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LEVELING SURVEY ON EAST ONGUL ISLAND, ANTARCTICA AND ITS IMPLICATIONS

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Abstract: A route for a repeat leveling survey was established on East Ongul Island (69°S, 39°E), East Antarctica by the 20th Japanese Antarctic Research Expedition (JARE-20) in 1979 and JARE-23 in 1982. One of the purposes for establishing the leveling route is to detect crustal movement in Antarctica. The leveling measurements were repeated in 1992 and in 1996. Because of the time limitation, only 2.3 km out of the total length of 5.3 km route was surveyed. The mean square error every one kilometer is obtained as ±0.57 mm. Bench Mark (BM) 1040 is taken as a reference point which is also the reference point for oceanic tide observations at Syowa Station and is located on the westernmost point of the route. The height change between measurements in 1982 and 1996 at the easternmost point BM 1026 is –0.2 mm. No appreciable change of height at BM 1026 was observed for the last 14 years. This fact supports the idea of a block movement of crust which is explained as a process of crustal uplift after deglaciation.

key words: leveling survey, crustal uplift, oceanic tide, elevated beach, local earthquake

1. Introduction

Many well developed raised beaches, due to crustal uplift after deglaciation, are recognized in ice free areas of the Antarctic coast (*e.g.* YOSHIDA and MORIWAKI, 1979). The maximum height of these raised beaches around Syowa Station (69°S, 39°E) in East Antarctica was about 20 m and the dating of the shell fossils from these beaches gave dates ranging between 5000–6000 years (*e.g.* YOSHIDA, 1983; KAMINUMA and AKAMATSU, 1992). However many different heights of raised beaches and different dates of shell fossils have been reported by many researchers during the last decade (*e.g.* HAYASHI and YOSHIDA, 1994).

Oceanic tide data at Syowa Station show apparent sea level falling at a rate of 4.5 mm/y (MICHIDA *et al.*, 1995). The sea level falling suggests that crustal uplift continues at present. A process of crustal uplift after deglaciation was proposed by KAMINUMA (1996). Such a process can explain the existence of raised beaches, sea level changes and microseimic activities around Syowa Station.

To detect crustal movements, a leveling survey route was established on East Ongul Island by the 20th and the 23rd Japanese Antarctic Research Expeditions (JARE-20 and JARE-23) in 1979 and 1982. This leveling route is the first in Antarctica. Repeat measurements over the route were done in 1992 and 1996. Because of the limitation of time in the Antarctic field survey, only 2.3 km of the total 5.3 km route could be covered by both measurements. This paper describes briefly the results of the leveling surveys.

2. Leveling Route on East Ongul Island

The route for repeat leveling measurements on East Ongul Island is shown in Fig. 1. This route formed a loop in the central part of East Ongul Island. A small branch loop connecting Bench Marks (BM) 23-15 ~ 23-17 was established in the northern part of the leveling route, because water tube tiltmeters and a bore hole type tiltmeter were operated in the branch loop area in 1981 (KAMINUMA and NAGAO, 1983; KAMINUMA *et al.*, 1983). In addition, a VLBI antenna, a GPS antenna and a gravity hut have been installed near the branch loop.

The measurements were made by one of the authors (KIMURA), a member of JARE-37, using a digital level (Wild NA 3003) and a bar-cord staff from the 2nd to 5th of February in 1996. Due to bad weather and shortage of time only 2.3 km of the route was covered in the three days. The measurements were done beginning with BM 1040 and

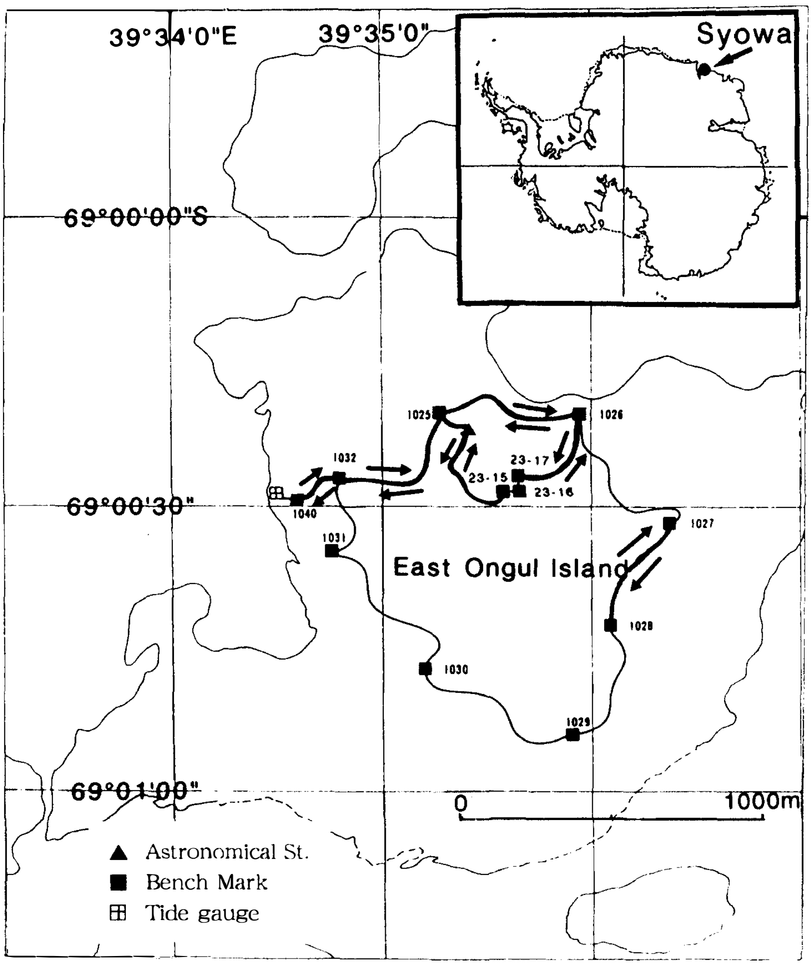

Fig. 1. Leveling route on East Ongul Island. Arrows show the survey route.

passing BM 1025, BM 1026, BM 23-15, BM 1025, BM 23-15 and BM 1026, and ending with BM 1040 as shown in Fig. 1. In addition, measurements between BM 1027 and BM 1028 were also made to detect height changes in the north-south direction. However, this measurement series was not closed as a leveling loop.

The oceanic tide has been continuously monitored for the last 26 years since 1970 near BM 1040, and the elevation of BM 1040 was well determined as H_{1040}=2.3380 m (OKA and FUCHINOUE, 1984). Syowa Station is the only station in the Antarctic coastal area where tide gauge observations have been continued for as long as three decades.

3. Height Change

The leveling measurements were done according to the specifications of the Geographical Survey Institute (GSI) of Japan. The discrepancy of forward and backward leveling, and closing error of the measurement circuit, were obtained within the limitation of the first order leveling of GSI. The average elevation error per kilometer was obtained as ±0.57 mm. BM 1040 is taken as the reference point for detecting the height change at each bench mark in 1992 and 1996 as shown in Fig. 2. A large height change of –10.9 mm is observed at BM 1032, while the change at BM 23-16 is +2.8 mm. Height changes at other points are less than 1 mm.

Figure 3 shows height changes between measurements in 1992 and in 1982, and in 1996 and in 1982. Height changes at BM 1032 were +7.6 mm between 1992 and 1982 values, and –3.3 mm between 1996 and 1982. During 1982–1996, height changes were +1.9 mm at BM 1025 and +3.3 mm at BM 23-16. Height changes at the other three points in Fig. 3 were less than 1 mm. Large height changes noticed at BM 1032 and BM 1025 might be due to artificial noise, because these bench marks are located along the road in the working area and near one of the station huts. The cause of large height

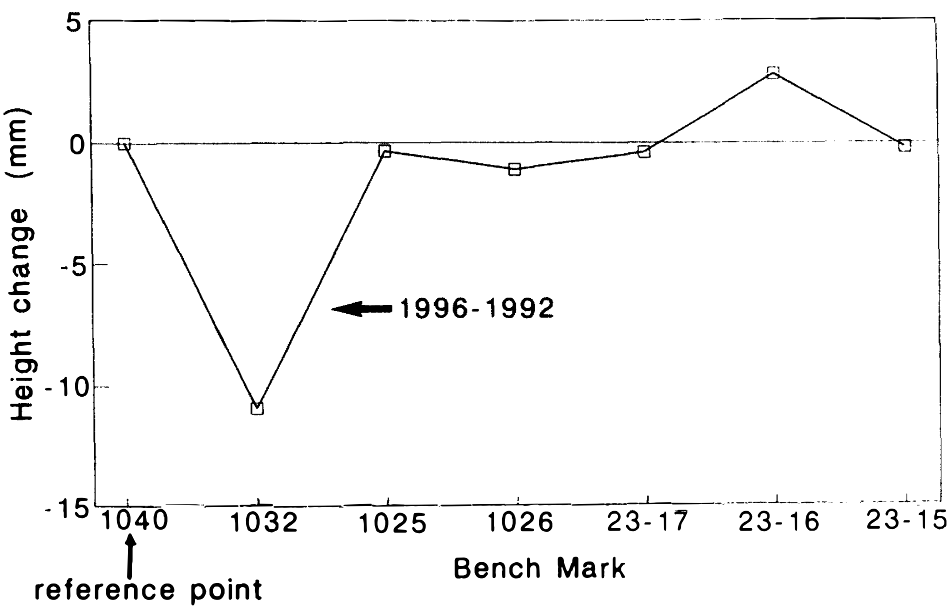

Fig. 2. Height changes between the measurements in 1992 and 1996.

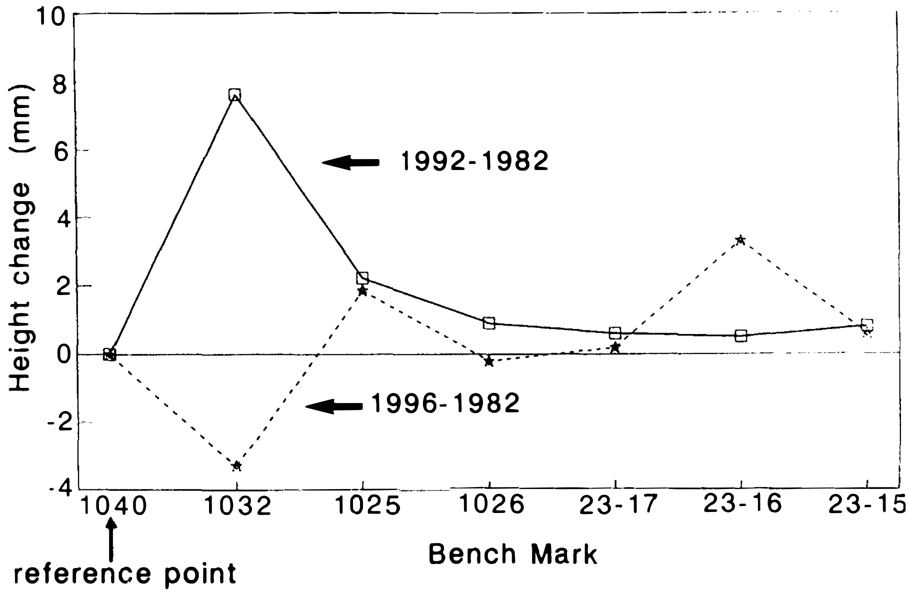

Fig. 3. Height changes between the measurements in 1992 and 1982, and between the measurements in 1996 and 1982.

change at BM 23-16 is not clear, but may be attributed to artificial phenomena too.

The height change at BM 1026, the easternmost point, was –0.2 mm during the last 14 years. No significant height change was detected in the east-west direction along the leveling route between BM 1040 and BM 1026 during 1982–1996. This indicates that there is no significant ground tilt along the route.

In the north-south direction, measurements at BM 1027 and BM 1028 were as follows :

BM 1027–BM 1028 +2.7523 m (1996)
BM 1027–BM 1028 +2.7528 m (1982).

The distance between BM 1027 and BM 1028 is only 0.5 km and the height change is ±0.5 mm. No significant height change has been detected even along the N-S direction during the last 14 years.

These observations indicate that no significant relative height change is discernible in East Ongul Island during the last 14 years.

4. Discussion

The following information concerning crustal uplift has been obtained around Syowa Station, as summarized by KAMINUMA (1996).

1) The rate of uplift of ice free areas relative to sea level is estimated to be 2.5 mm/y during the last 6000 years, from geomophological data such as the maximum height of raised beaches and shell fossils found on the beaches (YOSHIDA and MORIWAKI, 1979).

2) A trend of sea level falling at a rate of 4.5 mm/y was obtained from tide gauge data during 18 years in 1975–1992 (MICHIDA *et al.*, 1995). Considering the existence of raised beaches on East Ongul Island, the sea level falling indicates the possibility of crustal uplift around Syowa Station during that period.

3) Ten local earthquakes were located by the tripartite array during the 29 months from June 1987 to October 1989. The locations of epicenters are in the coastal and offshore areas. The occurrence of local earthquakes is intermittent, estimating from the annual number of local earthquakes in the vicinity of Syowa Station counted on the routine observation seismogram. The local earthquakes are inferred to be caused by tectonic stress accumulated by crustal uplift after deglaciation. The crustal uplift occurs only for a few years during one decade/more. The occurrence of earthquakes corresponds with the intermittent crustal uplift (KAMINUMA and AKAMATSU, 1992).

The hypothesis of intermittent crustal uplift is also supported by sea level falling around East Ongul Island. As described in 2), sea level fall at the rate of 4.5 mm/y was calculated from data during 18 years, 1975–1992 (MICHITA *et al.*, 1995). However, the data in 1977–1980 were excluded in the calculation of the falling rate, because the reliability of the data in that period was very low or on account of instrumental troubles. A faster rate of sea level fall, 9.5 mm/y, was noticed during the period of 7 years in 1981–1987 (ODAMAKI *et al.*, 1991). The data of this period were included in the calculation by MICHIDA *et al.* (1995). There is a possibility that the two falling rates are actually larger than 4.5 mm/y and 9.5 mm/y, because the global mean sea level is estimated to have increased at a rate of 1–2 mm/y (WARRICK, 1993). It is strongly pointed out by one of the authors (KAMINUMA) that the two different falling rates in sea level suggest that the sea level fall is intermittent. The process of sea level change is estimated from two falling rates: 1) sea level fall at the rate of about 10 mm/y during 1981–1987; 2) the falling rate in the rest of the 18-year period was mostly 0 mm/y or less than 4.5 mm/y; and 3) the mean falling rate throughout the 18 years was 4.5 mm/y. The local seismic activity in 1987–1989 was estimated to be associated with the sea level fall in 1981–1987.

Moreover, crustal uplift is not a tilt trend movement but represents a block movement along the coastal and offshore boundaries, because the earthquake epicenters are in the coastal and offshore areas, and the maximum height of raised beaches increases with distance from the ice sheet edge (KAMINUMA and AKAMATSU, 1992; KAMINUMA, 1996).

In the light of the above observations, it has been proposed that crustal uplift around Syowa Station is due to isostatic imbalance after deglaciation (KAMINUMA, 1996). The hypothesis is as follows: Crustal uplift around Syowa Station (or the coastal area of the Antarctic continent) causes isostacy after deglaciation; uplift at a rate of 10 mm/y continues a few years after a quiet period of one/two decades; and the uplift is a block movement.

The results of the repeat leveling survey can also be explained by the above hypothesis. From oceanic tide data, sea level fall (apparent crustal uplift) of 5–6 cm was observed around BM 1040 during 1981–1987 (ODAMAKI *et al.*, 1991). If uplift is assumed to be a tilt trend movement, then the crustal uplift was 0 mm at the edge of the ice sheet and 5 cm at BM 1040 5 km from the edge of the ice sheet. Similarly, the distance between BM 1040 (the westernmost of the leveling route) and BM 1026 (the easternmost) is about 900 m and a height change of –9 mm is expected at BM 1026 if the uplift is a tilt trend movement.

There must be detected a westward up trend of crustal movement on East Ongul Island if tilt trend movement occurs as shown in the upper part of Fig. 4. However, the height change is only –0.2 mm at BM 1026, the easternmost point, within the closing

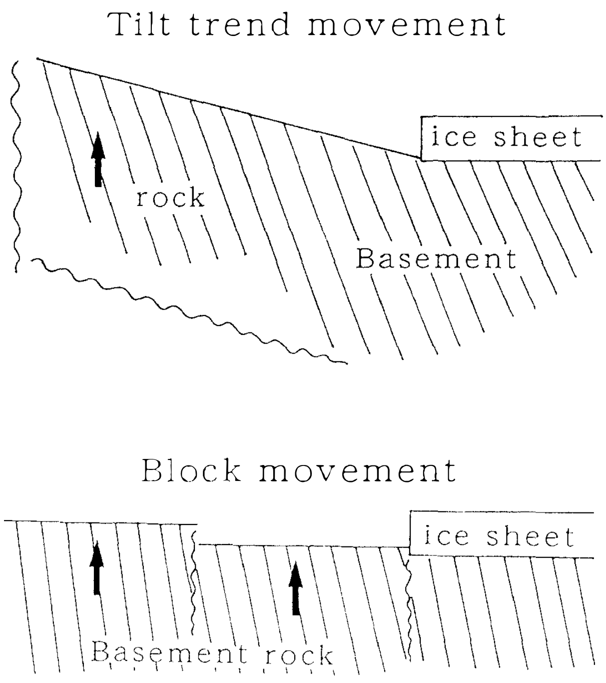

Fig. 4. A scheme of crustal uplift in the Antarctic coastal area. Tilt trend uplift (upper) and block movement (lower).

error of the circuit during 14 years. These facts show that the crustal uplift is a block movement as illustrated in the lower part of Fig. 4.

5. Conclusions

Results of a leveling survey on East Ongul Island, Antarctica are summarized briefly as follows:

1) Height changes at some bench marks are very large, about ten times of mean elevation error. These large changes seemed due to artificial noise (Figs. 2 and 3).

2) There was no significant height change of leveling at Syowa Station during 14 years. This result supports the hypothesis of a block movement of crust which is explained a process of crustal uplift (Fig. 4).

3) The leveling survey was done over only 40% of the circuit. A survey around the whole circuit is necessary as soon as possible to increase the reliability of the conclusion (Fig. 1).

4) Observations of oceanic tide and seismic monitoring are also continued at Syowa Station and crustal uplift after deglaciation continues around Syowa Station. Therefore, Syowa Station is one of the best locations to continue such surveys and studies such as crustal uplift which need a long term to detect the phenomena.

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