This is the twelfth article of a 15-part series on the GLOF research and mitigation project between May 2009 and March 2012. The articles will highlight latest findings on glacier, glacial lakes condition and natural hazards in the Bhutan Himalayas. Experts from the department of geology and mines (DGM), Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST) are involved with the project.

Topographic survey on the glaciers in Lunana

Thorthormi glacier in Lunana region is one that's worth noting of due to recent dramatic changes in the glacier surface and an on-going GLOF mitigation project. Satellite images in 1967 and 2009 show the drastic change of the glacier surface condition (Fig 1 and 2). In 1967 Corona (Fig 1, US reconnaissance satellite) image shows scattering small ponds around the glacier tongue (inside of the red line area). A new satellite image in 2009 by PRISM (Fig 2, a panchromatic radiometer on ALOS Japanese earth-observation satellite) shows two large ponds (A and B in Fig 2), and those are coming to coalesce. A site photograph (Photo 1) shows the nearly coalescing point. At the time of the last field survey in 2011, we gingerly crossed this narrow corridor one by one to go onto the main body of Thorthormi Glacier (arrow in Photo1.) The corridor width has changed every time the lake level fluctuated. Fortunately, we could return to the front side (landward) via moribund corridor in this field campaign. However, there is no guarantee that the corridor will remain in the next survey.

The expansion of ponds on the glacier surface means shrinkage of the glacier ice. To evaluate the glacier volume change quantitatively, which can be recognized only by a three-dimensional assessment, we performed field measurement using Global Positioning System (GPS) on Thorthormi glacier from September18 to 24, 2011.

Three different teams surveyed the Thorthormi glacier area to gather extensive topographic information on the glacier. Despite rugged glacier surface, each team tried to zigzag as much as possible. In some cases we jumped small crevasses with pounding heart. Figure 2 shows tracks of the GPS survey around Thorthormi glacier. Light yellow line indicates the track on Thorthormi glacier. The measurement errors are 0.11 m horizontally and 0.17 m vertically.

Changes in elevation on the glacier surface will be analysed by comparing previous GPS data measured in 2004 autumn by a Japanese team. Preliminary calculation showed surface lowering of Thorthormi and Luggey glaciers and another glacier situated north of Luggey. The surface lowering of Thorthormi glacier is 10-25 m for the period of 2004-2011. As mentioned above, we can clarify glacier health conditions by the combination of field measurements and satellite data analyses. And those diagnostic results would contribute to determine the priority of GLOF mitigation operation site in future.

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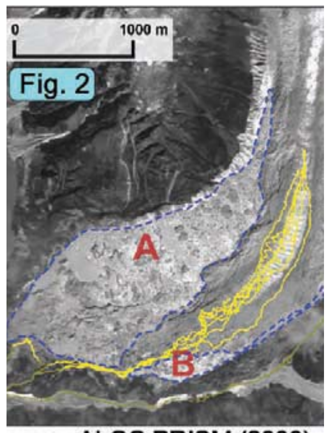
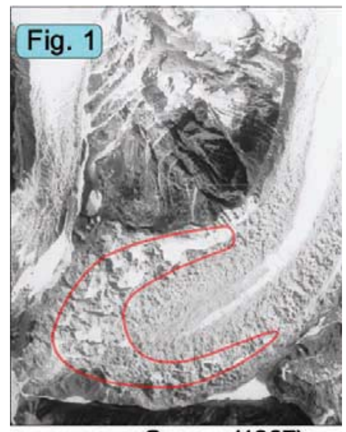


ALOS PRISM (2009)



Corona (1967)

Photo. 1 Width of the corridor was just for one person

Geophysical Study of Moraine Dam

To complement the study done by glaciologists, geophysical studies were carried out in the moraine to determine the thickness of ice and to study on subsurface glacial lakes. Any kind of materials of ground soil and rock as well as water can pass electric current regardless of the amount. "Electric Sounding Method", one of the geophysical exploration approaches, can delineate the electric character in the ground by measuring the resistivity when high electric current from the ground surface is artificially generated. The electric character in the ground depends on the constituent materials (Fig 3). For instance, saturated fine-grained soil has low resistivity, whereas dried coarse-grained sand shows high value. Resistivity of fresh and massive rock is very high, but the one of weathered or highly fractured rock is comparatively low. This method has been well used in investigation of groundwater, slope stability study and mineral exploration field, where direct observation by drilling is restricted.

When we consider the potential risk of Glacial Lake Outburst Flood, it is essential to understand internal structure and materials of the moraine dam, which impounds a large volume of lake water behind. We applied the Electric Sounding Method for several moraine dams lying in the Po Chhu and the Mangde Chhu River basins.

We often generated the high current, which can electrocute animals if they touch the iron pole, to achieve the resistivity in the deep underground. Besides, we needed to scout about few kilometers around the survey site to obtain a proper marshy area of high conductivity. It was really laborious work in high altitude area.

Ice body in moraine dam is one of the key issues to assess the dam stability because it may behave as an impermeable material in the dam. At the same time, it could be a factor of subsidence and deformation that may contribute to destabilization of the dam. In general, ice body has extremely high resistivity. It can be clearly identified in the moraine.

Zanam C glacial lake, one of our target glacial lakes in the Mangde Chhu River basin, has 200m height steep moraine slope (Figure 4). The Electric Sounding result showed that there is no ice body inside, contrary to our expectation, but a characteristic resistivity distribution signifying "Bedrock" could be observed in the shallow part (Figure 5). We concluded that the most bulk of moraine slope is composed of stable bedrock, and debris material must be limited at only shallow zone less than 30m. The obtained fact is significant information to assess the potential risk of outburst of the Zanam C moraine dam.

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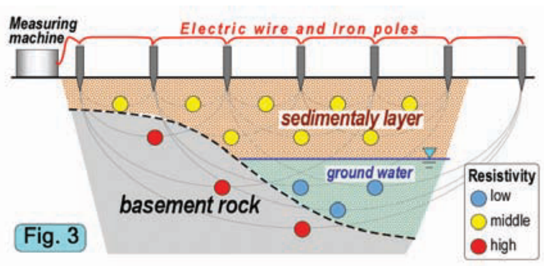

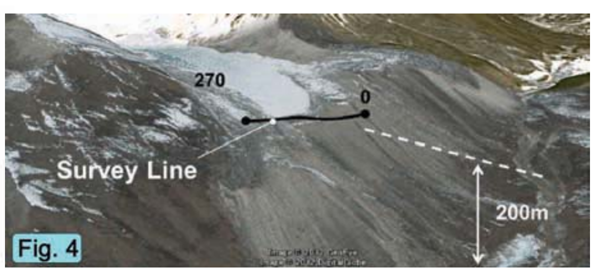

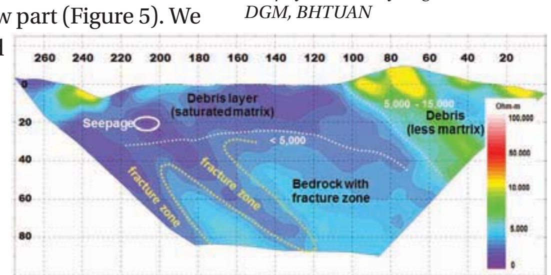

Fig.5 Resistivity section and estimated geological condition in Zanam-C Glacial Lake. The survey line was illustrated in Figure 4.