

The Sub-Bottom Archaeological Sites of Lake Biwa (Japan) Lessons for the Modern Water-Front Region on Earthquake Disaster

Kamai, T.,¹ Hayashi, H.,² and Haraguchi, T.³

¹Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto, 611-0011, Japan

E-mail: kamai@landslide.dpri.kyoto-u.ac.jp

²School of Human Culture, The University of Shiga Prefecture, 2500 Yasaka, Hikone, Shiga, 522-8533, Japan

E-mail: hhayashi@shc.usp.ac.jp

³Graduate School of Science, Osaka City University, 3-3-138 Sugimoto, Sumiyoshi, Osaka, 558-8585, Japan

E-mail: haraguti@sci.osaka-cu.ac.jp

Abstract

Archaeological village ruins discovered in the bottom of Lake Biwa should be the records of tectonic and non-tectonic movement of coastal ground and its influence on the history and development of coastal towns from the medieval ages. Recent investigations in the Naoe-senken (village) and the Shimosakahama-senken of the eastern coast of Lake Biwa revealed that liquefaction of coastal ground (soft sand) induced landslides moved into Lake Biwa. Modern cities are intensively developed until coastal line on the similar ground condition around large lakes and ponds. The archaeological and geological investigations on sub-bottom village ruins in Lake Biwa should point out the hazard risk and provide the assessment for sustainability of the modern water front cities.

1. Introduction

Lake Biwa is in central Japan covering 670 square kilometers, is the largest freshwater lake in Japan. The lake is also said to be one of the ancient lake in the world, dating back some 5 to 6 million years (Huzita et al., 1973). There are more than 450 rivers and streams flowing into the lake, whereas there is only one natural outlet, the Seta River, so that the lake-level has been controlled by a weir at the outlet. The area around Lake Biwa was once called Omi. Adjacent to the country's political center, Kyoto, Omi district used to be transportation hub between east and west Japan in traditionally. There are abundant archaeological evidences to indicate the coastal region of Lake Biwa; the Omi district was developed since the ancient times in Japan. Because the archaeological achievements, mostly stone-wares and ceramics were also derived from the bottom of Lake Biwa, the existence of sub bottom archaeological sites in Lake Biwa was already known in 18th century. The modern archaeological survey with dry-up method on a few sub-bottom sites was intensively conducted from 1977 to 1991, however, the cause of the sub-bottom sites has been discussed, and geological, geotechnical approaches were needed to understand it (Shiga Prefecture Museum, 2009).

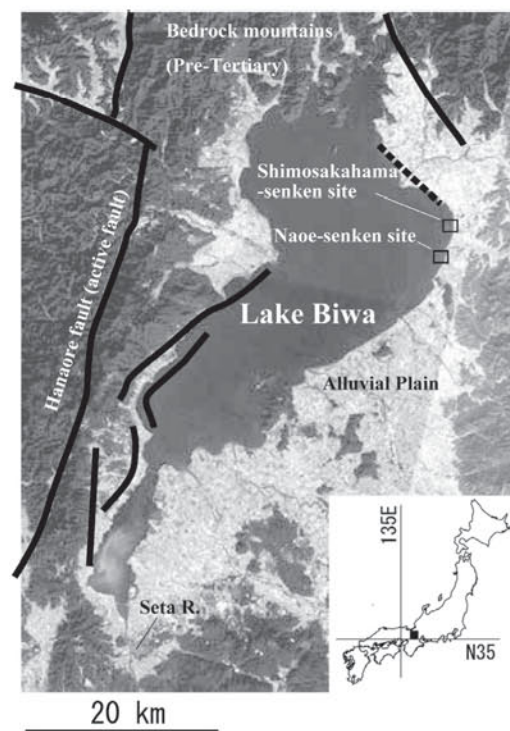


Figure 1: Index map of the sites

We conducted interdisciplinary studies using methods of archaeology, geology, and geophysics to make clear the cause of the sub-bottom archaeological sites, especially submerged village ruins called the Naoe-senken and the Shimosakahama-senken in Lake Biwa. During Japan's pursuit of rapid economic growth in the postwar period, urbanization in this district changed the coastal environment and system of land use. The archaeological and geological investigations on sub-bottom village ruins in Lake Biwa should provide the assessment for sustainability of the modern water front cities.

2. Sub-Bottom Archaeological Sites in Lake Biwa

Eighty to hundred sub-bottom archaeological sites are known in Lake Biwa. The age of sites are widely distributed from the Jomon era (the Neolithic age in Japan) to the 19th century. Sub-bottom archaeological sites in Japan were also discovered from Suwa Lake (central Japan) and Abashiri Lake (Hokkaido, Japan); however, Lake Biwa is a worldwide rare case where many of the submerged ruins concentrate on the same region in the lake. Although typical submerged ruins in other case

were found in shipwrecks, more than twelve submerged ruins of villages (sunken villages) or habitation sites were found in the northern part of Lake Biwa (Figure 2). To discuss the origin of these types of sub-bottom sites, the rising of lake-level or ground subsidence needs to explain the origin of the submerged ruins in Lake Biwa. The exact records on the lake-level changes in Lake Biwa were known since 1718. The lake level during 18th century was higher about 1 m than the controlled normal lake level in modern age (+84.371 m). Although there were no exact measurements on the lake level before 1718, some historical evidences on the elevation of archaeological sites indicate that the lake level in the medieval times (14th – 17th century) was 2 -3 m higher comparing to the normal lake level. Based on these considerations on the lake level change, the ground subsidence appear to be the cause of the archaeological sites distributed in the bottom of Lake Biwa that is deeper than 3m in depth. Various causes could be attributed for the mechanism of ground subsidence around coastal region of the lake, e.g. tectonic movements by active fault system, liquefaction, and landslides along the coast of Lake Biwa.

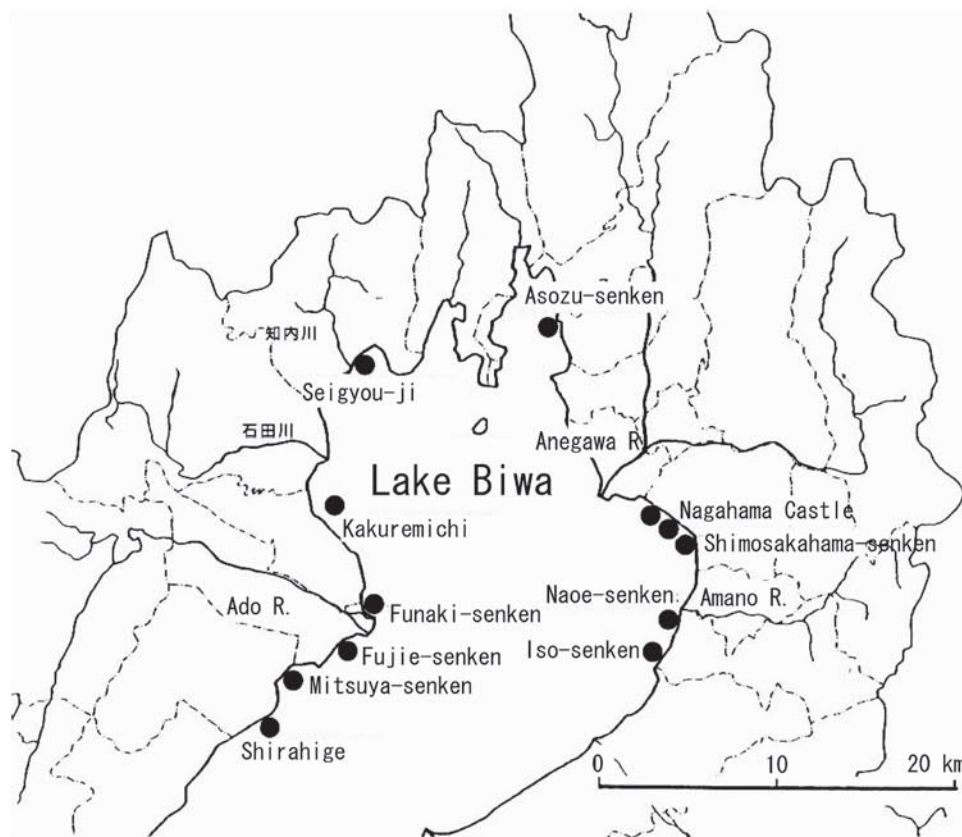


Figure 2: Distribution of sunken villages in Lake Biwa (Hayashi, 2004)

3. The Naoe-Senken Site

3.1 History

The Chikuma shrine located on the east coast of Lake Biwa is the one of the oldest shrine in this region with history for 1000 years and more. This shrine has an old drawing map made in AD 1291 (Figure 3). Because this map is a copy in 17th century (the original was lost), the exact age have been discussed, however, it is also noteworthy that the coast line of Lake Biwa was further offshore and the two village, i.e. Nishimura and Kandachi, that were lost at present were illustrated in this map. Thus, the map could be evidence that the land including these villages has subsided from the coastline in the width of about 600 m in the medieval times. This sub-bottom archaeological site is called the Naoe-senken at present (*senken* in Japanese means 1000 houses). The oldest historical document describing the sunken villages is "The catalogue of the Chikuma shrine" written in AD 1597. This document set the area of the shrine, and pointed out that the main gate of the shrine, the "Torii"; abnormally exist in the Lake Biwa.

3.2 Geologic Structure in the Coastal Terrain

Figure 4a shows an S-wave velocity (V_s) cross section based on the results of high precision surface-wave explorations (Hayashi and Suzuki, 2001) in the Chikuma shrine along the section perpendicular to the coastline. The shrine and villages were located on the narrow sand bar between Lake Biwa and the inner lake called the "Irie-naiko" that was reclaimed during 1960's.

The area of the right hand side of the cross section with low V_s , lower than 150 m/s corresponds to the reclaimed land of the Irie-naiko. In the left hand side of the section, the old sand bar and the new sand bar (embankment) showing higher V_s than 150 m/h is intercalated by low V_s (less than 150 m/h) beds of about 2m thick, and it has been gently sloping toward Lake Biwa. As shown in Figure 4b, this gentle sloping geologic structure was confirmed by Swedish Weight Sounding Tests (SWS) and boring core sampling with Standard Penetration Test (SPT). The intertrappean weak layer of 4 m in depth is loose compacted sand with organic soil. The liquefaction strength ratio (RI_{20}) by cyclic triaxial compression tests for the undisturbed samples from the weak layer (4m in depth) is about 60 % compare with the sample from dense sand in 6 m (center of the sand bar). The precise radiocarbon ages of the weak layer was determined by accelerator mass spectrometry (AMS). The two-sigma calibrated western calendar date ranges are AD 10-140 for the organic sediments.

3.3 Geology and Geomorphology of Lake Bottom

The geophysical survey of the Naoe-senken region of Lake Biwa was carried out. The survey track of side-scan sonar (SSS) consisted of 26 lines run parallel to the coastline at 10 to 20 m intervals. The survey track of the sub-bottom profiler (SBP) consisted of 13 lines run perpendicular to the coastline at 10 to 50 m intervals, and 2 lines are in parallel.



Figure 3: Drawing map of the Chikuma shrine in 1291 (Hayashi, 2004)

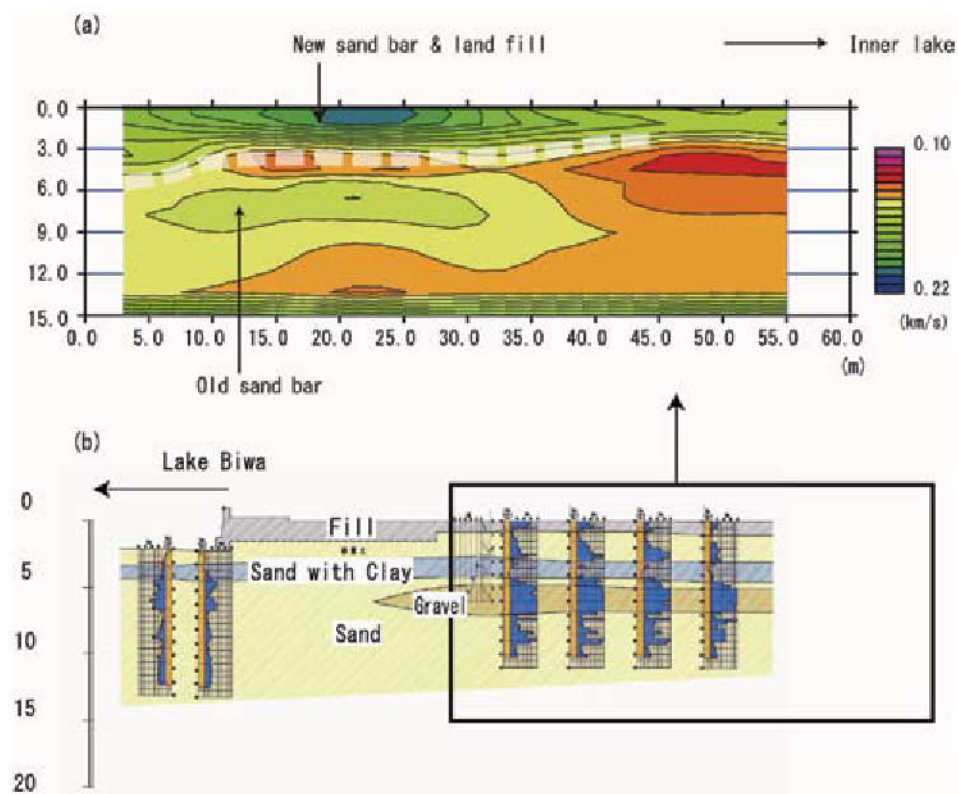


Figure 4: Geologic cross section of the coastal area of the Naoe-senken,
 (a) S-wave velocity (V_s) cross section,
 (b) Cross section made from SWS and boring survey

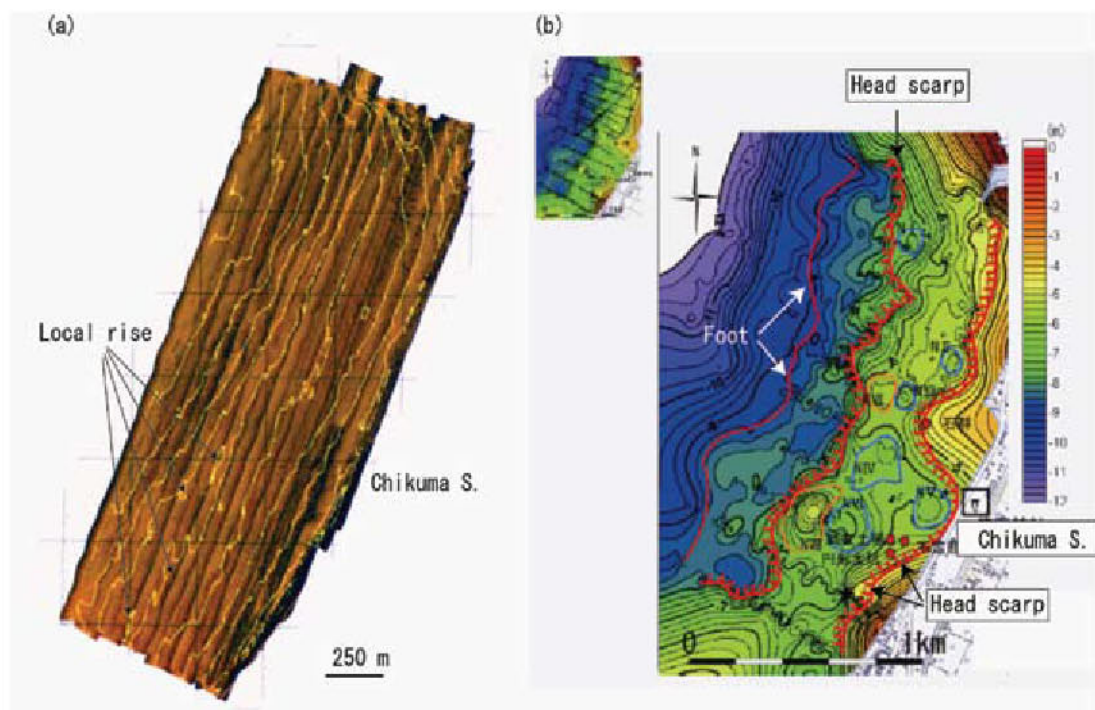


Figure 5: Geophysical survey results in the Naoe-senken
 (a) The bottom image detected by SSS survey
 (b) Topography of the first reflection surface by processing on SBP results

Although basically smooth bottom topography was detected from coastline to offshore, spotted anomalies on the bottom of the lake, local rise and depression of few meters in diameters are shown in the detailed topographic map produced by side-scan sonar (SSS) data (Figure 5a). The first highest reflector in the sub-bottom profiler (SBP) images is widely distributed throughout the site and generally gives a clear, strong reflection. Recent sandy lake sediments accumulated between the bottom surface and the first reflection surface. Topographic configuration of the first reflection surface by eliminating the recent sediments is shown in Figure 5b. The parallel cliffs along the coastline indicate the head scarp of submerged landslides.

4. The Shimosaka-Hama Senken Site

4.1 History

The Shimosakahama-senken site was discovered at the lake bottom of the 6 km north from the Naoe-senken site. Luis Fróis, the famous Jesuit missionary in 16th century, sent his report about the earthquake in 1586 (named the Tensho earthquake) to the Jesuit headquarters of Asia in Goa, India. He wrote, "The Hukata village near Nagahama city was completely submerged during the earthquake, and almost all houses were washed out from the coast to the lake."

The Hukata village is the old name of the Shimosakahama. It indicates that Fróis report should describe the causing event of Shimosakahama-senken site in 1586.

There are many verbal traditional memories about the submerged village. The local Buddhist temple located on the coast line, the Ryouchu-ji temple, originally situated a few hundreds meters far from the present coast line to off shore of the lake. The broken pieces of stone pagoda were shown at the lake bottom. The survivors of residents of Hukata, the old Shimosakahama, moved to another village after the earthquake. Even today, they called 'the peoples coming from water', and have strengthened the ties of solidarity in a long time after the disaster.

4.2 Geomorphology of Lake-Bottom

The side-scan sonar image in Figure 6 has revealed the details of relief of the lake-bottom that indicate important features of landslides. Hummocky patterns of the bottom topography are thought of as flow mounts of sliding body, and continuing cliff along coastline can be considered as head scarp of landslides. The scale of the landslide is estimated about 800 m of width, and about 600 m of length. The first highest reflector in the sub-bottom profiler (SBP) images gives more apparent pattern of this landslide topography.

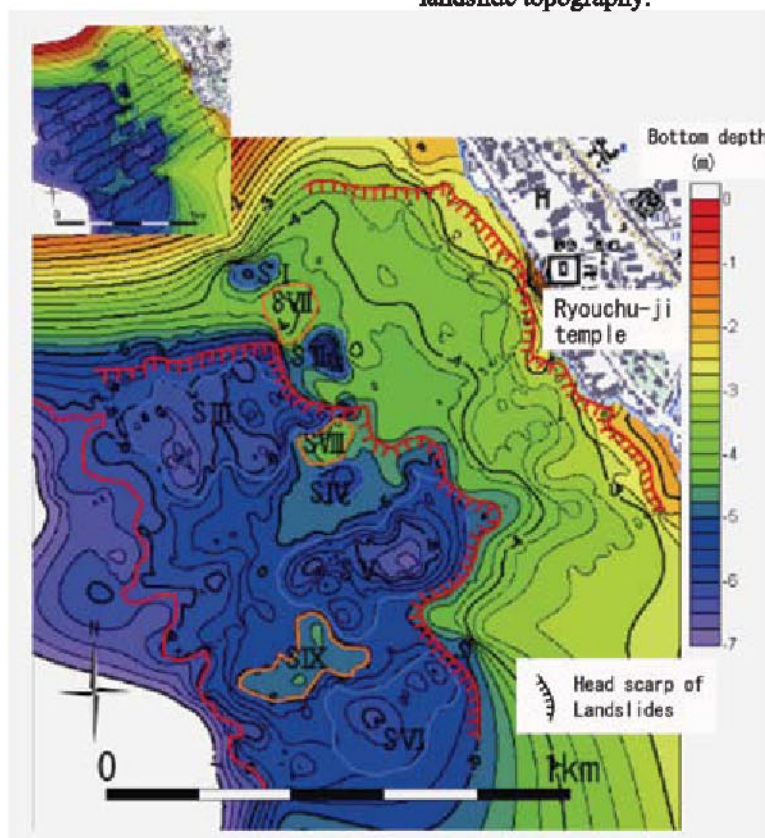


Figure 6: The bottom image detected by SSS survey in the Shimosakahama-senken

4.3 Geologic Structure in the Coastal Terrain

Figure 7 shows the geologic cross section confirmed by Swedish Weight Sounding Tests (SWS) and boring core sampling with Standard Penetration Test (SPT) from the Ryouchu-ji temple to the beach along the section perpendicular to the coastline. The ground here consists of thick alluvial beds, i.e. sands, clays, and gravels. The structure is almost horizontal. The gravel layer intercalated 2-5 meters deep, just beneath the artificial fill, is unnaturally compacted to be firm as alluvial sediments in this region. The previous Ryouchu-ji temple had wider area of site up to 40 ha including whole area of the investigation in coastal terrain. Thus, the firm gravel beds of the shallow depth will be considered as the foundation of the old large temple to be compacted diligently in the past. It should be distinctive characteristic of geologic structure that the base of this firm gravel bed does not continue. The base of the gravel layer bedded almost horizontally, however, it has a few meters gap of level between the beach and coastal terrain at 20 meters west from shoreline. This irregular gap of base level of the artificially compacted gravel layer suggests the piece of the head scarp of the landslide that was induced by the earthquake in 1586.

5. Discussion

5.1 Earthquake in Cause

Dense active fault systems developed around Lake Biwa have caused historical inland earthquake disasters in coastal region of Lake Biwa (Research

Group for Active Faults of Japan, 1991 and Okada and Tougo, 2000). Based on the seismo-archaeological approach, evidences on liquefaction induced by earthquakes were discovered from sub-bottom archaeological sites in Lake Biwa (Sangawa, 1992). Because the changes of lake level were limited during the medieval age, the ground subsidence induced by a historical earthquake was likely the cause of the Naoe-senken and the Shimosakahama-senken sub-bottom archaeological sites. The Shimosakahama-senken has obvious records on the earthquake in cause, the 1586 Tensho earthquake (M7.9-8.1). In contrast, we should discuss the Naoe-senken case. Considering the historical evidences, e.g. the drawing map of the Chikuma shrine, ages of the Naoe-senken were limited from AD 1291 (the age of drawing map) to 1567 (the oldest age of the historical document about the site). Based on the catalogue on the historical earthquake (Usami, 1997), earthquake in AD 1325 (M6.5) is a major potential event as the earthquake with possibility to have submerged the original villages. This earthquake related to the Yanagase active faults system, and induced serious damages in the northern district of Lake Biwa. The Ane-gawa earthquake in 1909 (M6.8) was known as similar earthquake related to the same Yanagase active faults system. The liquefaction of ground in coastal region of the lake was caused by the 1909 Ane-gawa earthquake.

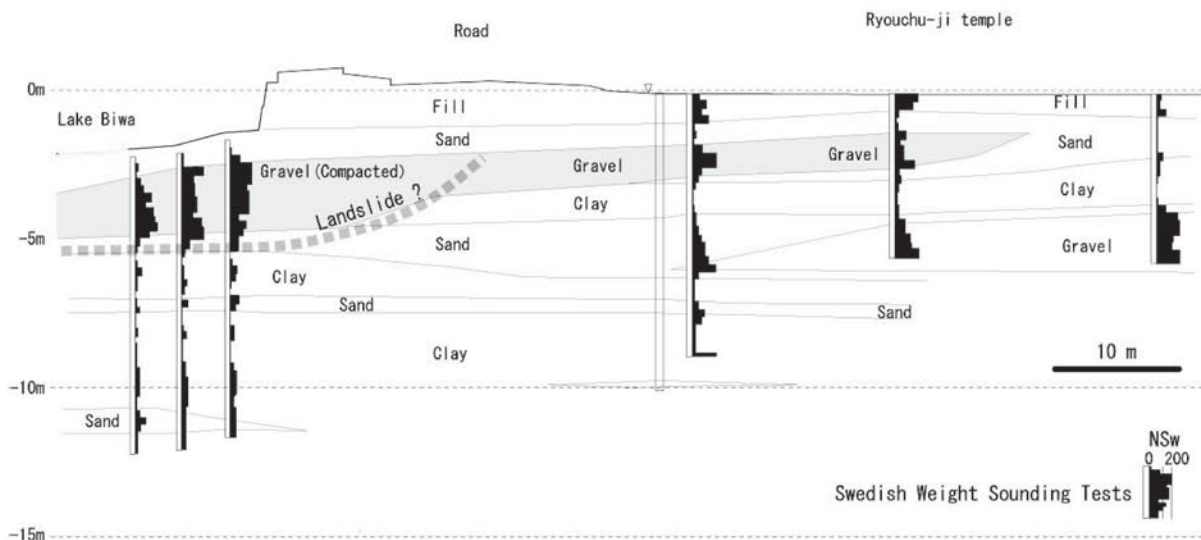


Figure 7: Geologic cross section in the Shimosakahama-senken

5.2 Liquefaction and landslide at coast

The cyclic shear resistance ratio (F_l) between the maximum cyclic shear stress ratio (L_{\max}) and the liquefaction resistance ratio (R_{\max}) is an index indicating the possibility of liquefaction (Seed, 1979). Based on the definition, a F_l value less than 1.0 indicates a high probability of liquefaction.

$$F_l = \frac{R_{\max}}{L_{\max}} = \frac{\left(\frac{\sigma_d}{2\sigma_0}\right)^{20}}{\left(\frac{r_{\max}}{\sigma_v}\right)}$$

Equation 1

Where R_{\max} is defined as the ratio between σ_d and $2\sigma_0'$ required to reach liquefaction at the twentieth loading cycle in the cyclic triaxial test. The maximum cyclic shear stress ratio (L_{\max}), was estimated by the conventional method as below.

$$L_{\max} = r_d \cdot k_h \cdot g \cdot \frac{\sigma_v}{\sigma_v}$$

Equation 2

$$r_d = 1.0 \times 0.015 \times x \quad x: \text{Depth (m)}$$

Equation 3

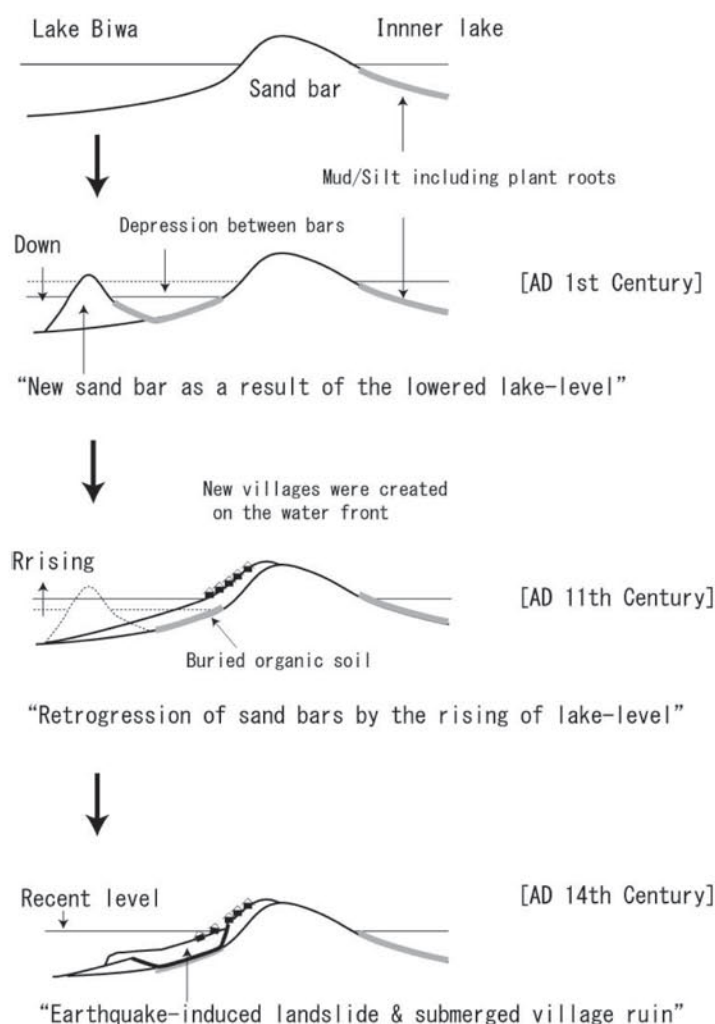


Figure 8: The formation process of the Naoe-senken

The results, F_i value should be controlled by the assumption for the horizontal earthquake force (k_h). When the horizontal earthquake force (k_h) of the earthquake in 1325 was assumed 0.3 based on the distribution of damages in the 1909 Ane-gawa earthquake, the F_i value of intertrappean weak layer would be less than 1.0 (liquefied), and the F_i value of lower sand layer would be greater than 1.0 (not liquefied). Because the geological structure is gently sloping toward the offshore, the ground around the shrine including the two villages was likely moved into Lake Biwa as a landslide with the slip surface along the liquefied weak layer on the dense sand (the old sand bar). The landslide would travel at least 200 m to offshore since that the sub-bottom profiler imaging revealed the toe structure of the landslide at the bottom of 8 m in water depth. Figure 8 shows the thematic illustrations on the formation process of geologic structure and sunken villages in the Naoe-senken.

6. Conclusions

The investigation results on sub-bottom archaeological sites in Lake Biwa, the Naoe-senken and the Shimosakahama-senken, suggest that the villages submerged into Lake Biwa as a result of earthquake-induced landslide associated with ground liquefaction caused by the earthquakes. Similar case studies were known in Japan, Turkey, and USA. The decline of the ancient Alexandria from 4th century could also have been caused by the subsidence of the artificial ground at the coast of the Mediterranean Sea induced by earthquakes. The sub-bottom archaeological sites were distributed offshore of the modern urban regions. Many of the recent artificial ground in this urban region were constructed on the soft natural coastal deposits. Because little attention is paid to basement conditions of fills (embankments), the extensive artificial grounds in urban coastal regions in Japan are subject to a high risk of failure during

earthquakes. Thus, the sub-bottom archaeological sites and recent coastal ground in urban region have essentially the same structure of problems, and the sub-bottom archaeological sites in Lake Biwa provide important information for such issues of our modern society.

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