BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 55 (1980), pp. 895-911

37. Tectonomagnetic Event Preceding a M 5.0 Earthquake in the Izu Peninsula —Aseismic Slip of a Buried Fault?

By Yoichi SASAI and Yoshinobu ISHIKAWA,

Earthquake Research Institute.

(Received October 31, 1980)

Introduction

Geomagnetic and geoelectric observations have been intensively carried out in the Izu Peninsula since 1976. In this local region of the central Japan, an anomalous crustal activity is under way, including an abnormal land upheaval in the eastern half and some destructive earthquakes (TSUMURA, 1977, SHIMAZAKI and SOMERVILLE 1979). Some results on magnetic observations have already been reviewed by RIKITAKE et al. (1980). The Magnetic Mobile Survey of the Earthquake Research Institute (ERI), University of Tokyo, is engaged in the geomagnetic total field measurements in the eastern part of the peninsula (SASAI and ISHIKAWA 1977, 1978, 1980). We will present here a brief description of a remarkable tectonomagnetic event accompanying the Higashi-Izu Earthquake of M 5.0 on Nov. 23, 1978.

Outline of Observations

Fig. 1 shows the location of temporary magnetic stations and survey points. Sugehiki (SGH) station was established in May, 1976 and is situated near the center of the anomalous crustal uplift in the northeastern part of the peninsula. Another proton precession magnetometer was set up at Kawazu (KWZ) in January, 1978, soon after the Izu-Oshima-Kinkai Earthquake of M 7.0. This station is situated in almost the center of the aftershock zone (TSUMURA et al. 1978). SHIMAZAKI and SOMERVILLE (1979) presumed a subsidiary fault to lie beneath the KWZ station, although the main fault extends in the E-W direction under the sea off the east coast.

Nighttime values of the total intensity at these stations are com-

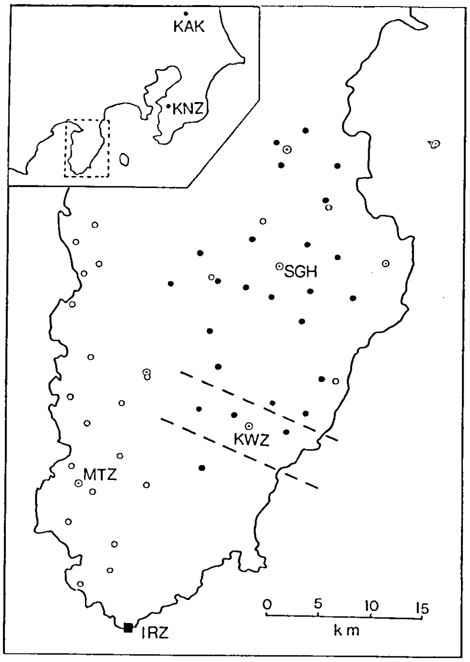

Fig. 1. Location of the F component observation points in and around the Izu Peninsula. KNZ (Kanozan) and KAK (Kakioka) are permanent standard stations. SGH (Sugehiki), KWZ (Kawazu) and MTZ (Matsuzaki, JMA) are temporary ones with continuously-recording magnetometers. Black dots in the eastern area represent survey points established by ERI, while the hollow ones in the western area are those by the Tokyo Institute of Technology. The observation site of the Irozaki volumetric strainmeter (IRZ) and the Kawazu seismic zone (denoted by a hatched belt near KWZ) are shown, which will be referred to later.

pared with those at Kanozan Geodetic Observatory (KNZ), the Geographycal Survey Institute (GSI), about 95 km east to SGH. The survey area is surrounded by direct current railways. Daytime records are severely contaminated with stray electric current noises, especially in the northern half of the area. At survey points in the noisy region, measurements are made all night with automatically-recording magnetometers. Field data is first compared to the simultaneous record of the F component at the nearest temporary station, i.e. SGH or KWZ. Adding the long-term average of simple differences between these stations and KNZ, we obtain the relative changes in the total intensity on the basis of the KNZ standard station. This greatly reduces errors caused by nonuniformities of the external field as well as the local induction effect. A preliminary investigation suggests that 2γ changes in the survey data would be reliable (SASAI and ISHIKAWA 1978).

Kawazu Tectonomagnetic Event

Fig. 2 shows changes in the total magnetic field at SGH and KWZ relative to KNZ during the period from Jan. 1978 to Mar. 1979. 5-day means of simple differences are plotted. The most evident is a rather

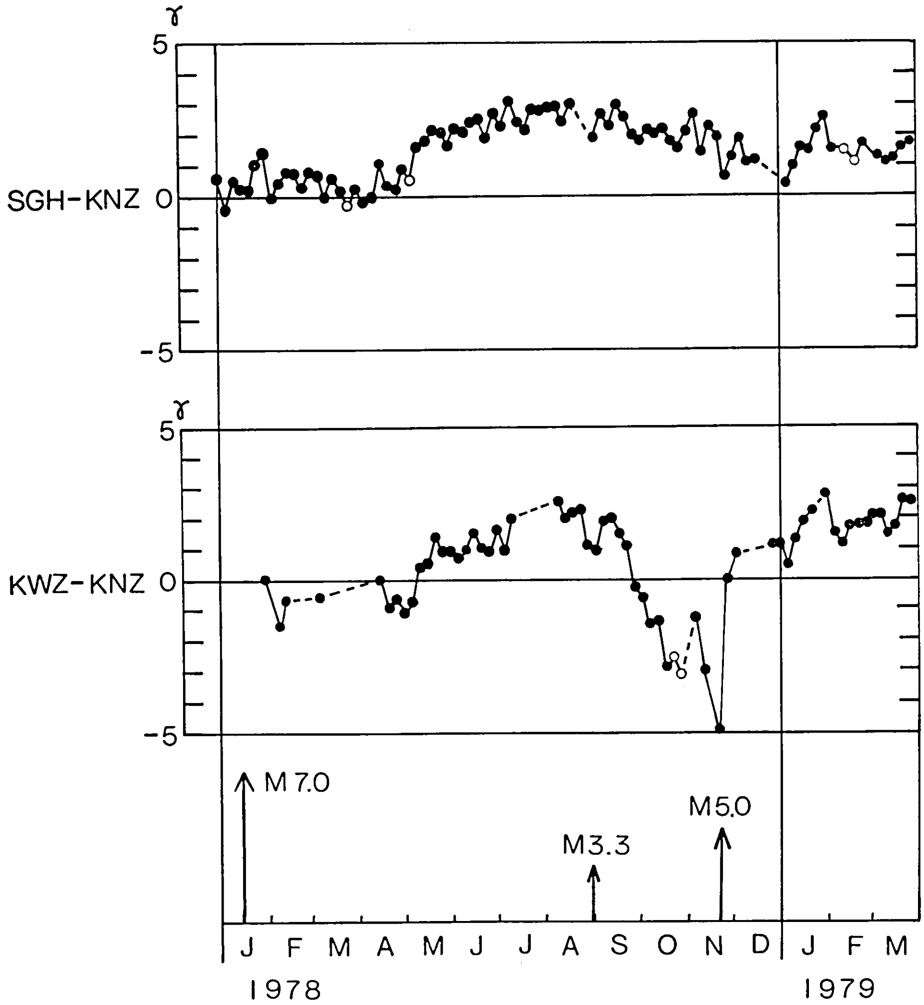

Fig. 2. Changes in the total force intensity at SGH and KWZ relative to KNZ, during the period from Jan. 1978 to Mar. 1979. Five-day means of simple differences of nighttime values are plotted. Arrows indicate the occurrences of major earthquakes along the Kawazu seismic zone.

steep decrease at KWZ from September to November. Unfortunately, the KWZ magnetometer suffered some instrumental problems from the middle of October: the observed values scattered off and on. Later the trouble was found to be a defective contact of a sensor cable connector. Such an intermittent defect persisted until the very moment the Higashi-Izu earthquake occurred at 10 h 43 m LT, Nov. 23, 1978.

It is happened that the strong shock revived the contact: the magnetometer has functioned normally since then. The total intensity differences between KWZ and KNZ showed an increse of more than 5 gammas as compared to those in the early morning of that day. Hence, the total field gap of 5 gammas before and after the M 5.0 earthquake as shown in Fig. 2 should be a coseismic one.

This anomalous magnetic event was unknown to us until the middle of November, since the KWZ data was not telemetered to ERI. We did not visit the KWZ station from early September to the beginning of December, and everything was over by that time. There was no evidence of any artificial disturbances, for the sensor has been carefully watched against magnetic substances by our entrusted observer at KWZ station. The total field difference was checked up between a reference point and the KWZ sensor at the times of our visits in September and December. The reference point is about 30 m apart, where a reference sensor was left unmoved at a height of 2.5 m since September. The KWZ sensor is mounted on a wooden scaffold 3 m high. No appreciable change was detected between the two measurements (the difference was only $-0.1\,\gamma$). Although there still remains some as to whether the Kawazu event might be caused by an unknown instrumental defect, all the circumstances support its reality.

Repeated magnetic surveys brought to light peculiar changes around the KWZ station. Fig. 3 shows the total field anomaly during the period from July to December, 1978. The F component change in the southern half of the survey area is characterized by its decrease up to 5 gammas at maximum. We see, however, fairly large complicated changes in the northern part. This northern anomaly bothered us, because the continuous observation at SGH did not indicate such a striking change.

Because of the restricted schedule in the December survey, we were obliged to make measurements only in the daytime at many of the survey points. Recently, we found that the daytime total field at some northern points are biased by several gammas owing to the stray electric current noises (SASAI and ISHIKAWA 1980). Hence, the total intensity changes as given in Fig. 3 would be significant only in the southern

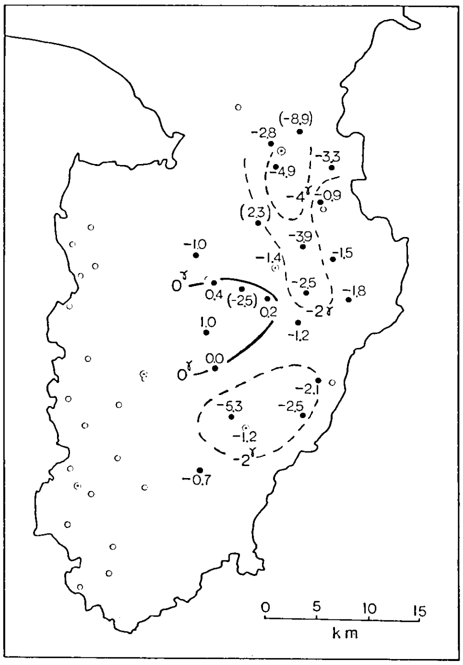

Fig. 3. Changes in the F component relative to KNZ during the period from July to December, 1978. Unit in gammas.

part. The negative change in this region seems to be consistent with the overall feature of the Kawazu event.

Higashi-Izu Earthquake of M 5.0

The Higashi-Izu earthquake occurred just to the southeast of the KWZ station. The epicenters of the main shock (OIEP, SEISMOLOGICAL DIVISION, JMA 1979) and its aftershocks (ERI 1979b), together with some damaged points (IROZAKI WEATHER STATION 1979) are summarized in Fig. 4. The focal plane solution is a nearly vertical strike-slip type (OIEP, SEISMOLOGICAL DIVISION, JMA 1979): one of the nodal lines runs in the WNW-ESE direction, which might represent the fault orientation as inferred from the aftershock distribution. This direction follows the lineation of the aftershock zone of the preceding Izu-Oshima-Kinkai earthquake, which is called the Inatori—Nekko Pass aftershock zone (TSUMURA et al. 1979).

The seismic activity along the WNW-ESE trending zone near Kawazu (including the Inatori—Nekko Pass aftershock zone) has been extremely high since the 1976 Kawazu earthquake of M 5.4. We will

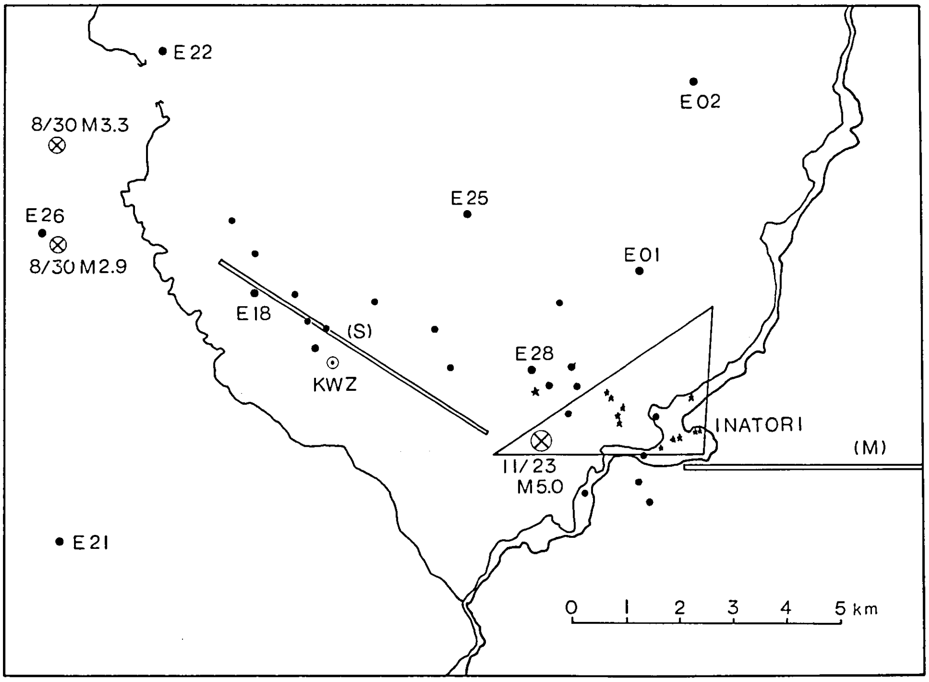

Fig. 4. Map showing the survey points (large black dots with station names) around KWZ station. Survey points E25, E26 and E28 were established after the Kawazu tectonomagnetic event. Two parallel straight lines indicate the surface projection of the main rupture fault (M) and the subsidiary fault (S) of the Izu-Oshima-Kinkai earthquake respectively, as determined by SHIMAZAKI and SOMERVILLE (1979). Also shown are epicenters (big circles with a cross) of the M 5.0 Higashi-Izu earthquake and the M 3.3 and M 2.9 felt earthquakes on Aug. 30; aftershocks (small dots) of the M 5.0 quake; and damaged points (stars) due to the M 5.0 quake.

tentatively call it the Kawazu seismic zone (see Fig. 1). Based upon past earthquake history, MOGI (1979) argued that the Kawazu seismic zone is one of the tectonically weak lines in the Izu Peninsula.

Shown in Fig. 4 are the main fault of the Izu-Oshima-Kinkai earthquake and its subsidiary fault as determined by SHIMAZAKI and SOMERVILLE (1979). The aftershock activity of the M 7.0 earthquake diminished monotonously along the Inatori—Nekko Pass zone until August (ERI 1979a). Some felt earthquakes with a magnitude 3 or so take place at the north-western edge of the seismic zone on Aug. 30 (Fig. 4). Then the seismic activity diminished abruptly (ERI 1979a), while the anomalous magnetic change at KWZ seems to have started at about that time. Hence the Kawazu tectonomagnetic event should be closely related to the reactivation of this seismic zone in the peninsula.

The Higashi-Izu earthquake might be viewed as an episodic event in the earthquake sequence along the Kawazu seismic zone. Except for the short-term duration of the aftershocks of the M 5.0 earthquake, the activity along this zone turned very quiescent. A new swarm activity started off Kawanazaki near Ito, 23 km NNE of Inatori, about 15 hours later as if it were triggered by the Higashi-Izu earthquake. The seismicity was most active near Ito from then until recently, including the Kawana-Oki (M 5.4, Dec. 1978) and East off Izu Peninsula earthquake (M 6.7, Jun. 1980).

Interpretation in Terms of Piezomagnetism

Fig. 5 shows the piezomagnetic total field change associated with a vertical rectangular strike-slip fault. The problem was solved analytically by one of the writers (SASAI 1980). The fault parameters are almost the same as those of SHIMAZAKI and SOMERVILLE's (1979) subsidiary fault, except that we ignore the fault inclination and a small dip-slip component in our model. Fault parameters and magnetic constants are listed in Table 1. This model successfully explains the total field change at the survey point E18 (see Fig. 4) before and after the Izu-Ohima-Kinkai earthquake (SASAI and ISHIKAWA 1978: observed ΔF is $-4.3\,\gamma$, while the calculated one $-3.1\,\gamma$).

Table 1. Parameters of a vertical rectangular strike-slip fault in Fig. 5.

fault orientation	φ	N58°W
fault length	2L	6 km
fault width	W	7 km
depth of burial	d	0.5 km
dislocation (right-lateral)	ΔU	−1.2 m
rigidity	μ	3.5×10^{11} cgs
Currie depth	H	15 km
average magnetization	J_0	1.0×10^{-3} emu/cc
stress sensitivity	β	1.0×10^{-4} bar^{-1}
average declination	D_0	N6°W
average magnetic dip	I_0	47°

An inspection of Fig. 5 shows that the dominant feauture of the magnetic anomaly is a decrease in the F component just upon the fault. This makes us think that the Kawazu tectonomagnetic event might be caused by the aseismic movement of an underground fault. Although the KWZ station belongs to the positive anomaly area in Fig. 5, the difficulty is overcome by shifting the fault position only slightly.

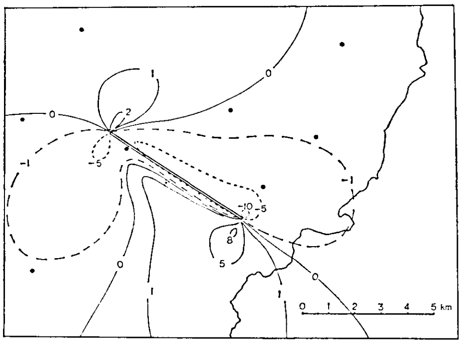

Fig. 5. Tectonomagnetic total field change accompanying a vertical right-lateral strike-slip fault. This fault occupies roughly the same position of SHIMAZAKI & SOMERVILLE's (1979) subsidiary fault. Units in gammas.

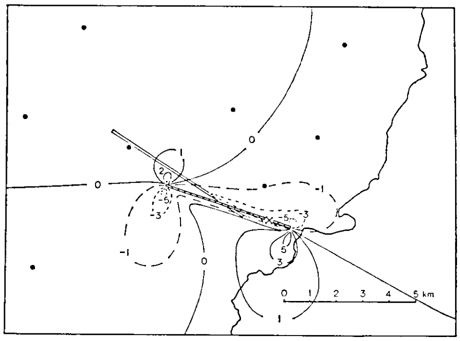

Fig. 6. An example of the tectomagnetic model, which explains the coseismic magnetic change at KWZ associated with the Higashi-Izu earthquake. Unit in gammas. A hollow thick line indicates the location of the Fig. 5 fault.

How can we explain the coseismic increase at the time of the M 5.0 earthquake? There exist two positive anomalies associated with the fault movement; namely (A) a narrow area beyond the north-western tip of the fault with a minor intensity and (B) a predominant anomaly on the southern side of the fault. It seems likely that the coseismic change is related to the type (A) anomaly. Fig. 6 shows the situation: the seismic fault generating the M 5.0 earthquake stretches almost to the KWZ station from the epicenter, roughly parallel to the arrangement of aftershocks. Parameters of the assumed fault are given in Table 2. Since the type (A) anomaly emerges in a very limited region near a fault edge, the NW tip of the fault is well constrained. This fault lies, however, slightly remote from the aftershocks and damaged area. This might imply that the actual seismic fault is dipping northward. Damage was clustered along the surface faults associated with the Izu-Oshima-Kinkai earthquake (e.g. TSUNEISHI *et al.* 1978), which indicates the ground foundation effect.

Table 2. Parameters of a fault accompanying the Higashi-Izu earthquake.

fault orientation	φ	N70°W
fault length	2L	5 km
fault width	W	5 km
depth of burial	d	0.3 km
dislocation (right-lateral)	ΔU	−0.5 m
(Other parameters are the same as those in Table 1.)		

The calculated total field change can be adjusted to the observed value by making the top of the fault shallower and/or by assuming a more intense magnetization J_0. The latter might be preferable, because the fault zone occupies the southern slope of the Amagi mountains which consist of Tertiary and Quarternary volcanic rocks. ISHIKAWA (1979) analysed the air-borne magnetic data in the central part of Japan and showed that the Izu Peninsula belongs to a distinct positive anomaly area. The anomaly can be interpreted by assuming an average crustal magnetization of 5.0×10^{-3} emu/cc or so beneath the Izu district. In this paper we take position that we fix the moderate values for the medium parameters such as μ, β and J_0; the model adjustment will be made solely by changing fault parameters. Hence it should be borne in mind that the dislocation slip ΔU and the depth of burial d in Table 1 and 2 would be possibly reduced by introducing a more intense magnetization.

Another point comes into question for this fault model. The seismic moment estimated from the fault dimension (AKI 1966) is much larger than the one expected from the Moment-Magnitude relationship (e.g. OHNAKA 1976). The following mechanism might be acceptable in order to avoid the difficulty: only a portion of the entire fault ruptured so as to generate seismic waves, while the remainder, the north-western half of the fault say, slipped much more slowly.

The interpretation of the coseismic ΔF increase depends somewhat upon the singularity of the fault edge effect. This feauture comes from the inappropriate modeling of the slip termination. Hence the possibility that the coseismic change is related to the type (B) anomaly cannot be ruled out. The KWZ station is situated in the transition of the positive and negative anomalies, where the sign and magnitude of the total field change are highly sensitive to the depth of burial of the fault. We might be able to construct some sophisticated models, including the successive fault slippage over portions of a single fault plane, so as to produce the coseismic ΔF increase at KWZ. Such an attempt is, however, trivial, because we have no information on the constraints of such models.

Finally, we present here a 2-faults model as shown in Fig. 7. An example of model calculations is summarized in Table 3. The agreement is rather qualitative. A more detailed model fitting is abandoned because of the many ambiguities in fault parameters. For example, the slip amount is not necessarily the same as that at the time of the Izu-Oshima-Kinkai earthquake. The fault A is the major source of the Kawazu tectonomagnetic event, which explains the 5-7 γ decrease during the 2-months period at KWZ as well as the general feature of the survey data.

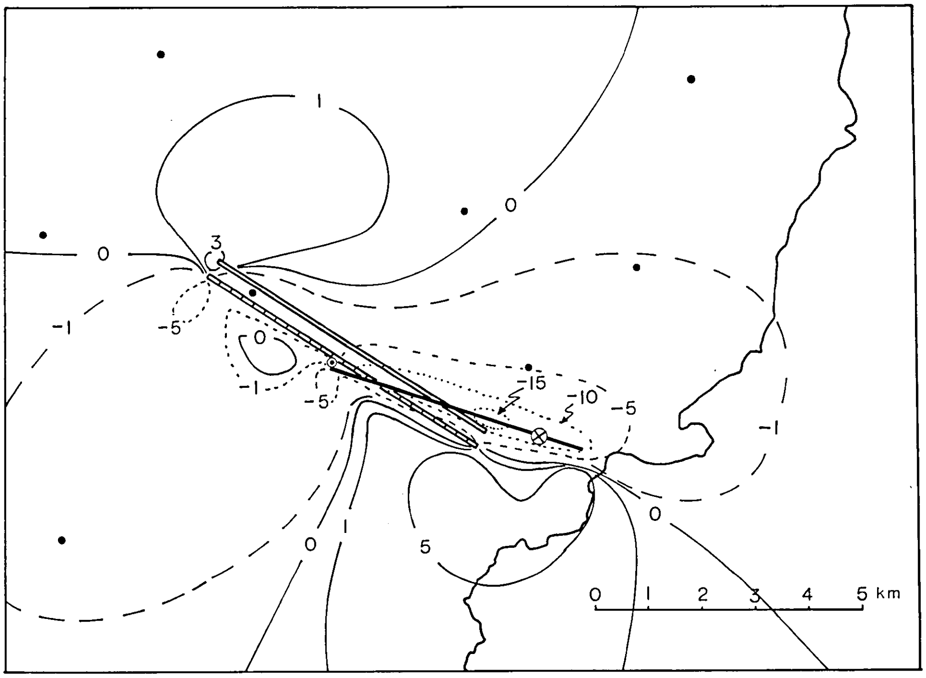

Fig. 7. Resultant total field of a 2-faults model, which can explain the temporal change at KWZ as well as the survey data. Unit in gammas. A hatched line indicates the Fault A, which runs parallel with the Fig. 5 fault (hollow thick line), about 350 m apart. A thick line denotes the Fault B accomanying the M 5.0 earthquake.

Table. 3. Comparison of observed and calculated total field changes: (a) Observation, (b) Fig. 5 fault, (c) Fault A, (d) Fault B and (e) Resultant (A+B), respectively.

Obs. site	(a)	(b)	(c)	(d)	(e)
KWZ	−1.2γ −6(*)	0.45γ	−4.45γ	3.79γ	−0.66γ
E18	−5.3	−3.08	−5.12	0.39	−4.73
E26	——	−0.10	0.01	0.08	0.09
E21	−0.7	−0.83	−1.06	−0.02	−1.28
E28	——	−3.98	−3.10	−1.01	−4.11
E01	−2.5	−0.87	−0.73	−0.26	−0.99
E25	——	−0.24	−0.13	0.23	0.10
E02	−2.1	−0.07	−0.06	−0.01	−0.07
E22	0.0	0.43	0.41	0.08	0.49

(*) preseismic change.

This fault is simply a parallel shift of the Fig. 5 model, about 350 m to the SSW. The fault B is accompanied with the Higashi-Izu earthquake, which produces the coseismic change at KWZ. The resultant total field are given in Fig. 7.

Fault A can be regarded practically the same as the SHIMAZAKI & SOMERVILLE subsidiary fault. The discrepancy of the fault position would be primarilly ascribed to our model, in which the fault inclination and the normal faulting component are neglected. Thus we may conclude that the underground subsidiary fault of the Izu-Oshima-Kinkai earthquake moved silently again from September to November, 1978, which caused the Higashi-Izu earthquake of M 5.0 beyond its southeastern edge. The Kawazu magnetometer was a close indicator of such a tectonic event.

Possibility of Aseismic Faulting

A fairly large amount of strike-slip faulting is proposed solely on the basis of magnetic data. Geodetic data to support the present idea is not yet available. The precise leveling was carried out along the route in Fig. 4 in 1979 (CRUSTAL DYNAMICS DEPARTMENT, GSI 1979, 1980). No significant height change was detected as compared with the early 1978 survey. Expected height changes accompanying a purely vertical strike-slip fault are very small. Hence, more direct evidence such as the triangulation or geodimeter measurements data is desirable in order to examine the present model.

UMEDA and MURAKAMI (1978) investigated special features of damage clustered along the "cataclysmal line", which runs in the N73°W direction within the Inatori—Nekko Pass aftershock zone. They concluded that the faulting motion of the subsidiary fault was very slow at the time of the Izu-Oshima-Kinkai earthquake. Even the aseismic movement of this fault was suggested by SHIMAZAKI and SOMERVILLE (1979); the near-field accelograms contain no such distinct later phases as correspond to the subsidiary fault action. Hence we might reasonably expect the aseismic faulting along the subsidiary fault, which would be ready for sliding under the applied tectonic stresses.

The assumed fault movement is, however, very different from the ordinary post-seismic slip; e.g. the Parkfield earthquake (SMITH and WYSS 1968), the Izu-Hanto-Oki earthquake (GEOLOGICAL SURVEY OF JAPAN 1980) and so on. Most of the observed after-slip can be realized as the termination phase of the earthquake faulting with the exponential decay. This type of after-slip was actually observed by the geodimeter resurvey, one month after the quake, although its amount is only a few percent of the coseismic one (HANDA *et al.* 1978). The Kawazu tectonomagnetic event, and hence the aseismic creep of the subsidiary fault, started about 8 months after the earthquake, the total dislocation being presumed nearly as much as the preceding movement. Such a large scale faulting with a long delay time is hardly explainable merely by the stress readjustment around the earthquake fault. The Kawazu "silent earthquake" was an independent tectonic event rather than one of the after-effects of the Izu-Oshima-Kinkai earthquake.

Matsuzaki Tectonomagnetic Event

An evidence exists to indicate the enhancement of tectonic stresses in the Izu district prior to the Kawazu event. In Fig. 8 reproduces the daily mean variation of volumetric strain at Irozaki and the total intensity changes at Matsuzaki (OHCHI *et al.* 1979). Although these stations are 16 km apart (see Fig. 1), we recognize some close correlation between the two different kinds of data: i. e. the Nov.-Dec. change before the Izu-Oshima-Kinkai earthquake and the Aug.-Sept. change prior to the Kawazu event. The former strain change is notable as a precursor to the M 7.0

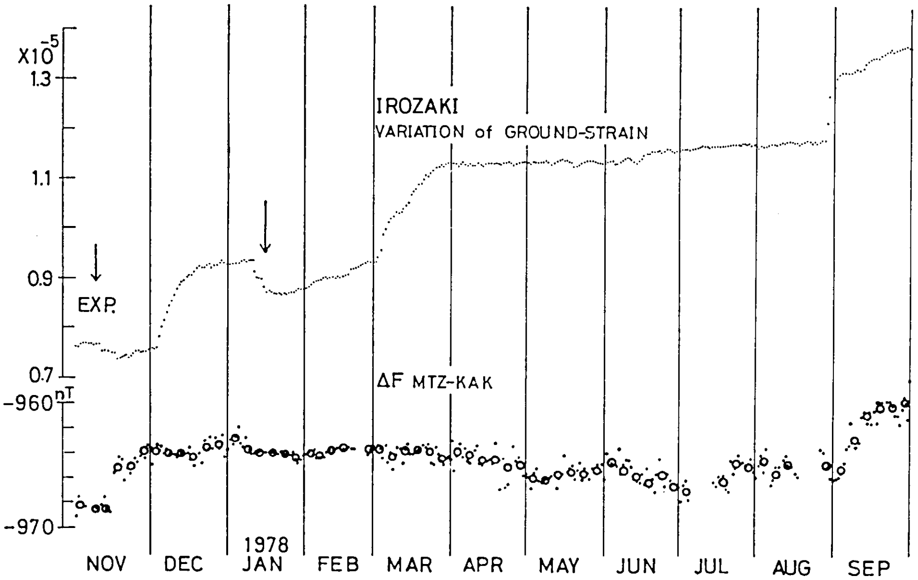

Fig. 8. The daily mean variations of ground strain at Irozaki and differences of total force intensity (after OHCHI et al. 1979). The arrow indicates the occurrence of the Izu-Oshima-Kinkai earthquake; hollow circles are the 5-day mean of the total force difference between MTZ and KAK (see Fig. 1).

earthquake (OIEP, SEISMOLOGICAL DIVISION, JMA 1978). The post-quake variation in the ground strain is not accompanied by obvious ΔF changes. The postseismic strain changes might involve partly the recovery of the mechanical contact with surrounding rocks, which might have been disturbed by the shaking ground motion.

SASAI (1980) showed that the tectonomagnetic total field change ΔF_{TM} at the earth's surface can be represented by

$$\Delta F_{TM} = 2\pi C_0 \left\{ \frac{\partial u_f}{\partial f} \right\}_{z=0}$$

$$+ \text{(some additional contributions from the free surface and the Currie point isotherm)}$$

where

$$C_0 = \frac{1}{2} \beta J_0 \mu \frac{3\lambda + 2\mu}{\lambda + \mu}$$

and $\{\partial u_f / \partial f\}_{z=0}$ denote the simple extension at the observation site in the direction of the geomagnetic field. Notice that the total field increase corresponds to the contraction, for the stress sensitivity β is conventionally measured in a sense as the compressive force to be positive. Fig. 8 demonstrates the relationship clearly. The magnetic changes at MTZ are by an order of magnitude larger than those expected from strain changes. For the uniformly magnetized crust with a magnetization of 10^{-3} emu/cc, the magnetic sensitivity against the strain change is 3.6×10^{-5} per gamma (SASAI 1980). Some amplification mechanism of tectonomagnetic signals is surmised, such as that due to local inhomogeneities of the crustal magnetization.

MOGI (1980) claimed that we should not put too much confidence in the precursory nature of the preseismic strain changes (the Dec.-Jan. event in Fig. 8), because the late-coming Aug.-Sept. event in 1978 has no apparent correlation with the occurrence of a large earthquake. If the Kawazu silent earthquake did occur, we might as well regard the latter strain change as a forerunner. The Izozaki strainmeter has been very stable during the past four years (1976–1980), only except for the three remarkable changes as shown in Fig. 8 (OIEP, SEISMOLOGICAL DIVISION, JMA 1980). Hence we are now of the opinion that the southern Izu Peninsula suffered some abrupt increase of compressive tectonic stresses at the end of August, 1978, which caused the Kawazu silent earthquake. We may say that the Matsuzaki tectonomagnetic event indicates the resional stress change, while the Kawazu event represents the relaxation process of such stresses by the aseismic fault movement.

Concluding Remarks

The interpretation of the Kawazu tectonomagnetic event as described in this paper is highly speculative at the present stage. The presumed mechanism follows, more or less, that of the precursory magnetic change along the San Andress Fault (SMITH and JOHNSTON 1976, JOHNSTON 1978). The tectonomagnetic model of the Kawazu event has much ambiguity. We see that model parameters are constrained practically by the data at only two points, namely the temporal change at KWZ and the survey data at E18. Even a very small-scale fault could explain the Kawazu event as well as the 5γ decrease at E18.

Another possible cause of tectonomagnetic changes is not taken into account here: the electro-kinetic effect (MIZUTANI and ISHIDO 1976, FITTERMAN 1979). We have poor information on time-changes in the self-potential and underground water. Some major magnetic events are directly related to crustal strain changes, especially the coseismic ΔF change at KWZ, and the nearly in-phase variation of the MTZ total field and the Irozaki volumetric strain in harmony with the piezomagnetic theory. The overall feature of the KWZ and MTZ tectonomagnetic events can be well understood in terms of the ordinary reversible piezomagnetic effect.

The experience of the Kawazu tectonomagnetic event is important in earthquake prediction research. According to the present study, the proton precession magnetometer functions as a sort of strainmeter. The excellent drift-free characteristics of this instrument should be more extensively utilized for the urgent monitoring if any crustal anomaly were to be found.

However, such a tectonomagnetic precursor as the Kawazu event might be rarely observable, since the aseismic faulting is not always guaranteed to occur. Even the term "precursor" should be used with reservation: the Kawazu silent earthquake is presumably the major tectonic event, while the Higashi-Izu earthquake is merely an induced one. In conclusion, the Kawazu tectonomagnetic event demonstrates the detectability of a preseismic fault creep with the suitable arrangement of magnetometers array near the active fault.

Acknowledgements

We are greatly indebted to Professor Yukio Hagiwara for his encouragement in the course of the study. We sincerely acknowledges Professor Takeshi Yukutake for his useful discussion and advices.

References

AKI, K., 1966, Generation and propagation of G waves from the Niigata earthquake of June 16, 1964, Part 2, Estimation of earthquake moment, released energy, and stress-strain drop from the G wave spectrum, *Bull. Earthq. Res. Inst.*, 44, 73-88.

CRUSTAL DYNAMICS DEPARTMENT, GSI, 1979, Crustal deformation in the eastern Izu district, (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 22, 68-71.

CRUSTAL DYNAMICS DEPARTMENT, GSI, 1980, Crustal deformation in the eastern Izu district, (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 23, 48-52.

EATHQUAKE RESEARCH INSTITUTE (ERI), 1978a, Seismic activity in the Izu Peninsula and its vicinity (May-October, 1978), (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 21, 83-86.

EARTHQUAKE RESEARCH INSTITUTE (ERI), 1979, Seismic activity in the Izu Peninsula and its vicinity (November 1978- April 1979), (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 22, 57-62.

FITTERMAN, D. V., 1979, Theory of electrokinetic-magnetic anomalies in a faulted half-space, *J. Geophys. Res.*, 84, 6031-6040.

GEOLOGICAL SURVEY OF JAPAN, 1980, After-seismic movement of the Irozaki earthquake fault, (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 24, 128-131.

HANDA, T., A. TOKUYAMA and S. YOSHIDA, 1978, Crustal deformation after the Off-Izu-Oshima Earthquake, 1978—An electro-optical measurement on a trigonometric net around the Inatori area, (*in Japanese with English abstract*), *Geoscience Rep. Shizuoka Univ.*, 3, 65-71.

IROZAKI WEATHER STATION, 1979, Minute investigation on the earthquake of East of Izu Peninsula, November 23, 1978, (*in Japanese*), *Quarterly J. Seismology, JMA*, 43, 103-105.

ISHIKAWA, Yu., 1979, The magnetic anomaly in the central part of Japan derived from the aeromagnetic survey results, (*in Japanese*), Thesis of M. Sc. submitted to the University of Tokyo.

JOHNSTON, M. J. S., 1978, Local magnetic field observations and stress changes near a slip discontinuity on the San Andreas fault, *J. Geomag. Geoelectr.*, 30, 511-522.

MIZUTANI, H. and T. ISHIDO, 1976, A new interpretation of magnetic field variation associated with the Matsushiro earthquakes, *J. Geomag. Geoelectr.*, 28, 179-188.

MOGI, K., 1979, Izu—Recent crustal activity—, (*in Japanese*), in *"The Ten-Years Activity of the Coordinating Committee for Earthquake Prediction"*, *Geogr. Surv. Inst.*. 121-140.

OHCHI, K., N. IJICHI, M. KUWASHIMA and M. KAWAMURA, 1979, Geomagnetic total force intensity variation associated with the Izu-Oshima Kinkai earthquake, 1978, (*in Japanese with English abstract*), *Memoirs Kakioka Mag. Obs.*, 18, 55-64.

OHNAKA, M., 1976, A physical basis for earthquakes based on the elastic rebound model, *Bull. Seism. Soc. Amer.*, 66, 433-451.

OIEP, SEISMOLOGICAL DIVISION, 1978, On the Izu-Oshima-Kinkai earthquake, 1978, (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 20, 45-50.

OIEP, SEISMOLOGICAL DIVISION, JMA, 1979, Earthquake swarm off Kawana, Izu Peninsula, Shizuoka Prefecture, (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 22, 63-67.

OIEP, SEISMOLOGICAL DIVISION, JMA, 1980, Observations of crustal strains by borehole strainmeters in the Kanto and Tokai district, (*in Japanese*), *Rep. Coord. Comm. Earthquake Predict.*, 24, 67-69.

RIKITAKE, T., Y. HONKURA, H. TANAKA, N. OHSHIMAN, 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. Geomag. Geoelectr.*, 32, 721-739.

SASAI, Y., 1980, Application of the elasticity theory of dislocations to tectonomagnetic modelling, *Bull. Earthq. Res. Inst.*, 55, 387-447.

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), (*in Japanese with English abstract*), *Bull. Earthq. Res. Inst.*, 52, 173-190.

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—, (*in Japanese with English abstract*), *Bull. Earthq. Res. Inst.*, 53, 893-923.

SASAI Y. and Y. ISHIKAWA, 1980, 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—, (*in Japanese with English abstract*), *Bull. Earthq. Res. Inst.*, 55, 1101-1113.

SHIMAZAKI, K. and P. SOMERVILLE, 1979, Static and dynamic parameters of the Izu-Oshima, Japan earthquake of January 14, 1978, *Bull. Seism. Soc. Amer.*, 69, 1343-1378.

SMITH, B. E. and M. J. S. JOHNSTON, 1976, A tectonomagnetic effect observed before a magnitude 5.2 earthquake near Hollister, California, *J. Geophys. Res.*, 81, 3556-3560.

SMITH, S. W. and M. WYSS, 1968, Displacement on the San Andreas Fault subsequent to the 1966 Parkfield earthquake, *Bull. Seism. Soc. Amer.*, 58, 1955-1973.

TSUMURA, K., 1977, Anomalous crustal activity in the Izu Peninsula, Central Honshu, *J. Phys. Earth*, 25, S51-S68.

TSUMURA, K., I. KARAKAMA, I. OGINO and M. TAKAHASHI, 1978, Seismic activities before and after the Izu-Oshima-Kinkai earthquake of 1978, (*in Japanese with English abstract*), *Bull. Earthq. Res. Inst.*, 53, 675-706.

TSUNEISHI, Y., T. ITO and K. KANO, 1978, Surface faulting associated with the 1978 Izu-Oshima-Kinkai earthquake, *Bull. Earthq. Res. Inst.*, 53, 649-674.

UMEDA, Y. and H. MURAKAMI, 1978, A cataclysmal line accompanying the 1978 near Izu-Oshima earthquake and disasterous features by the largest aftershock in the Izu Peninsula, (*in Japanese with English abstract*), *J. Seism. Soc. Japan, Ser. 2*, 31, 275-286.

1978年東伊豆地震 (M 5.0) に先行した地磁気異常変化 —潜在断層の非地震性横ずれ運動?

地震研究所　笹井洋一
石川良宣

伊豆大島近海地震の余効変化を調べる目的で，河津に設置されたプロトン磁力計が，1978年9月から11月下旬にかけて極めて異常な変化をした．11月下旬に至るまでに約5〜7γの減少を示し，11月23日10時43分東伊豆地震（M 5.0）と同時に，約5γの増加を示した (Fig. 2. 10月中旬よりコネクター接触不良による断続的欠測がある）．これは地震に先行，もしくはそれに伴った地磁気変化としては，従来知られている中でも最も顕著な観測例である．くり返し磁気測量によって河津観測点付近で明瞭な全磁力減少が認められ，河津異常変化の空間的拡がりがある程度判明した (Fig. 3. 但し北部の変動は電車ノイズ等による見掛け上のもの).

垂直横ずれ断層に伴うピエゾ磁気変化モデルの特徴から，この異常変化は観測点のほゞ真下を走る潜在断層が，ごくゆっくりと右横ずれ運動を行なったためと解される．伊豆大島近海地震で伊豆半島内陸に延びた地震断層が，河津観測点付近を通ることは，多くの研究者の成果に共通している．ここでは SHIMAZAKI and SOMERVILLE (1979) の副断層モデルに依拠して，地磁気変化のモデル計算を行なった．彼等の推定したモデルとほゞ同じ断層が再び動いたとすれば，観測をよく説明できる．東伊豆地震はこの非地震性断層運動によって，断層南東端に応力集中が起って誘発されたと考えられる．地震時の全磁力増加は，東伊豆地震に伴う断層の北西端が，河津観測点のごく近傍まで延びているとして説明される．この第二の断層は M5.0 の地震にしては大き過ぎる．地震波を発生するような急激な破壊を生じたのは，断層面の一部であったかも知れない．上記のモデルは地磁気データのみをうまく説明するように決めたものに過ぎず，任意性は大きい．測地的データによって正否を検討されるべきものである．

このような非地震性断層運動（静かな地震）が起り得るのかという疑問が当然生ずる．これに答えるのは筆者等の力量を越える．梅田・村上 (1978) は伊豆大島近海地震の被害の様相から，陸上部の潜在断層の運動はごくゆっくりしていたと推定している．SHIMAZAKI and SOMERVILLE (1979) は強震計記録に副断層の運動に対応する卓越した相が見られないことから，非地震性運動の可能性さえ示唆している．元来動き易い状態にあった副断層が，何らかの地殻応力の高まりでゆっくり滑ったとするのは不自然ではないと思える．

河津の異常変化の直前に，伊豆半島南部で地殻応力の変化があったことを示唆する観測がある．第8図は松崎における全磁力変化と石廊崎の体積歪計記録を対比させたものである（大地，他 1979)．1977年11月〜12月および1978年8月〜9月の急激な変動において，両者の対応が非常に良いことに気付く．1977年末の歪計異常変化は，伊豆大島近海地震の前兆として名高い．一方，可逆的ピエゾ磁気による全磁力変化は，観測点の地球磁場方向への地殻伸縮率に比例する成分を持つ (SASAI 1980)．第8図の変化は，地磁気方向への短縮＝全磁力増加という符号を含めて，理論的予想と一致している．従って1978年8月末の松崎の地磁気異常変化は，石廊崎の体積歪変化と考えあわせると，おそらく南北方向に卓越した圧縮力の増加を意味すると思われる．この広域応力の変化が河津潜在断層の静かな横ずれ運動を引き起したものであろう．河津と松崎に現われた地磁気異常変化は，地磁気観測が地殻活動監視の一手段として有効であることを示している．

謝辞　我々の観測は伊豆半島現地の多くの方々の協力を得て遂行されている．特に静岡県田方郡中伊豆町菅引の本成寺住職，宇佐美日浄師，同県賀茂郡河津町上佐ヶ野，河津営林署上佐ヶ野種苗場の相馬充氏，斉藤政義氏には，既に数年にわたる地磁気連続観測に御協力頂き，貴重な記録が得られている．気象庁地磁気観測所の河村譜所長および大地洸主任研究員には，松崎における観測成果について常に情報を頂き，更には第8図の本論文への再録も許可して頂いた．以上の方々に心から感謝の意を表します．