Long-term geomagnetic changes observed in association with earthquake swarm activities in the Izu Peninsula, Japan

Naoto Oshiman (1), **Yoichi Sasai** (2), **Yoshimori Honkura** (3), **Yoshinobu Ishikawa** (2) **and Shigeru Koyama** (2)

(1) *Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan*
(2) *Earthquake Research Institute, University of Tokyo, Japan*
(3) *Department of Earth and Planetary Sciences, Tokyo Institute of Technology, Tokyo, Japan*

Abstract

Anomalous crustal uplift has continued since 1976 in the Izu Peninsula, Japan. Earthquake swarms have also occurred intermittently off the coast of Ito since 1978. Observations of the total intensity of the geomagnetic field in the peninsula started in 1976 to detect anomalous changes in association with those crustal activities. In particular, a dense continuous observation network using proton magnetometers was established in the northeastern part of the peninsula, immediately after the sea-floor eruption off the coast of Ito in 1989. No remarkable swarm activities were observed there from 1990 to 1992. However, after the occurrence of a small swarm in January 1993, five large swarm activities were observed. At some observation sites, we observed a remarkable long-term trend in the total geomagnetic field in association with the change in the distribution pattern in the seismicity of the earthquake swarms.

Key words *geomagnetic field – tectonomagnetism – earthquake swarm – total force*

1. Introduction

Remarkable crustal activities, anomalous crustal uplift and earthquake swarms, have continued for about 20 years in the Izu Peninsula, Japan. The swarm activities, which have occurred off the coast of Ito intermittently since 1978, are interpreted as being due to intrusions of magma or pressurized fluid (*e.g.*, Tada and Hashimoto, 1988; Okada and Yamamoto, 1991).

The total intensity of the geomagnetic field in the northeastern part of the peninsula has been recorded employing a dense network of proton magnetometers since 1989 (Oshiman *et al.*, 1991, 1997). No remarkable swarm activities were observed there from 1990 to 1992. However, after the occurrence of a small swarm in January, 1993, five large swarm activities were observed off the coast of Ito in May, 1993, September, 1995, October, 1996, March, 1997, and April, 1998.

At some observation sites, we observed a remarkable long-term trend in the total geomagnetic field associated with a change in the distribution pattern of the seismicity of the earthquake swarms. In this paper we report the observed change focusing on the rather long-term period after the sea-floor eruption in 1989.

Mailing address: Dr. Naoto Oshiman, Disaster Prevention Research Institute, Kyoto University, Gokasho Uji, Kyoto, 611-0011, Japan; e-mail: g53032@sakura.kudpc.kyoto-u.ac.jp

2. Earthquake swarm activities from 1981 to 1996

An earthquake swarm occurred east off the Kawanazaki Promontory, Ito City, at the end of November 1978. Since then, the swarm activi-

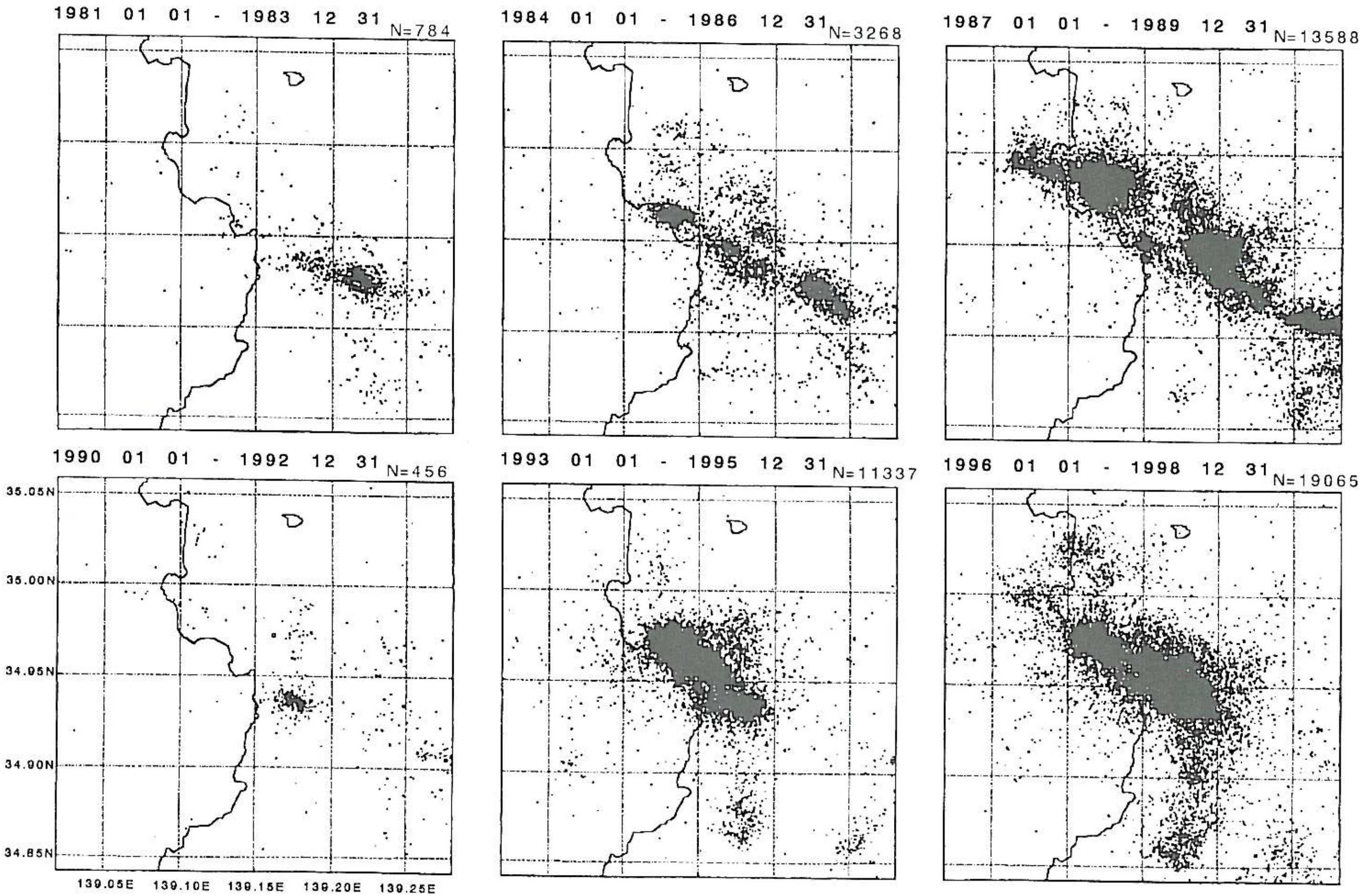

Fig. 1. Seismicity in the north-eastern part of the Izu Peninsula determined by NIED (reproduced from NIED, 1999). Temporal changes in spatial distribution of the seismicity are shown at 3-year intervals from 1981 to 1998. The upper three panels show seismicity change for 9 years including the sea-floor eruption off the coast of Ito City, while the lower three panels show the change for 9 years after the eruption.

ties have occurred intermittently for the past 21 years in the eastern part of the Izu Peninsula.

The National Research Institute for Earth Science and Disaster Prevention (NIED, 1999) summarized the past 18 year activities of the earthquake swarm off Ito, which are shown in fig. 1 as changes in epicentral distributions, at three-year intervals during the period from 1981 to 1998. NIED (1999) pointed out that:

1) Linear distribution of epicenters in the direction of WNW-ESE is seen.

2) Changes in density of the distributions for three-year intervals become higher not only in the former nine years of the whole period, but also in the latter nine years.

3) Density concentration of the epicenters is higher in the former half of the whole period than the latter half.

4) In the last three years, distribution of the epicenters extends towards the north.

The alignment of the epicentral distribution in the WNW-ESE direction was also recognized

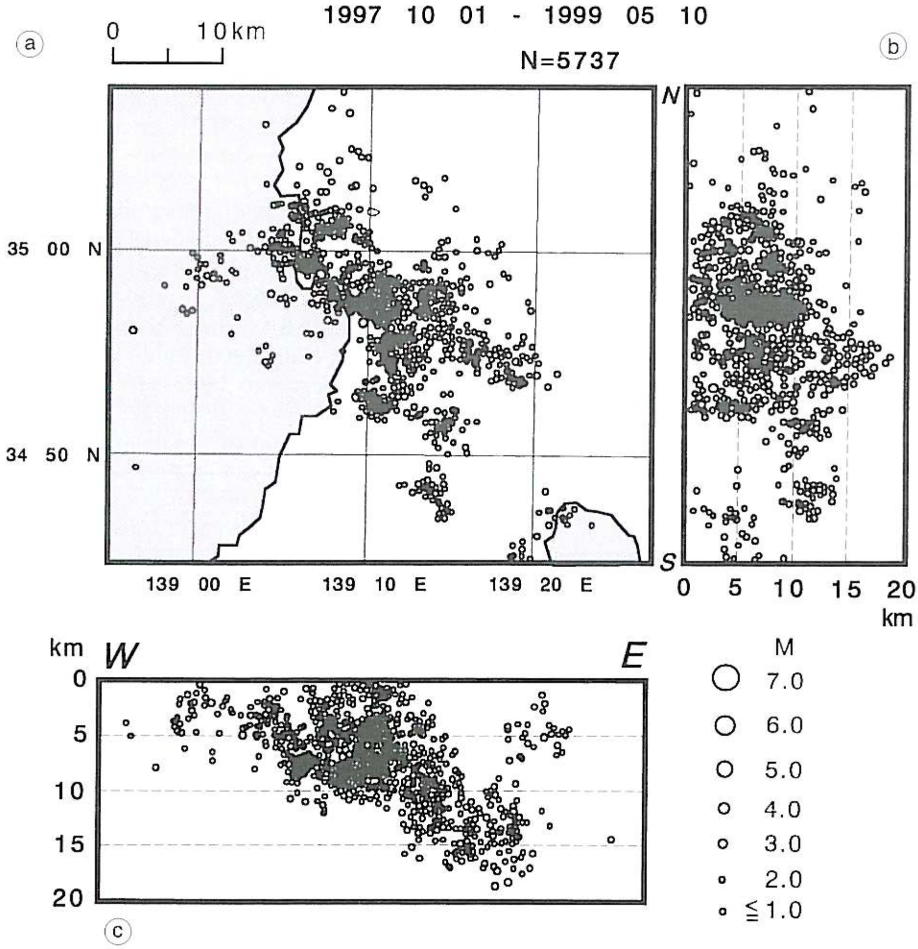

Fig. 2a-c. Seismicity in the north-eastern part of the Izu Peninsula during the period from October, 1997 to May, 1999 determined by JMA (reproduced from JMA, 1999). a) Epicentral distribution; b) vertical cross section of N-S direction; c) vertical cross section of E-W direction.

by many researchers before the 1989 sea-floor eruption. For instance, Tada and Hashimoto (1991) claimed that the crustal deformation data observed in the Izu Peninsula before the sea floor eruption could be interpreted by a tension crack model whose strike was NW-SE and which was placed along the epicentral distribution extended in the direction of WNW-ESE.

The monogenetic volcanoes in the northeastern part of the Izu Peninsula also align themselves in the NW-SE direction (Aramaki, 1976; Aramaki and Hamuro, 1977). Okada and Yamamoto (1991) also explained the crustal movement data observed in the 1989 activities including the sea-floor eruption using a model which consisted of an E-W-trending shear fault and two WNW-ESE-trending tensile faults.

On the other hand, recent activities revealed by the Japan Meteorological Agency (JMA, 1999) are shown in fig. 2a-c, where hypocentral distributions during the period from October 1997 to May 1999 are used. In this figure, very shallow (less than 10 km) activities are observed in the area close to the coastline northern from 35.0°N. This activity is also seen in fig. 1, and is one of the characteristics of the changes in epicentral distribution in the latest three years, as pointed out by NIED (1999). It is also pointed out here that the depth of epicenters becomes shallower towards WNW direction, as seen in fig. 2a-c.

3. Outline of the magnetic observation

Figure 3 shows locations of the continuous observation sites of the geomagnetic total field intensity. Geomagnetic observation in the Izu Peninsula commenced in 1976. Since then, intensive observations of the total field intensity have been carried out (*e.g.*, Rikitake *et al.*, 1980; Sasai and Ishikawa, 1977, 1978, 1980a,b, 1982, 1985, 1991; Oshiman *et al.*, 1983). Stations HAT, UKH, ARA, YSD, IKE, KWZ, and SGH were in operation before the 1989 sea-floor eruption. After the occurrence of the sea-floor eruption off the east coast of Ito City in the peninsula in 1989, a very dense network observation using more than 20 proton magnetometers has been in operation for about 10 years (Oshiman *et al.*, 1991, 1997). The sites, KWZ and HED, shown in the map at the bottom of fig. 3, are located at places far from the area concerning the crustal uplift and earthquake swarms. Thus, they are used as reference sites for obtaining the differences in the total intensity to separate local changes in the geomagnetic field.

Figure 4 shows changes in total intensity at six sites in the eastern part of the Izu Peninsula during the period from January 1980 to September 1991, obtained by Sasai and Ishikawa (1991). Monthly means of simple differences of nighttime values (0:00-04:59 LT) are plotted in this figure, the reference site used, was the KWZ station shown in fig. 3. According to Sasai and Ishikawa (1991), the variation of these differences showed some characteristics of the geomagnetic changes which could be summarized as:

1) At YSD and SGH, the total field intensity gradually increased towards the end of 1983 and it turned to gentle decrease. At ARA, the intensity remained almost constant from 1980 to 1983 and then began to decrease in 1984. The decline tendency at YSD and SGH ceased at the beginning of 1987.

2) The ARA station continued to decrease even after 1987. On the other hand, the intensity at HAT began to increase in 1987, where it remained constant during 1983-1986. This synchronous variation at HAT and ARA is the paired anomaly which can be regarded as a long-term precursor to the 1989 sea-floor eruption.

3) Earthquakes seem to have no clear relationship to magnetic changes. However, volcanic eruptions appear to have occurred at the turning points of long-term trend in the total intensity variations, which are directly controlled by activation or decay of magma reservoirs beneath the Eastern Izu Peninsula.

However, if figs. 4 and 2 are examined carefully, a clear relationship can be found between changes in the spatial distribution of the swarm activities and the tendency of the observed changes in the total intensity during the period from 1981 to 1989, although Sasai and Ishikawa (1991) concluded that earthquake swarm activities seem to have no clear relationship to magnetic changes. The long-term trend pointed out by Sasai and Ishikawa (1991) can be interpreted from the view of intrusions of magma or pressurized fluid into the swarm active area in each epoch.

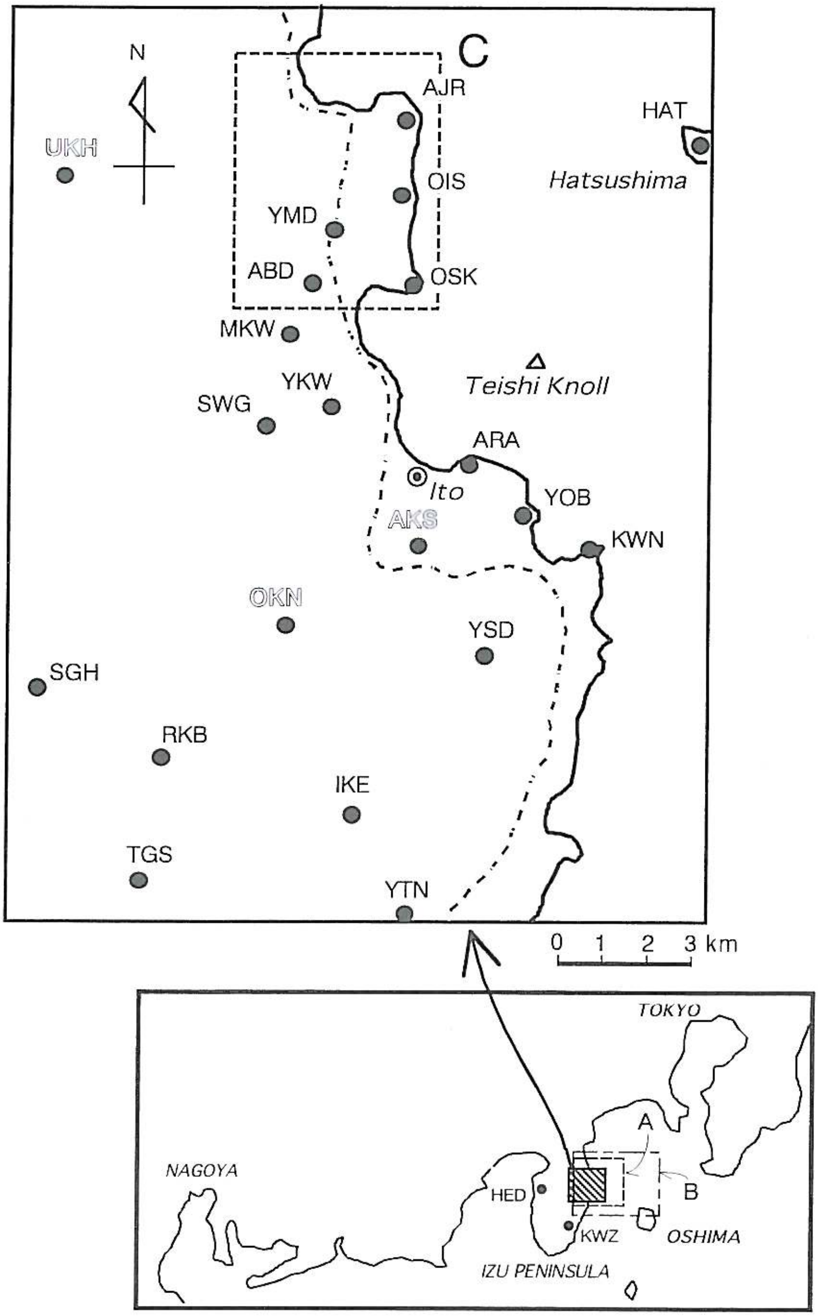

Fig. 3. Distribution of continuous observation sites of the total intensity of the geomagnetic field in the Izu Peninsula since 1989. Seismicity in the areas denoted by A and B, are shown in figs. 1 and 2a-c, respectively. The area, C, surrounded by a thick dashed line in the top panel is shown again in fig. 6a.

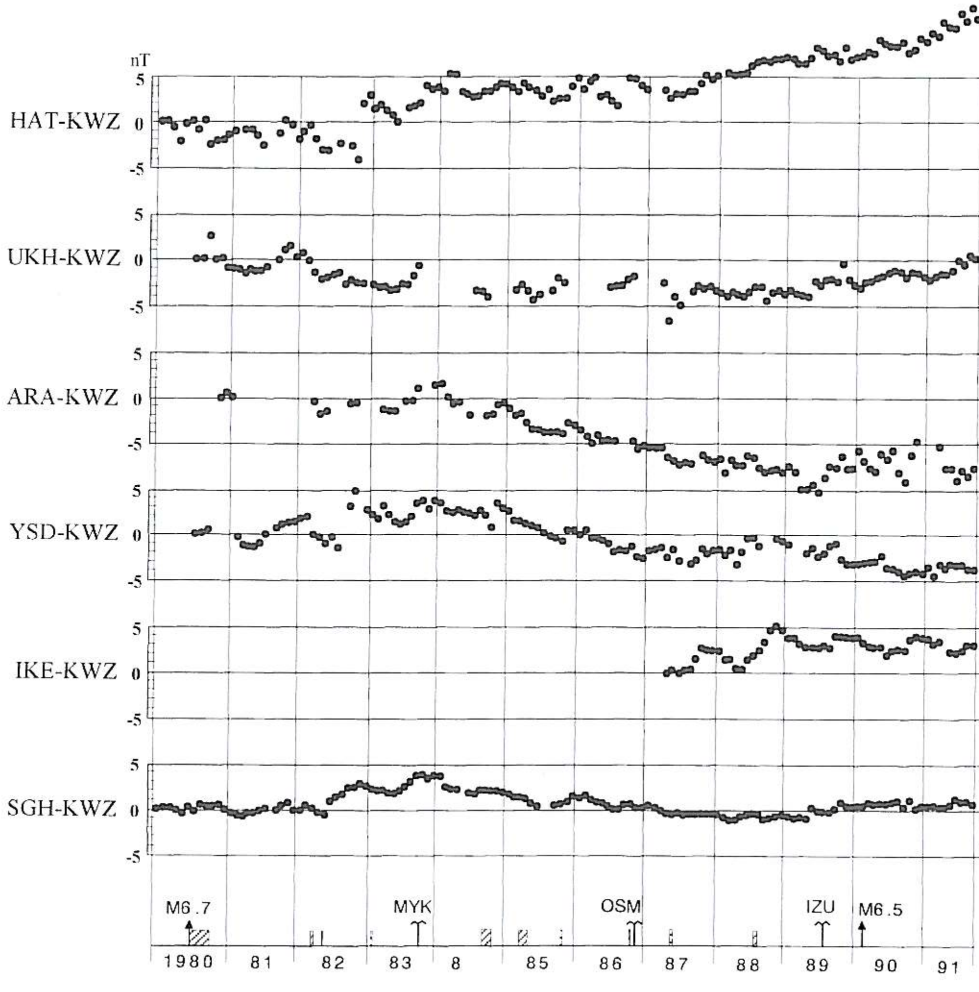

Fig. 4. Monthly mean of simple differences of night-time values between each site and KWZ during the period from 1980 to 1991.

In this paper, we describe remarkable local changes in the total intensity observed at several sites in association with the swarm activities during the period from 1990 to 1998.

4. Geomagnetic changes from 1990 to 1998

Changes in total intensity in the northeastern part of the Izu Peninsula during the period from 1990 to 1998 are shown in fig. 5. Monthly means of simple differences of night-time value (0:00-4:00 LT) relative to KWZ are plotted in this figure. At the bottom of the figure are indicated occurrences of earthquake swarm off the coast of Ito. The order of energy released as seismic wave, which is calculated by JMA (1999), is plotted in the panel.

The very large variation seen at HAT during the period from 1990 to 1992 is caused by artificial disturbance due to a construction of a large hotel on the tiny Island. The large decrease

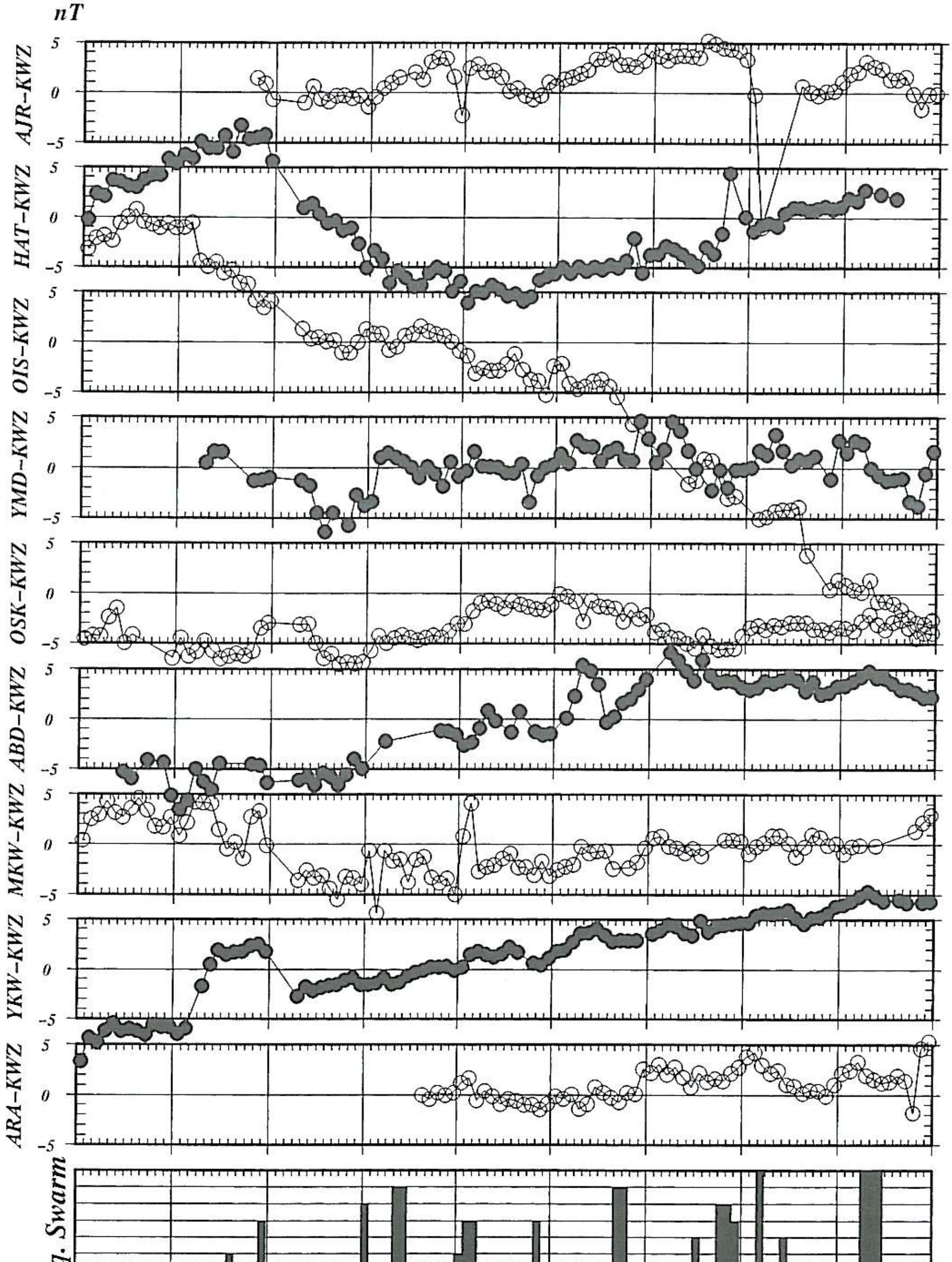

Fig. 5. Monthly mean of simple differences of night-time values during the period from 1990 to 1998.

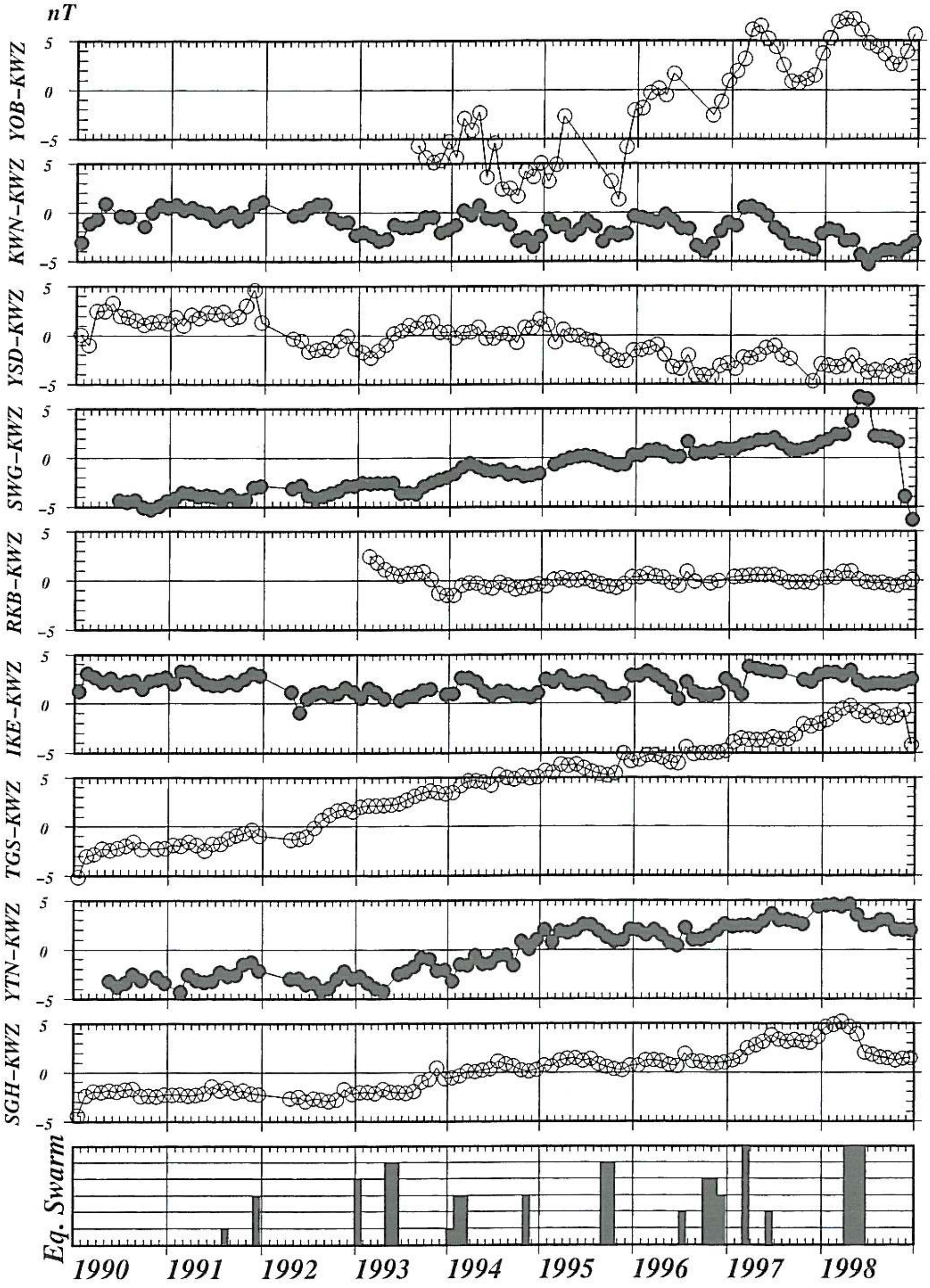

Fig. 5 (*continued*).

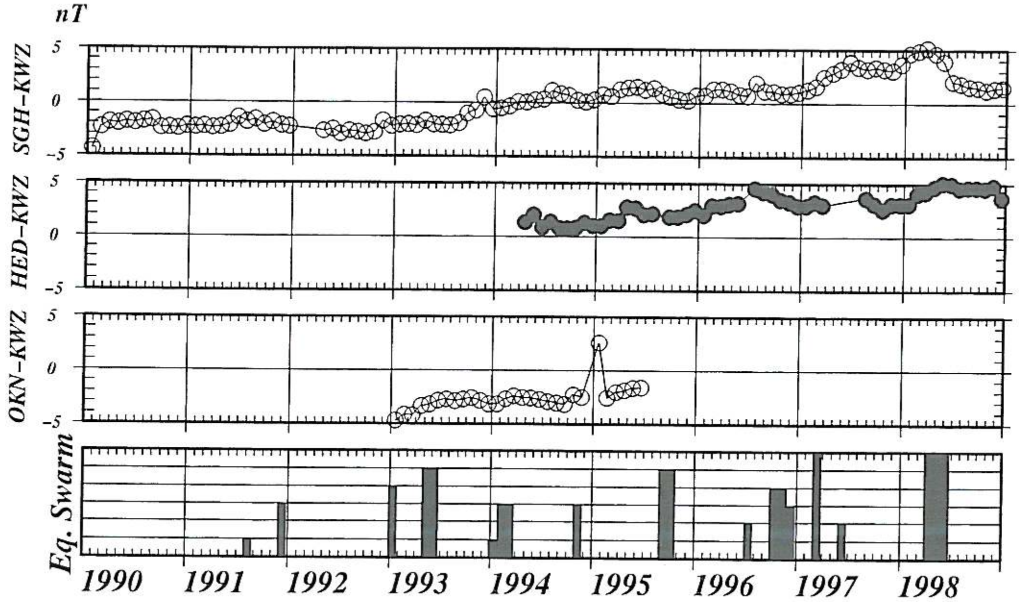

Fig. 5 (*continued*).

observed at OIS during the period from 1990 to the beginning of 1992 is also due to a construction.

The most remarkable variation in the figure, except the artificial disturbances mentioned above, is the one with a very large rate of decrease at OIS since the end of 1993. On the other hand, after the hotel construction, the total intensity at HAT remained almost constant until the end of 1995, then the intensity showed an steep increase.

At KWN and YSD, decrease tendencies are seen since 1992. At SGH, SWG and YTN, the total intensity remained almost constant until the end of 1993 and it turned to increase. Almost the same rate of increase has been seen at MKW and YKW since 1993. The increase since 1993 at ABD ceased in 1996 and the intensity turned to gradual decrease.

At YSD, OSK, ARA, RKB and IKE, the total intensity remained almost constant.

A prominent annual change with amplitude of about 6 nT is seen at YOB. The cause of such a variation is not clear at present. TGS shows constant increase throughout the period.

5. Local features of geomagnetic changes

Among the changes mentioned above, a remarkable one was changes observed at the OIS station. As already described in the previous section, the decrease of the total intensity at OIS during the period from 1991 to 1992 can be thought to be an artificial disturbance of a construction near the site. However, since 1993 no artificial disturbances can be considered as the cause of the remarkable decrease at OIS. So we set up one sub-site, OI2, about 150 m west of OIS as is shown in fig. 6a in December, 1997. Since a magnetometer at OI2 is in operation using only batteries, the total intensity is measured at an interval of five minutes for saving power consumption of batteries. We monitored the difference between OIS and OI2, for about one year and we detected almost no changes at all, except seasonal variation of about 2 nT as seen in fig. 6b. This means that the decrease observed at OIS since 1993 has spatial extent. Decrease at OI2 with the same rate at OIS can be seen in fig. 6c for one year. Decrease at OIS and OI2 seems to have ceased

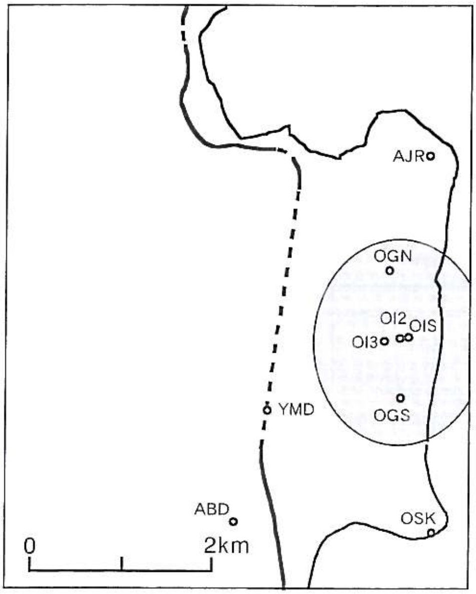

Fig. 6a. Localities of continuous observation sites of the geomagnetic total intensity around OIS to clarify distribution of the abnormal geomagnetic change observed at OIS. Dashed line in the figure indicates electric railway of the Izukyu line.

since the beginning of 1999. Sites OGS and OGN were set up in March, and OI3 was set up in April 1999 to clarify the spatial distribution of the remarkable changes. Unfortunately, at OGN, no data have been observed because of trouble in the power supply system of solar panels which was used. The results are also shown in fig. 6b. As already shown in fig. 2a-c, shallow earthquake activities have been observed beneath the area around OIS since 1996.

At KWN, which is one of the closest observation sites to the swarm area, changes in the total intensity showing a good correlation with the occurrence of the swarm were observed. Namely, a decrease in the total intensity at KWN, was observed before the occurrence of the swarm, and a recovery phase was also observed after the activity. However, as seen in fig. 3, large seasonal changes, which have very similar phase with changes at KWN, are observed at YOB. The distance between the two sites is only about 2 km. So more study is required to clarify whether changes observed at KWN are associated with the crustal activities or not.

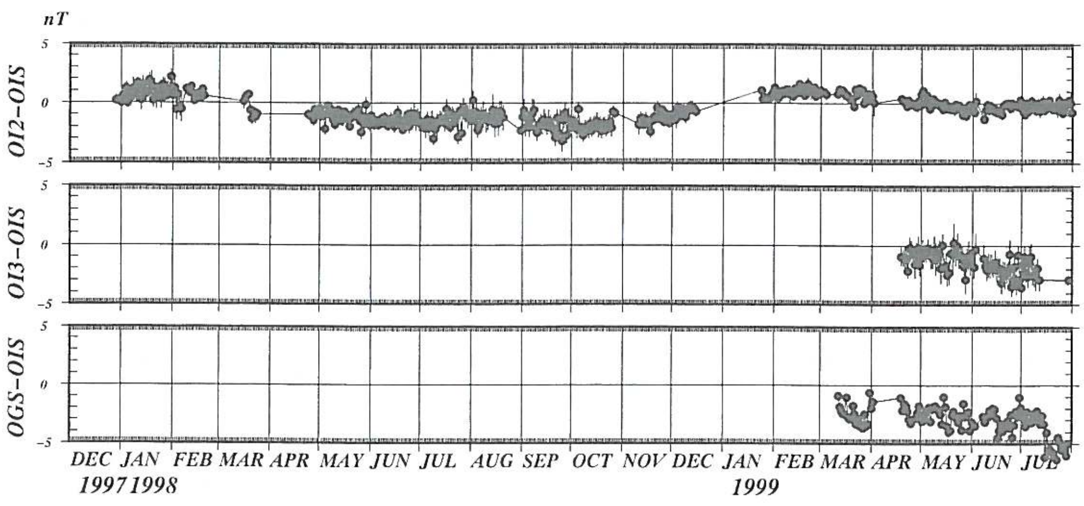

Fig. 6b. Changes in the difference relative to OIS during the period from end of December, 1997 to July, 1999. Five day means of night-time (0:00-4:00 LT) differences are shown. Vertical bars denote 2 σ (σ = standard deviation).

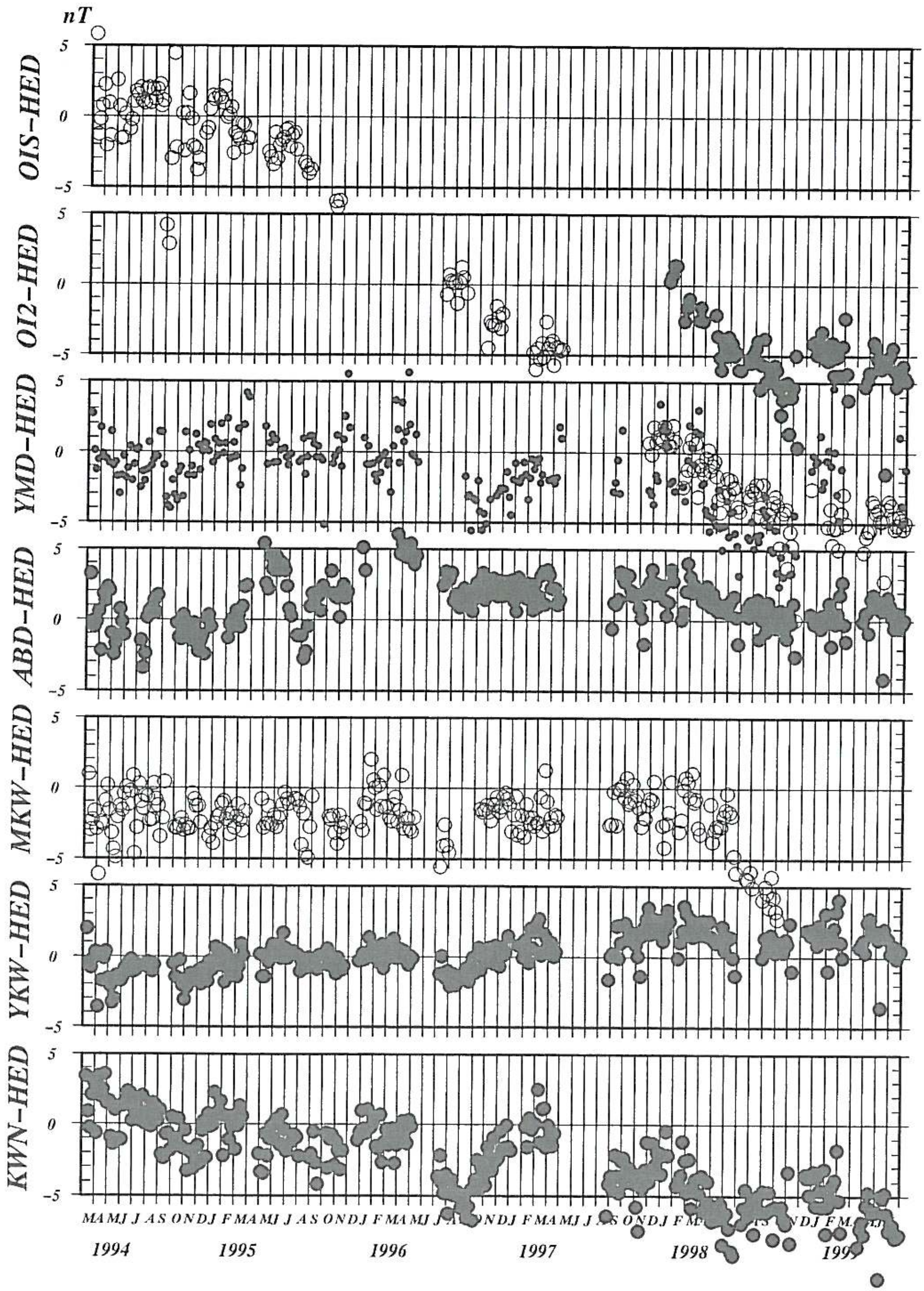

Fig. 6c. Differences at OIS and OI2 relative to HED from 1994 to 1999.

6. Conclusions

Very shallow (less than 10 km) seismic activities are observed around the OIS site and the depth of the distribution of epicenters becomes shallower towards WNW direction. As already mentioned above, swarm activities in the northeastern part of Izu Peninsula are interpreted as being due to intrusions of magma or pressurized fluid. So the observed decrease at OIS and OI2 could be interpreted as demagnetization of crustal rock due to such pressurized high temperature fluid. Accordingly, we should pay further attention to the remarkable decrease observed at OIS in relation to the shallow swarm activities. At least, determination of the spatial distribution of the anomaly is required to clarify the source of the changes.

Acknowledgements

The authors are grateful to two anonymous referees who kindly reviewed the paper and suggested possible improvements.

REFERENCES

ARAMAKI, S. (1976): Assessment of volcanic activity in the Eastern Izu Peninsula, *Rep. Coord. Comm. Earthq. Predict.*, **16**, 92-94 (in Japanese).

ARAMAKI, S. and K. Hamuro (1977): Geology of the Higashi-Izu monogenetic volcano group, *Bull. Earthq. Res. Inst., Univ. Tokyo*, **52**, 235-278 (in Japanese).

JMA (JAPAN METEOROLOGICAL AGENCY) (1999): Seismic activity in and around the Izu Peninsula, *Rep. Coord. Comm. Earthq. Predict.*, **61**, 218-221 (in Japanese).

NIED (NATIONAL RESEARCH INSTITUTE FOR EARTH SCIENCE AND DISASTER PREVENTION) (1999): History and recent features of earthquake swarms at eastern off Izu Peninsula, *Rep. Coord. Comm. Earthq. Predict.*, **61**, 190-201 (in Japanese).

OKADA, Y. and E. YAMAMOTO (1991): Dyke intrusion for the 1989 seismovolcanic activity off Ito, Central Japan, *J. Geophys. Res.*, **96**, 10361-10376.

OSHIMAN, N., Y. SASAI, Y. ISHIKAWA, Y. HONKURA and H. TANAKA (1983): Local changes in the geomagnetic total intensity associated with crustal uplift in the Izu Peninsula, Japan, *Earthq. Predict. Res.*, **2**, 209-219.

OSHIMAN, N., Y. HONKURA, Y. SASAI, Y. ISHIKAWA, H. UTADA, S. KOYAMA, Y. TANAKA and T. YUKUTAKE (1991): Magnetometer array observation in the North-Eastern Izu region after the Teishi knoll seafloor eruption in 1989, *J. Phys. Earth*, **39**, 321-328.

OSHIMAN, N., Y. SASAI, Y. HONKURA, Y. ISHIKAWA and Y. TANAKA (1997): Geomagnetic changes correlated with crustal movement in the north-eastern part of the Izu Peninsula, Japan, *Ann. Geofis.*, **40** (2), 479-494.

RIKITAKE, T., Y. HONKURA, H. TANAKA, N. OSHIMAN, Y. SASAI, Y. ISHIKAWA, S. KOYAMA, M. KAWAMURA and K. OHCHI (1980): Changes in the geomagnetic field associated with earthquakes in the Izu Peninsula, Japan, *J. Geomagn. Geoelectr.*, **32**, 721-739.

SASAI, Y. and Y. ISHIKAWA (1977): Changes in the geomagnetic total force intensity associated with the anomalous crustal activity in the eastern part of the Izu Peninsula (1), *Bull. Earthq. Res. Inst., Univ. Tokyo*, **52**, 173-190 (in Japanese with English abstract).

SASAI, Y. and Y. ISHIKAWA (1978): Changes in the geomagnetic total force intensity associated with the anomalous crustal activity in the Eastern part of the Izu Peninsula (2) – the Izu-Oshima-Kinkai earthquake of 1978, *Bull. Earthq. Res. Inst., Univ. Tokyo*, **53**, 893-923 (in Japanese with English abstract).

SASAI, Y and Y. ISHIKAWA (1980a): Tectonomagnetic event preceding a *M* 5.0 earthquake in the Izu Peninsula – aseismic slip of a buried fault?, *Bull. Earthq. Res. Inst., Univ. Tokyo*, **55**, 895-911.

SASAI, Y. and Y. ISHIKAWA (1980b): Changes in the geomagnetic total force intensity associated with the anomalous crustal activity in the eastern part of the Izu Peninsula (3) – the east off Izu Peninsula earthquake of 1980, *Bull. Earthq. Res. Inst., Univ. Tokyo*, **55**, 1101-1113 (in Japanese with English abstract).

SASAI, Y. and Y. ISHIKAWA (1982): Changes in the geomagnetic total force intensity associated with the anomalous crustal activity in the eastern part of the Izu Peninsula (4) – anomalous change observed in the north-eastern area in 1981, *Bull. Earthq. Res. Inst., Univ. Tokyo*, **57**, 739-757 (in Japanese with English abstract).

SASAI, Y. and Y. ISHIKAWA (1985): Changes in the geomagnetic total force intensity associated with the anomalous crustal activity in the eastern part of the Izu Peninsula (5) – 1982-1984 Off-Kawanazaki swarm earthquakes and crustal uplift, *Bull. Earthq. Res. Inst., Univ. Tokyo*, **60**, 147-177 (in Japanese with English abstract).

SASAI, Y. and Y. ISHIKAWA (1991): Tectonomagnetic signals related to the seismo-volcanic activity in the Izu Peninsula, *J. Phys. Earth*, **39**, 299-319.

TADA, T. and M. HASHIMOTO (1988): Origin of the anomalous crustal activity in the northeastern Izu Peninsula (2) – Tension crack model, *Programme and Abstract, Seismological Society of Japan*, No. 1, 139 (in Japanese).

TADA, T. and M. HASHIMOTO (1991): Anomalous crustal deformation in the Northeastern Izu Peninsula and its tectonic significance – tension crack model, *J. Phys. Earth*, **39**, 197-218.