

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ABSTRACT

A sand layer 8 meters above sea level in a freshwater marsh in southwestern Ishigakijima most likely resulted from a tsunami washing across the island from the east. The lowest point separating the east and west sides of southern Ishigaki is 35 meters above sea level, suggesting that the wave which deposited this layer reached at least that height. Historical documents from Ishigakijima state that the 1771 Meiwa tsunami washed over the island from east to west, although no geologic evidence has yet been reported.

The deposit is sheet-like, covering an area at least 60 by 100 meters, and found about 50 centimeters below the current ground surface. The sheet ranges from 5 to 50 cm thick, and is thickest to the southwest, in the direction of the gap leading to eastern Ishigaki. Grain size varies from fine to coarse sand, fining to the southwest. The sand itself is generally subangular and siliciclastic, but sparse rounded grains of carbonate are present. It is compositionally and texturally similar to sand found in the same stratigraphic position in low-lying areas just east of the gap separating the two sides of the island.

The sand is best explained as a tsunami deposit. Coastal flooding seems unlikely, since the marsh is more than 2 km inland and 8 meters above sea level, and the grain-size trends in the deposit are opposite what might be expected from a storm deposit. Flooding from nearby streams also seems unlikely because the sand contains carbonate material-there is no upland source of carbonate in western Ishigaki. For carbonate material to be incorporated in the deposit, the sand must have come either from the west coast of Ishigaki, more than 2 km away, or from eastern Ishigaki. Either event would require a tsunami, but the deposit's grain-size trend rules out a tsunami from the west and suggests that a wave from the east was responsible for creating this sand sheet, a wave which reached at least 35 meters above sea level as it overtopped the island.

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INTRODUCTION

On April 24, 1771, an earthquake with an estimated magnitude of 7.4 struck southern Okinawa near the island of Ishigaki. Although the earthquake was relatively small, the tsunami it generated killed nearly 10,000 people in the southern Ryukyu islands, including entire villages in Ishigaki and Miyako. The tsunami is reported to have consisted of three waves (Imamura, 1938), and to have left coral blocks up to 5 meters in diameter in its wake. There is an argument, however, about how high the waves went—historical records suggest the wave may have washed through a narrow gap in the highland of southern Ishigaki and attacked villages on the western side of the island, whereas modern geological studies tend to support runup less than 30 meters-too low to have reached the gap.

Makino (1981) collected historical documents from Ishigakijima and showed that these documents state that the 1771 Meiwa tsunami washed over the island from east to west, reaching heights of 85 m above sea level on the southeastern part of the island:

> The wave spread from the Todoroki River lowland. Takara Pe-chin from Miyara saw the wave travel from east to west, flowing between Makinaka and Kayanni. He saw the wave from Miyara meet the wave from Todoroki and grow bigger. The wave passed over the lowland of Kawahara and Kainan, heading for Nagura. Boulders were left in the lowland by the wave...At that time, Nagura was located on a hill above the marsh, so it was undamaged by the tsunami. But the wave from Miyara and Todoroki passed Takeda and entered Nagura Bay. That wave met a wave entering the bay from the west. Kandahara, Uradahara, Hirajihara, Wakugawara, Pinada, Shiramizu, and Toureihara were submerged until the wave drained, almost like a lake.
>
> Makino (1981)

Kayanni no longer appears on maps, but from context is probably located on the north side of the Todoroki River. Of the locations listed for Nagura only Kandahara survives in modern use, as the name of a bridge over the Nagura River. The prevalence of "hara" and "da" ("meadow" and "rice paddy", respectively) in the place names suggests, however, that these were locations in the lowland of Nagura Marsh (Figure 1).

More recent geological research (Kato, 1987; Kato and Kimura, 1983; Kawana and Nakata, 1994; Kawana et al. 2000) has used the maximum elevation of coral boulders transported by the tsunami to estimate the wave runup. These estimates range from about 20 meters to about 30 meters as the maximum height of the wave.

Recent geological attempts to estimate the size of the Meiwa tsunami assume that boulders moved by the tsunami were transported to nearly the maximum runup of the wave. Model experiments suggest, however, that boulder movement may cease well before maximum runup is reached (Moore, 1999). Sand, however, might be carried much farther than boulders. If the Meiwa tsunami did surge through the gap between the Miyara and Nagura river valleys, then sandy tsunami deposits should be present in the Nagura valley and in the gap between the two (Figure 2).

GEOLOGIC SETTING

Ishigakijima lies at the southern end of the Ryukyu Island Arc, resulting from the subduction of the Philippine Plate under the Eurasian Plate. Large earthquakes have occurred on the plate boundary at least eight times in the past 400 years, including a 1911 M = 8.0 tremor near Amamishima that generated a small tsunami.

The bedrock geology of Ishigakijima comprises metamorphosed Paleozoic sediments intruded and overlain by Tertiary felsic rocks. These are overlain by the Pleistocene Sakishima Group, which consists of the Nagura Gravel and the Ryukyu Limestone. In southern Ishigakijima, the Nagura Gravel forms flat terraces dissected by the Miyara, Todoroki, and Nagura rivers (Foster, 1965). In interfluves, the Nagura Gravel can be capped by Ryukyu Limestone on the Miyara side, but not on the Nagura side.

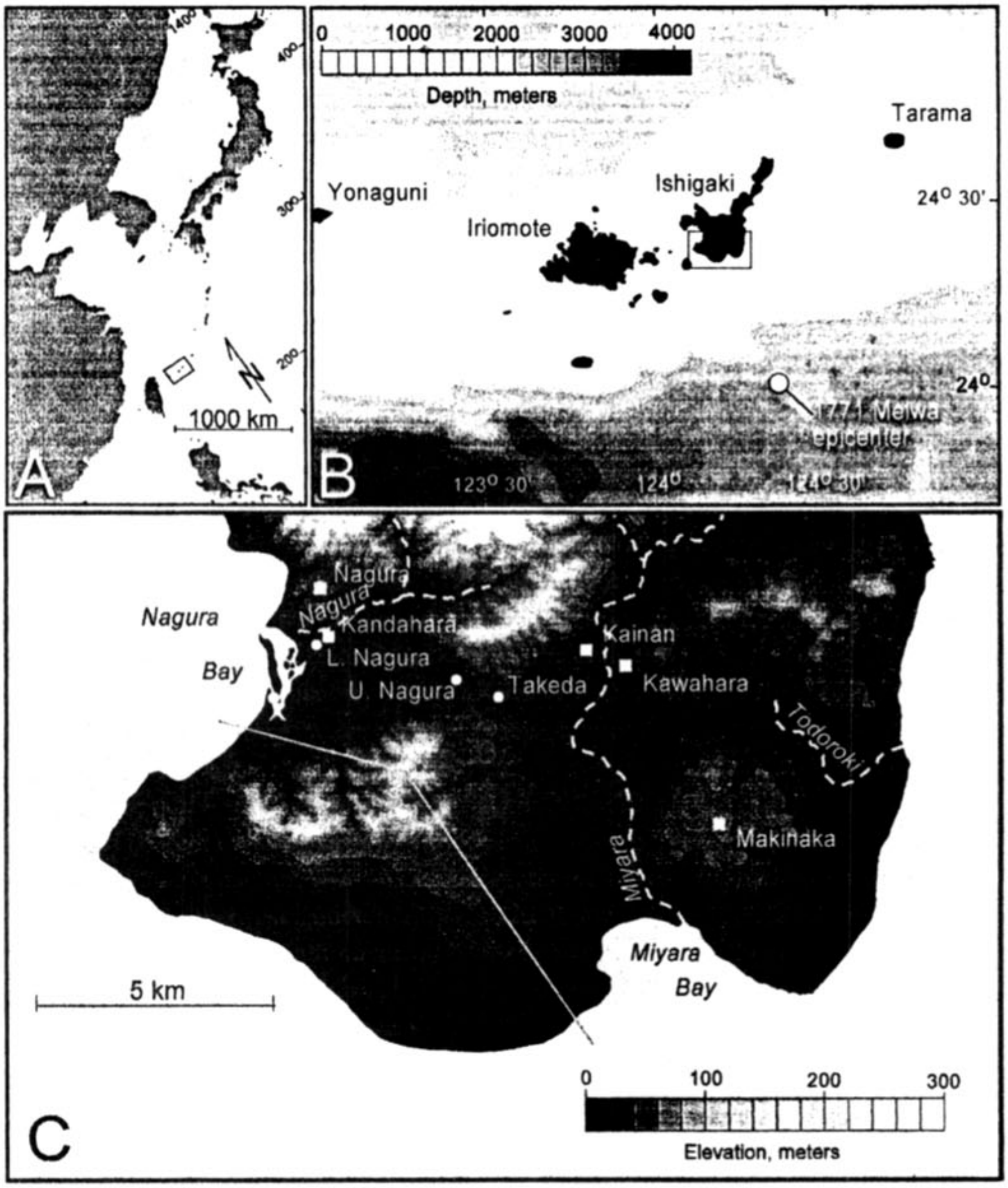

Figure 1 . Location maps. A. Location of Ishigakijima in the Japanese archipelago. B. Bathymetry surrounding the Yaeyama Islands. Contour interval is 200 meters. C. Location of study areas (light circles) and areas mentioned in the text (gray squares). Contour interval is 20 meters.

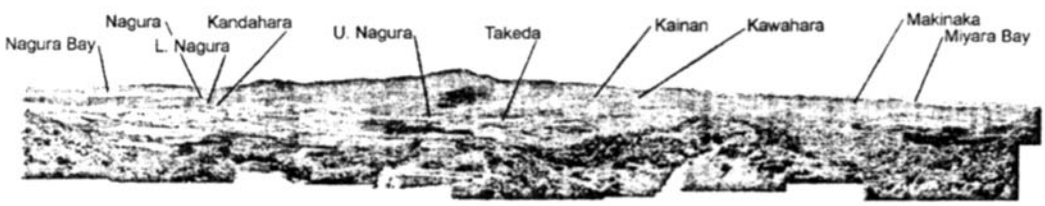

Figure 2 . Photo mosaic of the study area. Areas mentioned in the text are indicated.

FIELD WORK

To search for a sandy tsunami deposit from the 1771 Meiwa tsunami, we investigated three locations in Ishigakijima-Lower Nagura, Upper Nagura, and Takeda (Figure 1).

Lower Nagura

Nagura Marsh is an extensive (2 km along-shore and 1.2 km cross-shore) salt marsh formed behind a long sand spit and at the mouth of the Nagura River. The landward part of the marsh has been converted to rice fields and is commonly reworked, but the seaward portion remains in its natural state (and is nearly impassable). In at least one location, the original stratigraphy of the marsh remains, and is revealed by drainage ditches and deep sumps. We dug a pit 1 meter wide by 1 meter long, and 2 meters deep in a rice field about 200 meters south of Kandabashi, and 50 meters west of a kiln built in the early 1700's. Stratigraphy in the pit consists of about 40 cm of dark brown or black mud, underlain by a thick sand layer more than one meter thick that overlies silty clay that continues to the bottom of the pit. The sand is normally graded, fining upward from cobbles to medium sand. This layer is continuous for more than 100 meters of exposure, and is probably correlative to coarse carbonate sand found in cores by the government of Okinawa (Figure 4). The deposit is poorly sorted and contains abundant very coarse angular sand, predominantly of quartz or feldspar grains. The finer grains are mostly carbonate debris. The sand appears structureless, but contains abundant very fresh branching coral debris and very common large articulated bivalves, and fresh gastropods. The bivalves are as large as 30 cm on the long axis, and range from bivalves common to reefs, to those common to sandy

Figure 3 . Stratigraphy in the Lower Nagura marsh. Just below the waterline the stratigraphy changes abruptly to stiff gray clay. Divisions on the shovel handle are 10 cm.

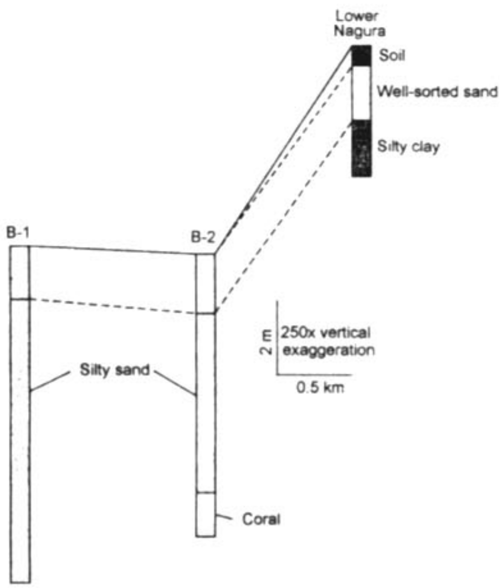

Figure 4 . Relationship between the Nagura bridge cores and the Lower Nagura marsh pit in Figure 3.

beaches, to those common to muddy environments. The coral debris is as large as 10 cm on the long axis, and often retains its delicate branching structure. Lastly, the sand contains common very angular fragments of phyllite, and well-rounded chert pebbles common in nearby streams.

Upper Nagura

A small marsh remains on the north bank of one branch of the Nagura River, 8 meters above sea level and 2 km inland from the Nagura side of Ishigakijima. The marsh ends against terraces of Nagura Gravel to the east and north, and is truncated by a road to the west.

There is a sand layer varying from 5 to 50 cm thick in this marsh (Figure 5). To map the extent and properties of the sand, we took 50 cores in a grid pattern over the marsh using a friction corer with a diameter of 30 mm. These cores show that the deposit is sheet-like, covering an area at least 60 by 100 meters, and found about 20 centimeters below the current ground surface (Figure 6). The sheet ranges from 5 to 50 cm thick, and is thickest to the southwest, in the direction of the gap leading to eastern Ishigaki (Figure 7). Grain size varies from fine to coarse sand, fining to the west (Figure 8). The sand itself is generally subangular to angular and siliciclastic, but sparse rounded grains of carbonate are present. At the base of the sand, subrounded to angular cobbles are present.

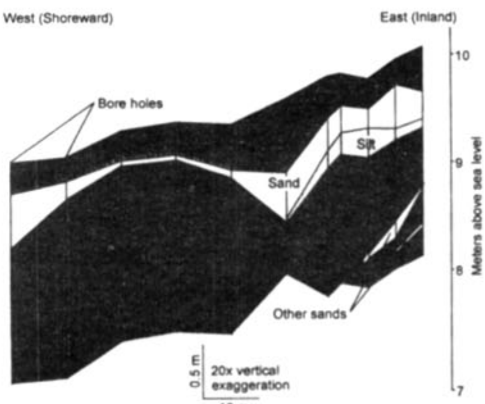

Figure 5 . Cross-section of the sand sheet in the Upper Nagura marsh.

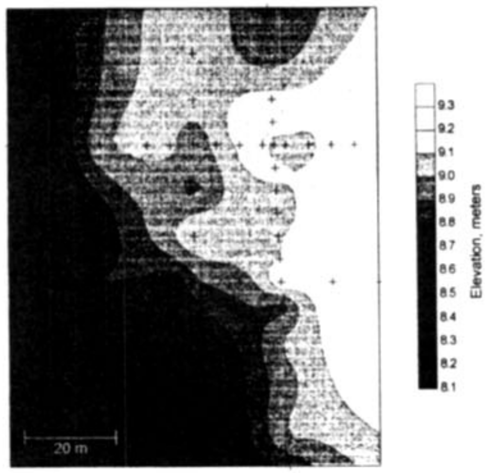

Figure 6 . Elevation of the base of the sand in the Upper Nagura marsh. Sample locations are marked with a +.

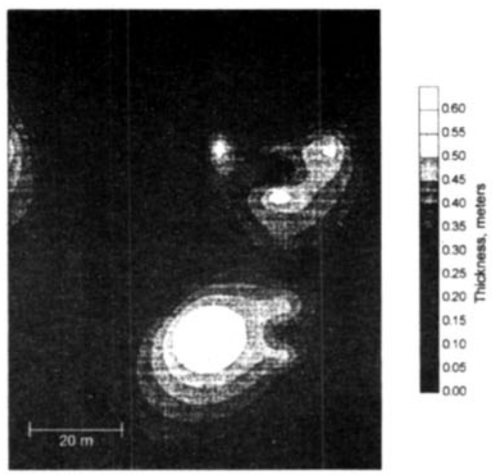

Figure 7 . Thickness of the sand in the Upper Nagura marsh. Sample locations are the same as for Figure 5.

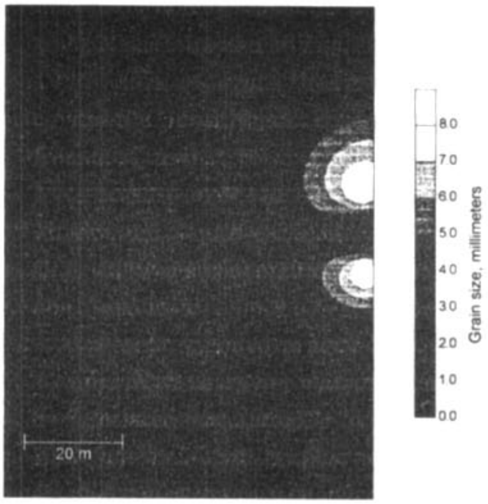

Figure 8 . Grain size of the sand in the Upper Nagura marsh. Sample locations are the same as for Figure 5.

Takeda

Three cores taken near the town of Takeda, on the Miyara side of Ishigaki, contain sand compositionally and texturally similar to the sand layer at Upper Nagura. The Takeda layer can be up to 1 meter thick, and appears to lack the cobble base seen at Upper Nagura (Figure 9). The sand overlies a reddish soil rather than peat, so coring is more difficult than at Upper Nagura, and the stratigraphy is often disturbed as a result of agriculture in the area.

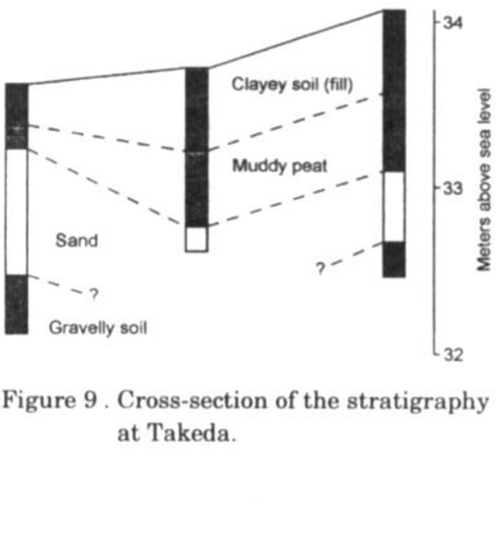

Figure 9 . Cross-section of the stratigraphy at Takeda.

DISCUSSION

The sands found at Lower Nagura, Upper Nagura, and Takeda probably represent the deposit of a tsunami. At Lower Nagura, unabraded coral and reef shells are found in the deposit-some extraordinary coastal force must have occurred to bring these organisms so far inland. If a tsunami reached the relatively protected shoreline of Nagura marsh, the wave must have been quite large.

At Upper Nagura, the presence of carbonate sand suggests that some unusual process was involved in the deposition of this layer, because no source of carbonate sand is available in the Nagura River watershed-the carbonate must either have been introduced by human activities, transported from the Nagura coast, or brought over from the Miyara watershed, which does have abundant outcrops of Ryukyu Limestone. Flooding seems unlikely, because it cannot account for the presence of lithologies not present in the Nagura watershed, and because the Upper Nagura site is so close to the headwaters of the valley, so that floods are probably marked more by the deposition of silt than by cobbles. Human activity also seems unlikely because definite sorting has occurred in the deposit-while vertical and lateral sorting is common for naturally deposited sands, it is unusual for human deposited sand on Ishigakijima. Analysis of human deposited sandy layers on Ishigaki has shown them to be clay-rich and very poorly sorted, in contrast to the Upper Nagura sand, which is clay-poor and well sorted. However, tsunamis commonly sort sediment and carry material from one drainage basin to the next, making tsunami the most favored mechanism for depositing this sand.

The Upper Nagura sand contains lateral grain size trends, becoming finer to the west. Because tsunami deposits commonly become finer in the downstream direction (Caminade, 2000; Nishimura and Miyagi, 1995; Shi et al., 1995), this suggests that the wave that created the Upper Nagura deposit was moving from east to west. If this is the case, it must have crossed over the saddle between the Miyara and Nagura drainages, and suggests that the wave reached at least 35 meters above sea level.

At present, we have no age control on these sediments, so that they cannot be proven to be associated with the 1771 Meiwa tsunami. However, their stratigraphic position within about 40 cm of the surface suggests relatively recent deposition, and no other sands have been found above the prominent sand layer, so that if the layers at Lower Nagura and Upper Nagura are from a tsunami, the 1771 Meiwa tsunami is the most likely wave. Two lower sand layers were noted in some cores at Upper Nagura, suggesting that older waves might also have overtopped Ishigaki, as suggested by Kawana and Nakata (1994).

SUMMARY

The sand layer in Upper Nagura marsh is best explained as the deposit of a westward moving tsunami. To reach that marsh from the west, such a wave would have to wash through the 35 meter high saddle separating the Nagura valley from the Miyara valley, this suggesting that a tsunami reached at least 40m above sea level on Ishigaki. The only such tsunami known from historical records is the 1771 Meiwa tsunami, which we conclude probably deposited this sand layer.

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