GROUND TILT OBSERVATIONS AT SYOWA STATION, ANTARCTICA

PART 1. BOREHOLE TILTMETER

Katsutada KAMINUMA,

National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173

Toshiyasu NAGAO

Faculty of Science, Chiba University, 33, Yayoi-cho 1-chome, Chiba 260

and

Kiyoshi ITO

Regional Observation Center for Earthquake Prediction, Faculty of Science, Kyoto University, 944, Nasahara, Takatsuki 569

Abstract: The first continuous observations of ground tilt in Antarctica were carried out at Syowa Station with a biaxial bubble-type borehole tiltmeter and a set of water-tube tiltmeter. The former was installed in a waterproof, steel-cased hole 196 cm deep and 144 mm in diameter. The observations began in April 1981. This paper discusses the borehole tiltmeter data from April to December. The signals were recorded on a 12-channel chart recorder in the data processing hut, 150 m north from the observation hole. The maximum tilt fluctuation during nine months was 17 μrad in the X-component (E-W) and 24 μrad in the Y-component (N-S). As the data seem to be seriously affected by underground temperature variations, the observed data were corrected for temperature assuming a linear relation between the ground tilt and the underground temperature. The corrected records showed a trend of upward tilt on the west and north sides throughout the observation period. The cumulative change of ground tilt during nine months of observation was -1.5 μrad in the X-component and 6 μrad in the Y-component. These observations demonstrate that a true ground tilt can be detected by the borehole tiltmeter.

1. Introduction

Elevated shorelines are found in the marginal snow-free areas of the Antarctic continent. These elevated shorelines are thought to form in response to ground uplift after deglaciation. However, no observations of current crustal movements have been carried out in Antarctica.

The Japanese Antarctic Station, Syowa, is located on East Ongul Island. Some elevated shorelines and beaches can be seen in the Ongul Islands around Syowa Station. The elevation of the elevated shorelines is about 20 m or more (OMOTO, 1977). Many fossil sea shells are found on the elevated beaches in the Ongul Islands. The fossils were dated at 3000–6000 years B.P. The elevated beaches are thought to be caused by isostatic rebound after deglaciation and/or glacial eustasy.

To observe the secular change of ground tilt due to uplift, a tiltmeter was installed at Syowa Station and observations began in 1981.

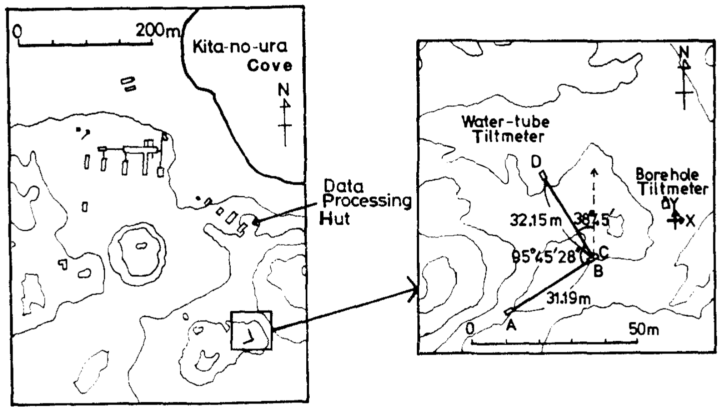


Fig. 1. Locations of the borehole type and the water-tube tiltmeters at Syowa Station, Antarctica.

For the first measurements of ground tilt in Antarctica a borehole type tiltmeter was selected to be installed at Syowa Station, because air temperature variations were thought to produce a high noise level. A set of water-tube tiltmeters was also installed, as described in Part 2 of this paper. The locations of the tiltmeters are shown in Fig. 1. The observation site for the tiltmeters was 150 m south of the data processing hut at Syowa Station.

2. Tiltmeter and Its Installation

The bubble-type borehole tiltmeter used at Syowa Station was a biaxial tiltmeter (Kinemetrix Model TM-1B). This instrument was installed in a waterproof steel-cased hole 196 cm deep and 144 mm in diameter as shown in Fig. 2. The hole was drilled using both air and water for cooling (KAMINUMA, 1983). The steel casing was attached to the wall of the hole with silica sand. The bottom of the hole was filled with cement 14 cm thick. The tiltmeter was packed into the hole with silica sand. While filling the hole with silica sand, the casing was hit repeatedly to ensure tight packing of the sand. The top of the tiltmeter is set 170 mm below the ground surface. The electronics package of the tiltmeter was installed in an insulated box which was placed beside the borehole.

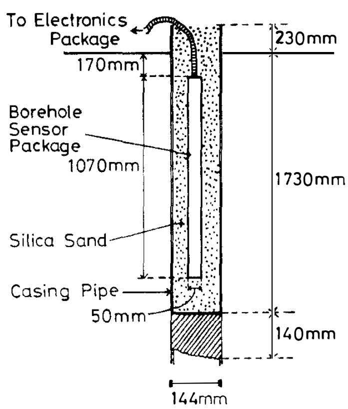


Fig. 2. A schematic view of the installation of the borehole type tiltmeter.

Two types of electrical outputs were monitored obtained for each axis, X and Y. The first output was the X- and Y-DEMOD signals which were used to identify the broad band ground motion from DC to approximately 10 Hz; the second output was the X- and Y-OUT signals which resulted from passing X- and Y-demodulater signals through low-pass filters having corner frequencies of either 1.6 Hz or 0.008 Hz. The signals of the four components were recorded on a 12-channel chart recorder in the data processing hut. The X-axis corresponded to the E-W component of tilt and the Y to the N-S component. The sensitivity of the X- and Y-OUT outputs was 37 mV per microradian and an attenuator of 1:5 was used. The full scale on the chart corresponded to a range of 0 to 50 mV, which is equivalent to 0–6.76 μrad. The sensitivity of the X- and Y-DEMOD outputs was 5 mV per microradian and the full scale was set at the same range of 0 to 50 mV. When the record drifted out of full scale, the position of the pen on the recorder was changed by an offset amplifier.

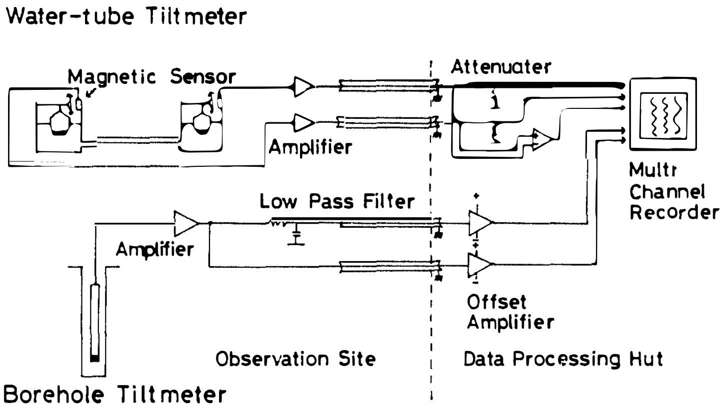


Fig. 3. Block diagram of the ground tilt observation. The borehole type and the water-tube tiltmeters are shown. The details of the water-tube tiltmeter are described by KAMINUMA and NAGAO (1983).

The block diagram of the observation system is given in Fig. 3. The left side of the figure shows the detector parts of both the borehole and the water-tube tiltmeters and the right side shows the schematics of the recording system in the data processing hut.

3. Observations

Observations started in April 1981. The variations of X- and Y-OUT, and X- and Y-DEMOD were observed from April to December as shown in Fig. 4. As all raw data were plotted hourly in Fig. 4, the records of OUT and DEMOD are very similar. The underground temperature variations at 1 and 2 m depths are also shown in Fig. 4. In a first half year, the X-component showed a trend of upward tilt for the east side on the records and the Y-component showed an upward tilt for the south side. A large, short-period fluctuation was observed in the winter season. Accumulated tilt in the X-component reached 17 μrad on the records in the first half year and

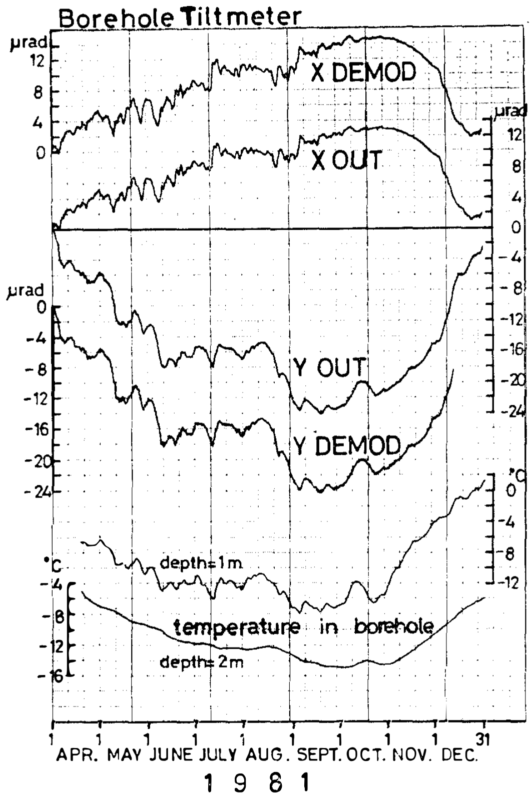


Fig. 4. Ground tilt of four output signals of the borehole type tiltmeter and underground temperature at 1 m and 2 m depths at Syowa Station.

24 μrad in the Y-component. Afterwards, the tilt direction reversed and the cumulative tilt became very small by December 1981.

It is noticed that the patterns of the tiltmeter records correspond closely to the underground temperature variations at 1 and 2 m depths.

4. Correction for Underground Temperature Variations

The long-period tiltmeter records appear to be affected by underground temperature variations at 2 m depth, as shown in Fig. 4. The observed data were corrected for underground temperature fluctuations assuming a linear relationship between the ground tilt and the underground temperature, because the cross correlation coefficients between X- and Y-OUT, and underground temperature at 2 m depth were -0.935 and 0.953. The observed data of X- and Y-OUT were therefore corrected as follows:

$$X(Y)_{i\ \mathrm{cal}} = X(Y)_i\mathrm{OUT} - f(T_i),$$

where $f(T_i) = a\,T_i + b$. T_i is underground temperature at 2 m depth, a and b are constants determined by a least squares method for X- and Y-OUT separately. Figures 5 and 6 show the raw and corrected values, and the corrections used.

The maximum variations of the corrected values are 6 μrad in the X-component and 8 μrad in the Y-component for the observation period. A vectorial presentation

Fig. 5.

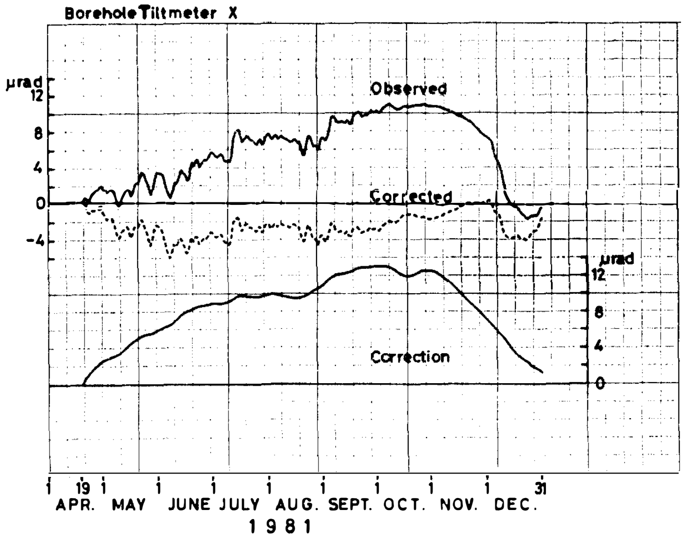
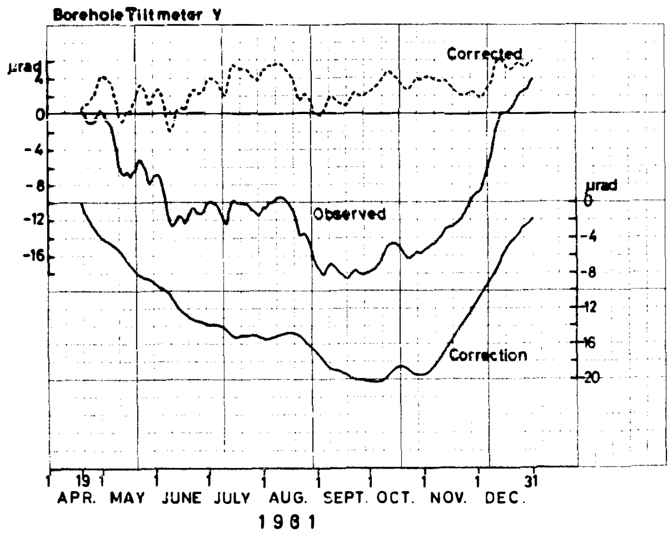


Fig. 6.



Figs. 5. and 6. Corrected ground tilt data of X- and Y-OUT.

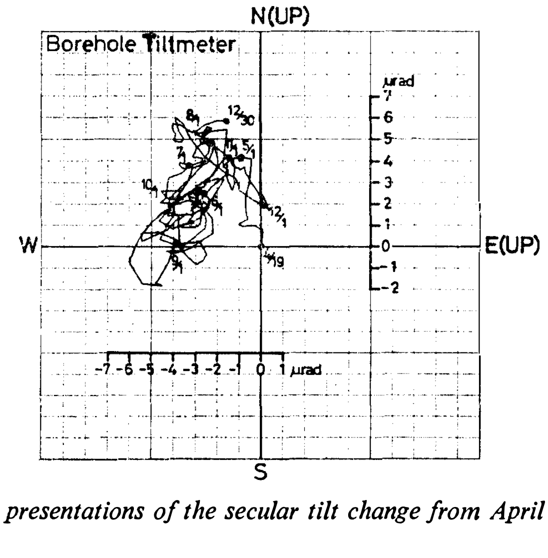


Fig. 7. Vectorial presentations of the secular tilt change from April to December 1981.

of the secular tilt change from April 19 to December 30, 1981 is given in Fig. 7 using the corrected data shown in Figs. 5 and 6. The cumulative ground tilt during the above period was 1.5 μrad west up and 6 μrad north up.

5. Discussion and Conclusion

SHICHI and OKADA (1979) showed that annual tilt variations in Japan measured by borehole tiltmeters typically ranged from 10^{-5} to $10^{-4.5}$ rad. The relative variations of ground tilt in this study were 2–6 μrad in the X- and Y-components. These values are within an order of magnitude of the annual changes observed in Japan. The ground tilt observations show a northwest up, southeast down tilt. This tendency of the tilt accumulation seems reasonable, since the ice sheet has retreated from the Ongul Islands sometime in the past 25000 years (OMOTO, 1977), and is still located on the continent, east side of the tiltmeter. It is important to continue observations of ground tilt with the borehole tiltmeter in the future, in order to resolve the long-term trends of tilt variations at Syowa Station, Antarctica.

Acknowledgments

The authors express their thanks to Dr. R. SHICHI, Nagoya University, and to Dr. Y. OKADA, National Research Center for Disaster Prevention, for their kind advice and discussion throughout this work. The authors are grateful to Profs. S. KAWAGUCHI and Y. YOSHIDA, leaders of JARE-21 and -22, for their kind organization of the observations. The authors also acknowledge Miss Y. SHUDO for her assistance in preparing the manuscript.

References

KAMINUMA, K. (1983): Nankyoku·Syowa Kiti no ganban bôringu (Core drilling at Syowa Station, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **77**, 134–143.

KAMINUMA, K. and NAGAO, T. (1983): Ground tilt observations at Syowa Station, Antarctica. Part 2. Water-tube tiltmeter. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 33–41.

OMOTO, K. (1977): Geomorphic development of the Sôya Coast, East Antarctica—Chronological interpretation of raised beaches based on leveling and radiocarbon datings. Sci. Rep. Tohoku Univ., Ser. 7 (Georg.), **27**, 95–148.

SHICHI, R. and OKADA, Y. (1979): Kônai ni okeru hizumi kansoku (Strain measurement in the vault). Sokuchi Gakkai Shi (J. Geod. Soc. Jpn.), **25**, 101–134.

(Received April 4, 1983; Revised manuscript received June 20, 1983)