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GLACIER-GENERATED GROUND MOTIONS AT BOMI, SOUTHEASTERN TIBET

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Abstract: Seismic observation was carried out from late July to early November 1992, at Bomi, southeastern Tibet, to assess glacier hazard. Glaciers in the area are so-called monsoon-maritime glaciers. Both accumulation and ablation are large in summer. Glacier-generated ground motions such as icequakes and continuous vibrations were observed frequently. General features of ground motions were similar to those from Antarctic continental glaciers. The continuous vibrations were characterized by monochromatic components, and their peak frequencies were 7.0 to 10 Hz, from which the effective thickness of glaciers was estimated as 25-36 m. Seismic observation was considered useful to monitor and predict catastrophic glacier-movements.

1. Introduction

Under the context of the International Decade for Natural Disaster Reduction (IDNDR), a cooperative research project, Glacier Surge Hazards in the Mountainous Area in Western China, has been carried out by the Disaster Prevention Research Institute, Kyoto University and Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences. The main object of the research project is to conduct studies on the hazard caused by the glacier system to obtain more reliable assessing and mitigating methods (AKAMATSU *et al*., 1992). On the basis of an understanding that a glacier hazard is an issue of a complex multi-disciplinary system, seismic observation (Bomi town), yearlong climatological observation (the Midui glacier) and glacial debris-flows observation (the Guxiang glacier) have been carried out in the glacier areas in Bomi County, southeastern Tibetan plateau.

The glaciers in the area are typical monsoon-maritime or temperate glaciers, and are active in summer. A large number of glacier-generated ground motions were recorded with the seismograph system. The characteristics of ground motions are comparable with those from the Antarctic continental glaciers.

In this paper, we discuss several features of glacier-generated ground motions to estimate the thickness of glaciers in relation to Antarctic glaciers. In addition, the climatological observation in the Midui glacier area is introduced.

2. Geological Setting and Glaciers at Bomi

Figure 1 shows the location of Bomi, southeastern Tibet. Bomi is located on the River Polung Zangbo, a branch of the Yarlung Zangbo (Brahmaputra), running from SEE to NWW between the mountain ranges of Nianqingtanggula (the highest peak: 6115 m) and Gangrigabu (6585 m). Rock formations are mainly argillacious rock, phyllite and limestone of the Carboniferous and Permian periods with granite formed in the Triassic and Jurassic periods. Huge fracture systems with NWW strike are developed.

There are many glaciers with typical Quarternary glaciation, forming terminal and lateral moraines. The Midui glacier is located on the north slope of Mt. Gangrigabu. It is about 10 km long and its terminus reaches as low as 3800 m a.s. l. Photo 1 shows the general view of the Midui glacier, and Photo 2, its ogives developed at its terminus. In 1988, glacier movements caused a glacier-lake flood, resulting in serious damage to the Sichuan-Xizang Highway and death of 5 persons (ZHANG, 1991).

The Guxiang glacier is located on the south slope of Mt. Nianqingtanggula, causing very frequent glacial debris-flows. In 1953, large debris-flows occurred very frequently in the Guxiang gully, and are considered to be caused by the unstable conditions of glaciers produced by the 1950 Assam Earthquake of **M** 8.6 (DU and

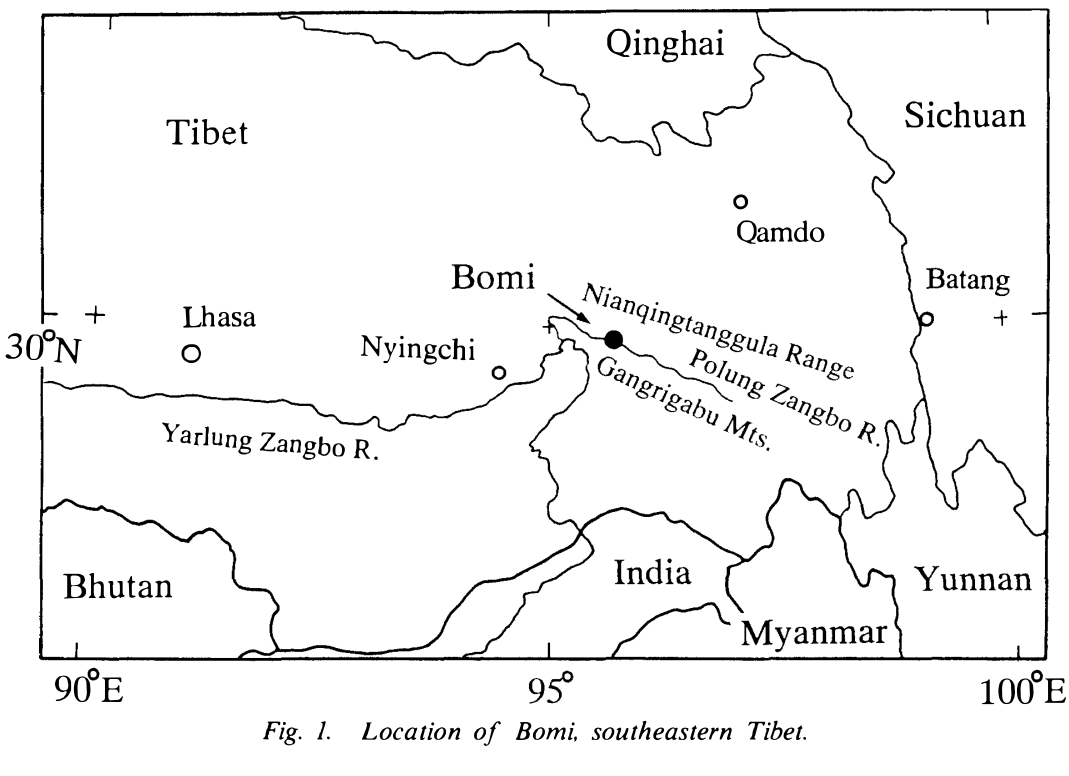

Fig. 1. Location of Bomi, southeastern Tibet.

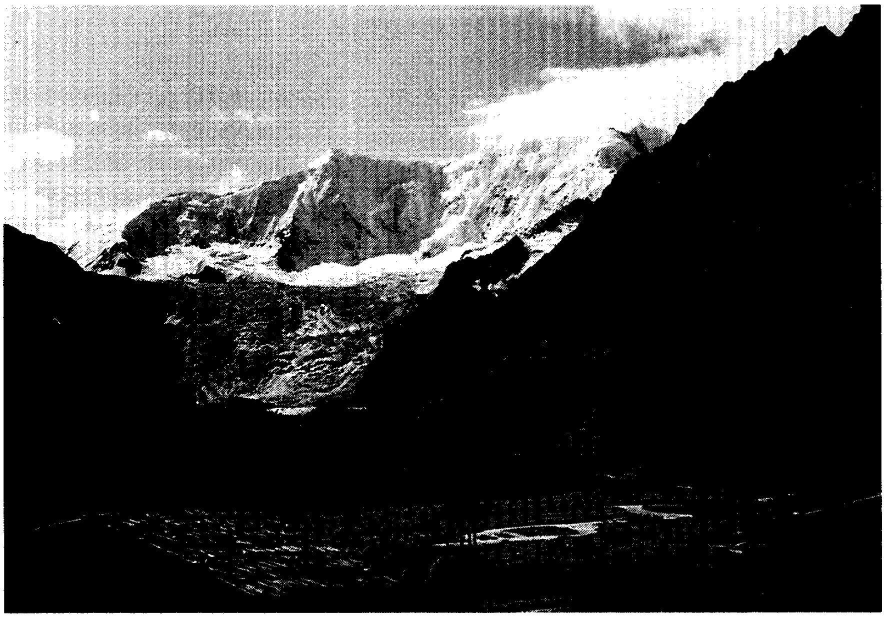

Photo 1. General view of Midui glacier at Bomi, southeastern Tibet. Ice-fall with frequent collapses develops near terminus.

Photo 2. Ogives developed at the terminus of Midui glacier. Average distance between ridges of ogives measured 30 m.

ZHANG, 1985).

These glaciers are so-called monsoon-maritime glaciers: both accumulation and ablation are large in summer. Consequently, the movements of glaciers are considered active in summer.

3. Seismic Observation at Bomi

The Bomi town-area is developed along the River Polung Zangbo between the mountain ranges. The observation site was set at the foot of northern range. Its altitude is about 2700 m. There are many glaciers within a distance of a few kilometers. The observation was carried out with 1-s 3-component seismometers and an analog magnetic recorder by the usual event-triggering method (threshold level $=2\times10^{-6}$ m/s). The observation system is shown in Fig. 2.

During 101 days from July 20 to November 6, 1992, 89 tectonic earthquakes were recorded. In addition, we observed very frequently two kinds of ground motions possibly generated by glacier movements and/or debris-flows: icequakes with pulsive forms and continuous vibrations. Table 1 lists the numbers of each event.

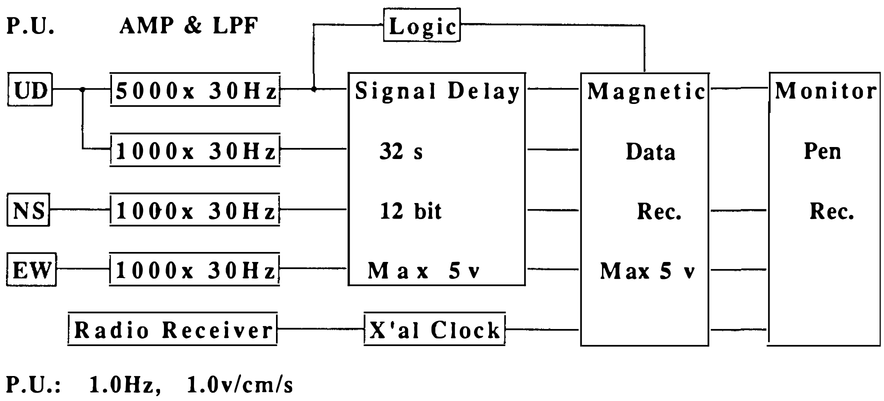

Fig. 2. Seismograph system used at Bomi. Velocity flat response is achieved from 1 to 30 Hz.

Table 1. Event lists of seismic observation at Bomi, south-eastern Tibet. Threshold level was 2×10^{-6} m/s. Observation period was total of 101 days; July 20-22, July 28-August 7, August 10-November 6, 1992.

Event	No.
Local earthquake	65
Regional earthquake	20
Far earthquake	4
Icequake	872
Continuous vibration	670
Total	1631

4. Characteristics of Glacier-Generated Ground Motions

Figure 3 shows examples of icequake swarm (a) and continuous vibrations (b). Although their source locations were not obtained from the seismograms, the glaciers around Bomi were considered to cause the ground motions, because we frequently saw collapses at the ice-fall in the Midui glacier, and the durations of acoustic sounds

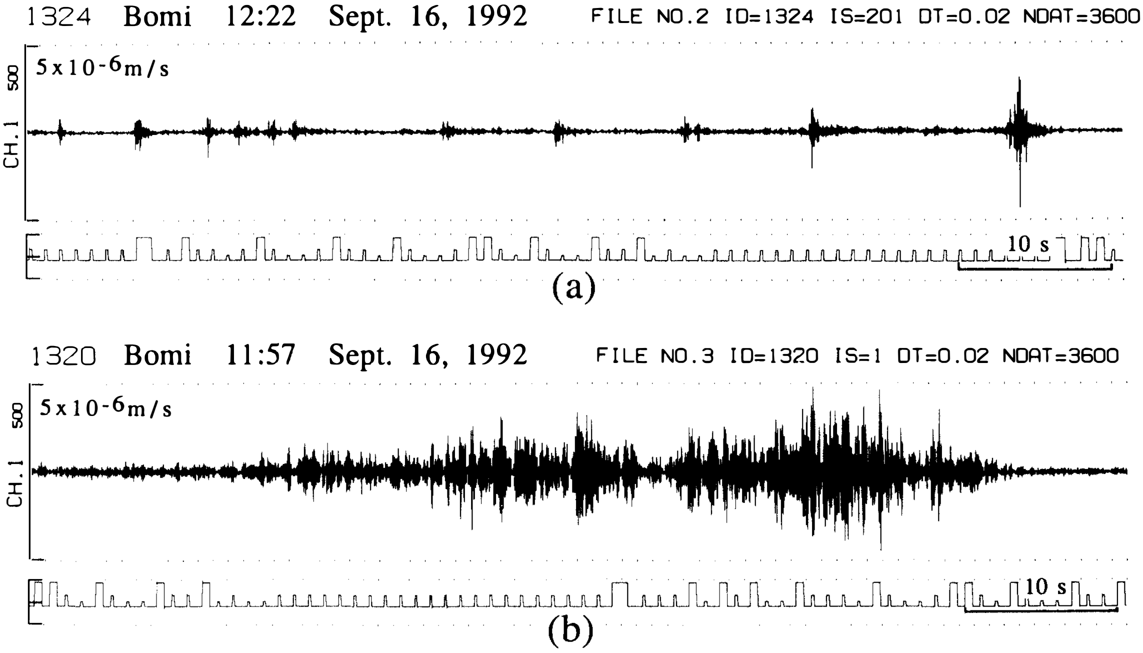

Fig. 3. Glacier-generated ground motions observed at Bomi: icequake swarm (a) and continuous vibrations caused by glacier-movements and/or glacial debris-flows (b). Note that general feature of continuous vibrations is similar to those from Antarctic glacier shown in Fig. 4.

exceeded 30 s. The duration of continuous vibrations occasionally lasted for more than several minutes.

The general features resemble those of ground motions caused by movements of Antarctic continental glaciers (AKAMATSU *et al.*, 1989, 1990). Around Syowa Station, various events related to ice were observed: icequakes of sea ice around the Ongul Islands, shock-type icequakes of ice sheet and continuous vibrations caused by glacier movements.

Figure 4 shows an example of continuous vibration, which was considered to be caused by movement of Langhovde glacier. The site, LAN, is located about 3.5 km from the terminus of Langhovde glacier. It was reported that in a typical case the continuous vibration continued for more than 10 min. The difference in duration

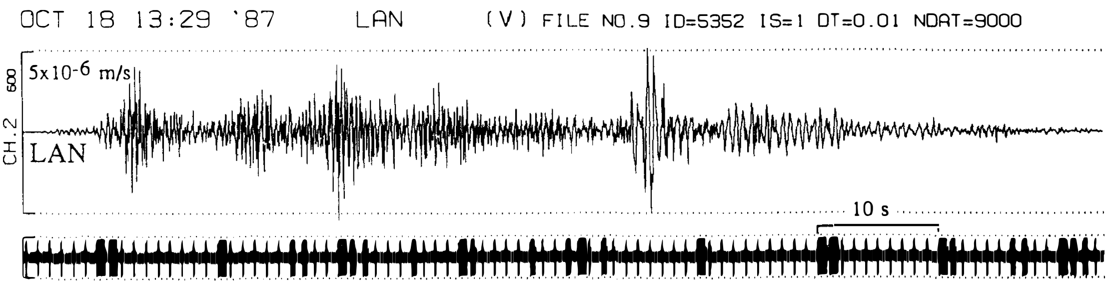

Fig. 4. Continuous vibrations caused by Langhovde glacier, East Antarctica, observed at Syowa Station. Observation site, LAN, is located about 3.5 km from the terminus of glacier.

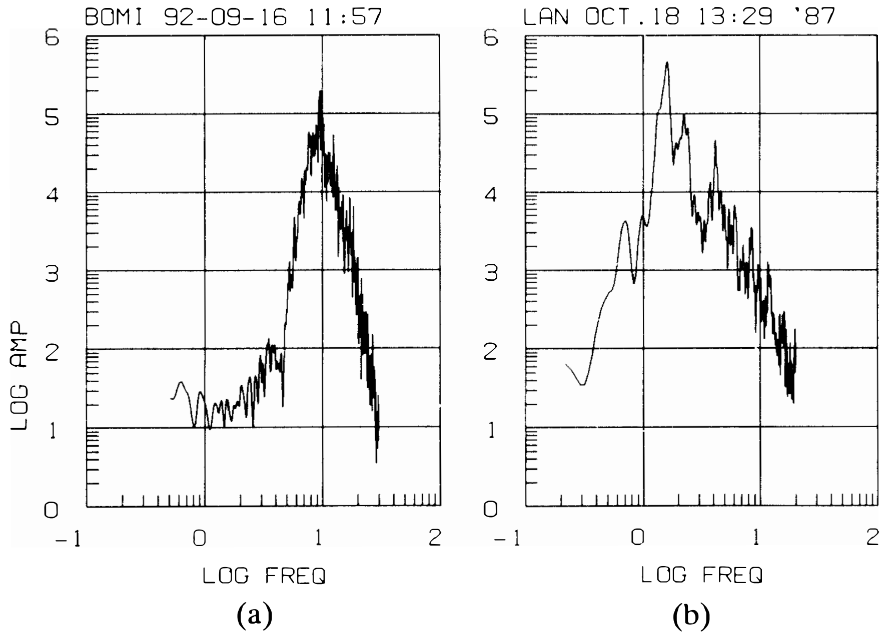

Fig. 5. Power spectral densities (arbitrary unit) of continuous glacial vibrations observed at Bomi (a) and East Antarctica (b). Note the monochromatic features with different peak frequencies and a striking contrast to wide frequency content of tectonic earthquakes as shown in Fig. 7.

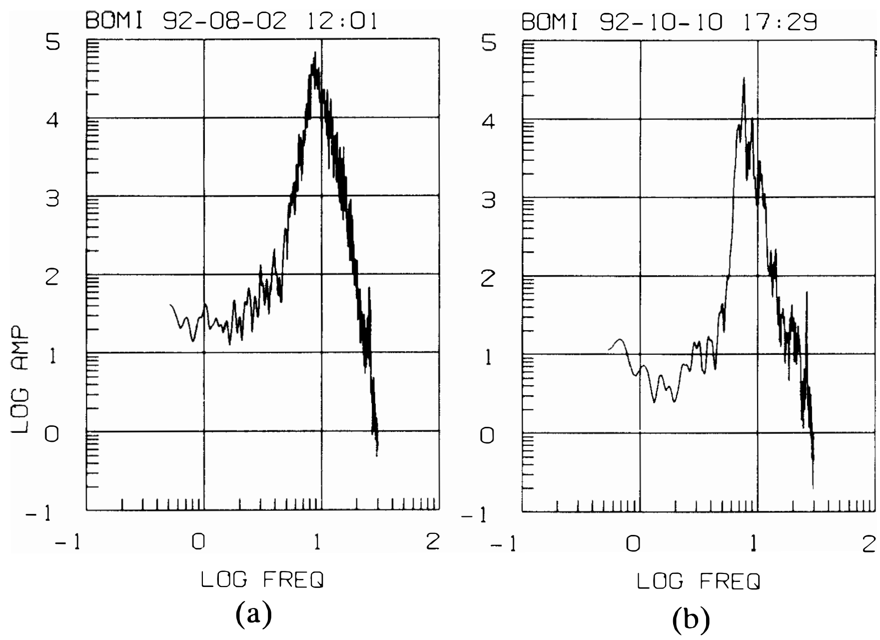

Fig. 6. Examples of power spectral densities (arbitrary unit) of continuous glacial vibrations observed at Bomi. Note that almost all of the events had peaks around 10 Hz (a), however, several events were characterized by lower frequency peaks of 7–8 Hz (b).

time between the mountainous glaciers at Bomi and the continental glaciers in Antarctica seems to relate to their scales and mode of movements.

5. Frequency Contents of Vibrations and Thickness of Glaciers

Figure 5 shows the power spectral densities (arbitrary unit) for the vertical components of the events shown in Figs. 3(b) and 4. The spectral shapes of horizontal components are almost the same as vertical ones. These spectra are characterized by monochromatic features. The peak frequencies are 9.5 Hz for Bomi and 1.5 Hz for Antarctica. Figure 6 shows the other examples of spectra at Bomi. Almost all of the spectra had peaks at 9–10 Hz. However, we observed several events with slightly lower frequency peaks at 7–8 Hz.

Generally, observed ground motions reflect source property, path effect and local site conditions due to surface geology. Soft surface layering also causes characteristic frequencies of vibrations.

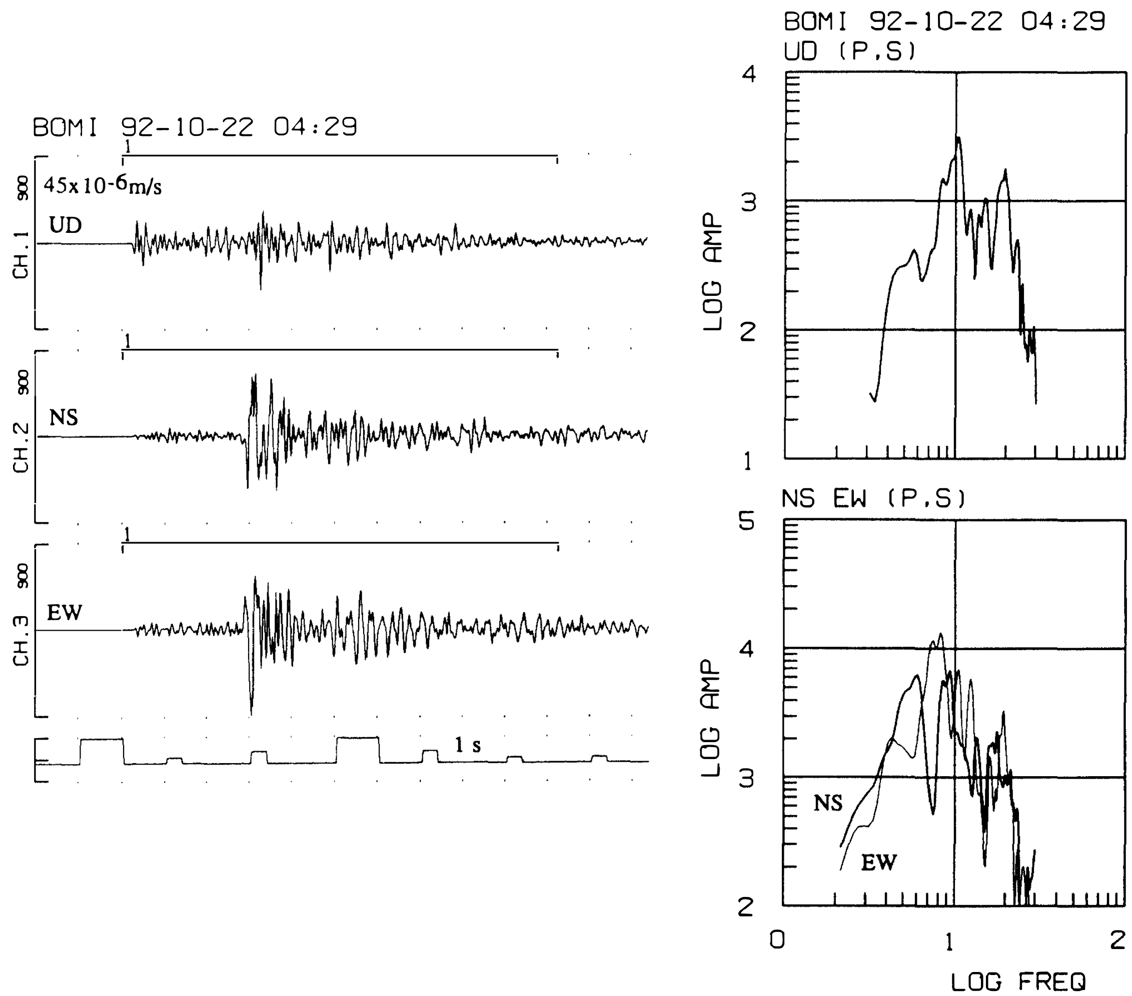

Fig. 7. An example of local small earthquake observed at Bomi and its power spectral densities (arbitrary unit). Note that the frequency content is wide from 3 to 20 Hz.

In order to examine the effect of surface geology, we evaluated the spectra of seismic waves from tectonic earthquakes. Figure 7 shows an example of a local small earthquake, demonstrating the existence of various spectral contents in the wide frequency range. Because the path effects are not large in these short hypocentral distances, and the site effects are nearly the same, the monochromatic feature of continuous vibrations is attributed to the source property of glacier movements. The monochromatic oscillations are most likely to be explained by resonance of glaciers (WOLF and DAVIES, 1986).

Using the quarter wave-length law (TAZIME, 1957), that is, $H = L/4$ and $V_s = fL$, where H: thickness of glacier, L: wave length, V_S: shear wave velocity in glacier and f: predominant frequency, then we can estimate the effective thickness of a glacier. With $V_s = 1800$ m/s as shown in Fig. 8 (IKAMI and KAMINUMA, 1984) and $f = 1.5$ Hz, the thickness will be 300 m for the Langhovde glacier. On the Prince Olav Coast, the thickness of the continental ice-sheet is estimated up to 600 m (ITO and IKAMI, 1984). Therefore, the value, 300 m, seems reasonable.

We have no information about V_s for the glaciers at Bomi. Using the same velocity data for shallow depth, $V_s = 1000$ m/s for 10–20 m deep (see Fig. 8) and $f =$ 7–10 Hz, the effective thickness of the Bomi glaciers becomes 25–36 m. Considering the topography of glacial valleys and the glacier width of a few hundred meters, the value of several tens of meters seems a proper estimation.

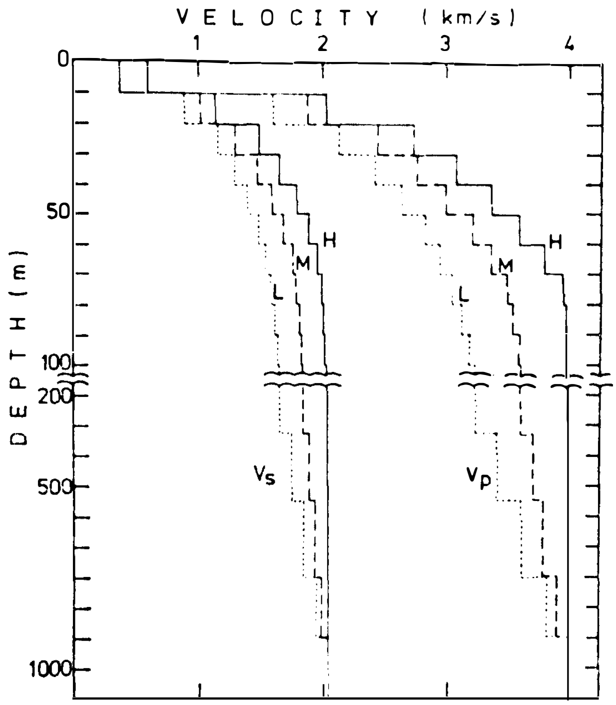

Fig. 8. Velocity profiles of ice sheet in Prince Olav Coast, East Antarctica. H, M and L mean a high, intermediate and low velocity model, respectively (after IKAMI and KAMINUMA, 1984).

6. Yearlong Glacio-Climatological Observation in the Midui Glacier Area

In the course of study for a glacier hazard system, it is very important to know the mass balance of the glacier. Unfortunately there have been no climatological/meteorological observations lasting throughout the year. We have set up climatological equipment in the Midui glacier area from 3700 m to 5200 m a.s.l. All equipment can operate more than 1 year without maintenance. The observed items are: (1) air temperature, (2) sun shine, (3) precipitation, (4) wind speed and wind direction, and (5) snow depth. All the data will be available in August 1993. The relation between the occurrence of glacier-generated ground motions and the climatological condition will be given in future.

7. Concluding Remarks

Seismic observation was carried out in a glacier area at Bomi, southeastern Tibet. The glaciers are typical temperate or monsoon-maritime glaciers, and consequently their activity is high in summer. Glacier-generated ground motions were observed frequently. Their characteristics are summarized as follows:

(1) There are two kinds of glacier-generated ground motions: icequakes with pulsive form, and continuous vibrations by glacier movements and/or glacial debris-flows.

(2) General features of glacier-generated ground motions are similar to those of Antarctic continental glaciers.

(3) Spectra of continuous vibrations are characterized by monochromatic contents and their peak frequencies possibly reflect the effective thickness of glaciers.

In conclusion, seismic observation is considered useful to monitor and predict catastrophic glacier-movements.

Acknowledgments

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