An investigation of a submerged landslide by using an innovative leisure-use sonar

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Abstract

There are many subaqueous topographies related to geohazards around the world. However, investigations for them are fewer than on land due to their difficulty. Recently, I used a fish finder designed for leisure use and other low-cost equipment to conduct an underwater acoustic survey. This paper introduced our investigation of a submerged landslide in Lake Ashinoko, Kanagawa, Japan. By our developed method, I created a bathymetric map and obtained side-scan images showing features of the landslide mass exposed on the lake floor, and found that the main landslide body is located on 300-450 m offshore at 30 m deep. The landslide body had trees standing on the surface, suggests it traveled on the lake floor without turbulence. The method is helpful to consider processes of submerged landslide.

Keywords: submerged landslide, submarine landslide, lake, fish finder, side-scan sonar

1. Introduction

There are many subaqueous topographies that related to natural hazards around the world. For example, submarine landslides, volcanos and active faults have caused deadly disasters. In earthquake-prone areas such as Japan, historical records has documented the occurrence of sudden landslides in coastal areas that have swept residences and other infrastructure into the sea or lakes. For example, in the 1792 Unzen Mayuyama landslide, a volume of 3.4×10^8 m^3 swept through Shimabara killing about 10,000 people. The landslide reached the sea and caused tsunamis that killed another 5000 people in and around Ariake Bay (Tsuji and Hino, 1993). In 2000s, Hayashi and his research group began to investigate 10th century-submerged ruins in Lake Biwa, Japan, by conducting dives and acoustic marine surveys. They inferred that these ruins were carried into the lake by landslides induced by the liquefaction of lakeside sediments (Hayashi et al., 2012). The aim of acoustic marine surveys is not only to conduct archeological research but also to estimate the vulnerability of areas to future hazards, particularly coastal areas. However, few studies have investigated subaqueous topographies related to geohazards because of the difficulties in surveying such areas.

In this study, we examined submerged landslide in Lake Ashinoko. In the lake, trees standing on a part of lake floor had been eyewitnessed for long time. Oki (1993) suggested the trees were carried by landslides with their diving investigation and the results of ^{14}C dating for trees. Because Lake Ashinoko is a dammed lake by a collapse of volcano in about 3000 years ago (Nagai and Takahashi, 2008). These trees aged around 1050, 1600 and 2100 years ago, those are quite younger than 3000 years ago. Oki (1993) made distribution map of trees on the lake floor by a traditional fish finder, but did not determine the shape and extent of landslides.

By the way, marine acoustic technologies have conventionally been employed to investigate seafloor topography. Obtaining shape of them are easy by using narrow and high frequency acoustic beam that are used for scientific research. However, these surveys are usually quite expensive. Recently, some leisure-use new fish finders have high frequency acoustic beam systems and side-scan sonar systems to find fish reefs, and such systems can couple the recorded sounding data with location data obtained by the global navigation satellite system (GNSS). I developed a method employing the fish finder to investigate subaqueous topography (Yamasaki and Kamai, 2015). In this paper, I present it thorough the investigation of submerged landslide in Lake Ashinoko.

2. Method

The application of acoustic reflections is a conventional method to obtain data on water depth,

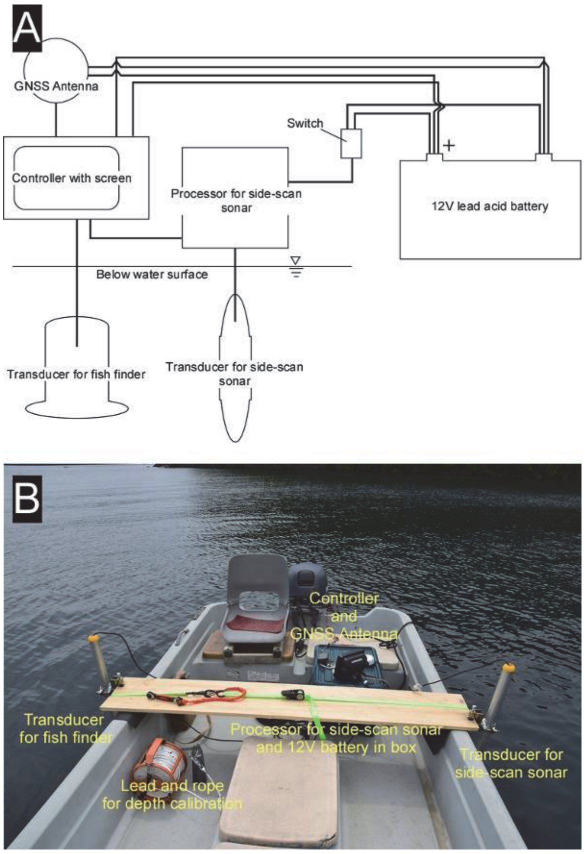

Fig. 1 (A) Schematic diagram of the fish-finder system and (B) photo of the boat equipped with the transducers. Further details are suggested in the text.

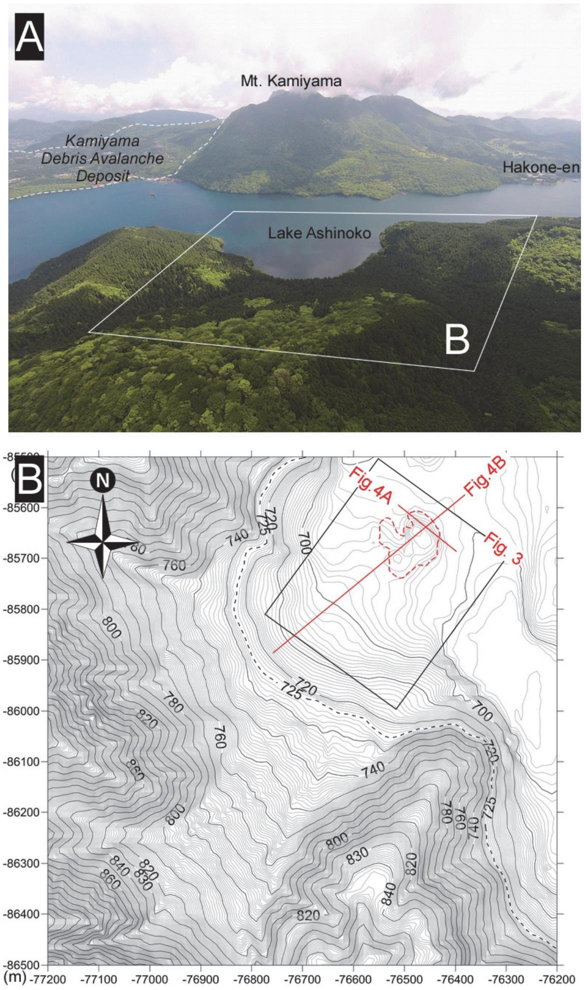

Fig. 2 (A) aerial photo of Lake Ashinoko and (B) Topographic and bathymetric map of the area shown in (A) (contour interval on land and under water, 1 m). Numbers in axes are the distance (meter) of the control point. The square indicates the boundary of the side-scan sonar scanning area (Fig. 3). Red dashed line enclosed area is "high reflection area" observed by side-scan sonar. Two black lines indicates the locations of the 455 kHz acoustic profile (Fig. 4). The bathymetric map was generated from data obtained from this study. The topography on land was obtained from 5-m DEM data of the Geological Survey Institute of Japan.

underwater topography, and bottom materials. A single-beam echo sounder (or single beam sonar) is used to measure depth and detect objects just beneath a ship; fish finders employed for leisure use are an example. Multi-beam sonars can measure multiple depth data simultaneously and have been used on scientific research vessels, but those systems are expensive and too heavy to be used on small boats, such as the inflatable raft that I used for my survey of shallow nearshore waters. Modern fish finders are small enough to be used on smaller boats. Some newer fish finders also employ GNSS to couple recorded depths with location information. Some leisure-use fish finders employ a side-scan sonar system, which enables them to obtain a wider image of the seafloor.

For the investigation in Lake Ashinoko, I used HDS-5 Gen2 fish finder (Lowrance, US), which was capable of obtaining consecutive location information to within 3 m horizontally through the use of a GNSS system. The transducer on the fish finder was a B60 (Airmar Technology Corporation, France) with an assigned frequency of 200 kHz. The minimum recordable depth interval was 1 cm. The data obtained by this transducer were used to create a bathymetric map because the fish finder has a narrower measuring interval than the side-scan sonar. I also used a side-scan sonar system (StructureScan LSS-HD, Lowrance) to record consecutive sonar and side-scan images and depth information on an SD card. The side-scan sonar system had a 25-cm-long transducer with an assigned frequency of 455 kHz. Both systems were powered with a 12-V lead acid battery. The total weight of both systems, including the battery, was about 10 kg, so I was able to place the equipment on a small boat that could navigate the shallow waters of

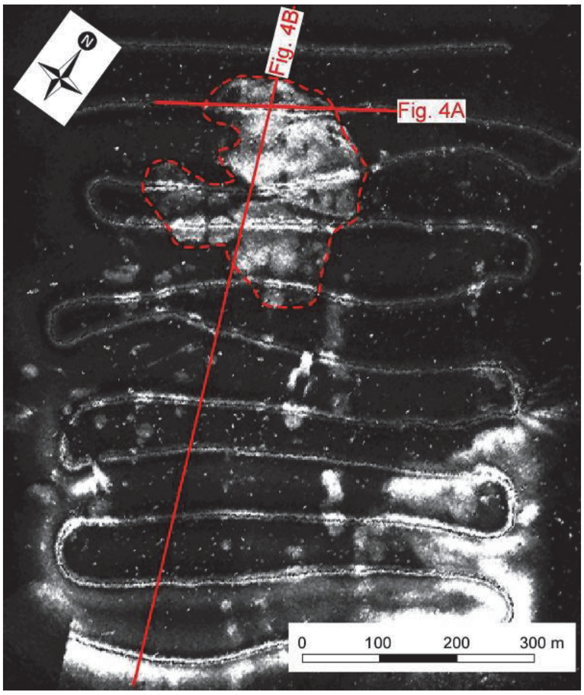

Fig. 3 Synthetic side-scan sonar images indicated in Fig. 2. Red dashed line enclosed area is "high reflection area".

the study area (Fig. 1).

The bathymetric survey was conducted in shallow water (<30 m) over an area of 1000 m × 700 m at intervals of 30 m. The side-scan survey was conducted over a smaller part of this area (400 m × 500 m) along 11 measurement lines. Side-scan images were captured directly from the display of the fish finder.

I extracted consecutive location information with coordinates and depths with SonarTRX software (Leraand Engineering, US), a sea-bottom mapping software application, from the data obtained by the fish finder. I then used the mapping software Surfer 12 (Golden Software, US) to construct a contoured bathymetric map. Interpolation was done by the kriging method. Then, to generate a geometrically corrected map, I corrected the coordinates of point data with Japanese rectangular plain system IX, for which the origin point is E139°50'00", N36°00'00".

Follow-up underwater camera observation was conducted after the acoustic investigations to confirm the findings.

3. Results and Discussions

In this paper, I show an investigation case for the north part of Lake Ashinoko with obtained data.

Generated bathymetric map (Fig. 2) shows a characteristic ca. 400-m-long ridge from the center of bay to the deeper part of lake. The steep slope is located from water surface to the depth of 20 m (725-705 m in Fig. 2). The ridge connects the foot of the slope and the ridge has a rise at its deeper part.

Synthetic side-scan image (Fig. 3) in the squared area in Fig. 2 suggests the rise is high acoustic reflection area (brighter color) suggesting the presence of high dense material exposed on the lake floor. The shape of "high acoustic reflection area" corresponds to the topography of the deeper part of ridge. In addition, smaller high reflection areas (bright color area) are separately distributed on shallower area than the rise, and they are scarce on deeper area. Low acoustic reflection area (darker color) that widely covered on the lake flower is lose lacustrine sediment. Hence, "high acoustic reflection area" is other origin, like the sediment on land.

Vertical acoustic profiles (Fig. 4) shows rises with high acoustic reflection and stick like structures standing on the rises. These stick like structures were trees were observed by an underwater camera (Fig. 4C). The trees on the lake floor has been reported by Oki (1993). A number of trees were tilted onshore (Fig. 4B). It is reasonable that the trees are carried from land, because trees were rare on the lacustrine sediment and on deeper part of the lake. At least they are not the trees before the lake advent.

Oki (1993) already suggested the trees on the lake floor caused by past landslides. The scattered

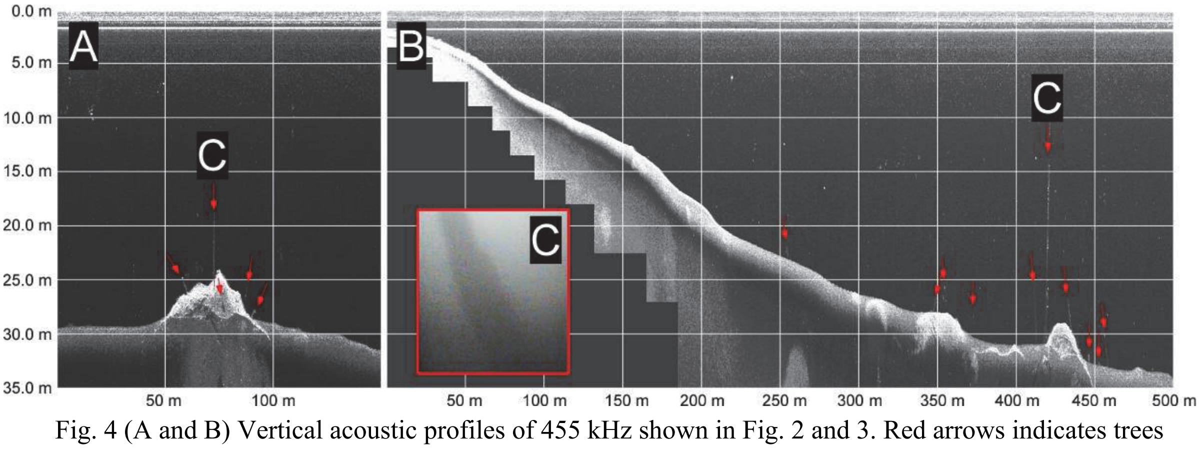

Fig. 4 (A and B) Vertical acoustic profiles of 455 kHz shown in Fig. 2 and 3. Red arrows indicates trees standing on the lake floor. (C) A trunk of tree observed by underwater camera.

high acoustic reflection areas under water are considered as scattered masses by a submerged landslide.

Since I do not have any information of the past lake water level, I cannot discuss where the landslide occurred. However, the bathymetric map give some clues. As the map showed, there is steep slope from the water surface to the depth of 20 m, it is the common feature around the lake. The landslide formed ridge is located on the foot of the steep slope. The steep slope has probably formed with erosion by rising water level. Also the landslide probably occurred in a certain past age. With rising water level, ground water level also rises. That situation makes preferable condition landslides occur.

The research group of Kihara Institute for Biological Research and Kanagawa Hot spring and Geological Research Institute took samples of trees around the "high acoustic reflection area" for ^{14}C dating and obtained chronological value of 1600 years ago (Oki, 1993). That value is quite younger than the age of lake (3000 years ago: Nagai and Takahashi, 2008). As Oki (1993) proposed, some strong earthquake might have triggered the landslide.

The bathymetric map and the side-scan image shows also clues of the submerged landsliding process. The large high acoustic reflection area is a part of large landslide mass. The trees on the mass may have tilted to onshore by water pressure. The landslide travelled at least ca. 300 m sliding parallel to the lake floor without turbulence.

4. Conclusions

I investigated a characteristic subaqueous topography of Lake Ashinoko by using a recent fish-finder, made bathymetric map, and obtained side-scan images and vertical acoustic profile images. I clarified the topography was formed by a past landslide, and discussed the landsliding processes and timing of the occurrences. The subaqueous investigation by using fish finders is useful for finding past subaqueous hazard events.

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