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Paleomagnetism of the Ibaragi Granitic Complex

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Abstract

The Ibaragi granitic complex is devided into two units of the Nose and Myoken plutons. The directions of remanent vector at each sampling site are well grouped and fall into two groups. The normal remanent vectors of the Nose pluton are almost northeasterly and the reversed ones are southwesterly. It is expected that some of these intermediate directions of magnetization was acquired at the time of a field transition. All samples from the Myoken pluton are normally magnetized and the directions of remanent vector are slightly northeasterly. A significant difference in direction of remanent vector between the Nose and Myoken plutons was found. This suggests that the directions of remanent vector have been affected by some tectonic movement after the intrusion of the plutons. Although there are a few restoring methods to find an original position of the plutons, we concluded that the Ibaragi complex has been tilted by a rotation about an axis in a tilted plane of about 15° upward from the horizontal plane.

1) Introduction

Reversals of the geomagnetic field have been reported by many workers (Irving, 1964; McElhinny, 1973) and a time scale of field reversals has been established by Larson and Pitman (1972) for the last 160 m.y. based on the study of magnetic lineations. According to this reversal stratigraphy, it is suggested that the geomagnetic field changed its polarity over a hundred fifty times throughout the last 160 m.y. However, the configuration of the geomagnetic field during such polarity transitions is less well known. Although this is likely to show that most of polarity transitions occurred very quickly, we have partially obtained reversal records from some intrusive rocks in which slow migration of the Curie temperature isotherm through the cooling intrusive has provided a continuous record of the geomagnetic field (Ito, 1963, 1965; Ito and Fuller, 1970; Dunn et al., 1971; Ito and Tokieda, 1972).

In Japan, dated small granitic rock bodies of the Cretaceous and Tertiary are widely distributed in Hokkaido, Honshu and Kyushu Islands (Nozawa, 1968, 1970). We preliminary collected samples of those dated rocks from Southwest Honshu and did paleomagnetic investigations of the samples. Consequently, it was found that the Cretaceous intrusions exposed in the north of Ibaragi city, Osaka Prefecture, Japan, have the stable normal and reversed natural remanent magnetization (NRM) within a single rock body. The intrusive rocks which are composed of two plutons have been named the Ibaragi granitic complex and the geological and petrological investigations of the body were carried out in detail by Tainosho (1971). Fortunately, geochronological study of the granitic complex by Rb–Sr method was also carried out by Ishizaka (1971). The biotite gave rock ages ranging from 79 to 83 m.y. for the representative rock facies of the Nose pluton and ages of 76 and 77 m.y. for two samples of the Myoken pluton. The K–Ar ages by Shibata (1971) are, however, 74 and 76 m.y. for two samples of the Nose pluton and 74 m.y. for a sample of the Myoken pluton.

Preliminary paleomagnetic studies of this complex has been previously done by Ito (1965) and Kanaya and Noritomi (1974). In this paper, some results of the paleomagnetic study will be described in detail by the new results of geological and petrological investigations and isotopic age determinations of this intrusion.

2) Geological setting and sampling

According to Tainosho (1971), the Ibaragi granitic complex (34°50′N, 135°30′E) consists of two bodies of the Nose and Myoken plutons. The Nose pluton is a small intrusive body with elliptical shape differentiated from coarse-grained qurtz diorite to fine-grained porphyritic adamellite and the size is approximately 10 km long and 5.5 km wide. This pluton intrudes the Paleozoic formation of Tanba zone. The Nose pluton is, roughly speaking, composed of following three rock types ranged in order from the outer part to the central part of the pluton.

(a) Coarse and medium-grained quartz diorite
(b) Coarse-grained granodiorite
(c) Fine-grained porphyritic adamellite

The Myoken pluton consists of two rock types of fine-grained pink adamellite and very fine-grained porphyritic pink adamellite. This pluton is approximately 6.5 km long and 2 km wide. The Ibaragi granitic complex is seemingly extending with the direction of N30°W.

The age of the Ibaragi granitic complex are given by Ishizaka (1971) and Shibata (1971). According to Ishizaka (1971), the Rb–Sr ages of the Nose pluton are 79 to 83 m.y. and the Myoken pluton is younger ages (76 and 77 m.y.) than those of the Nose pluton. On the other hand, the K–Ar ages of the Nose pluton are 74 and 76 m.y. by Shibata (1971) and the age of the Myoken pluton is 74 m.y. These results of age determination suggest that the Myoken pluton was emplaced at a later stage than the Nose pluton. The sampling localities for these radiometric dating are indicated by the closed square (Ishizaka, 1971) and closed triangle (Shibata, 1971) in Fig. 1.

Oriented hand samples were collected from twenty three sites of both the Nose and Myoken plutons. Their sampling sites are also shown in Fig. 1. About ten hand samples were taken at each sampling site and one or two core samples with 2.5 cm in

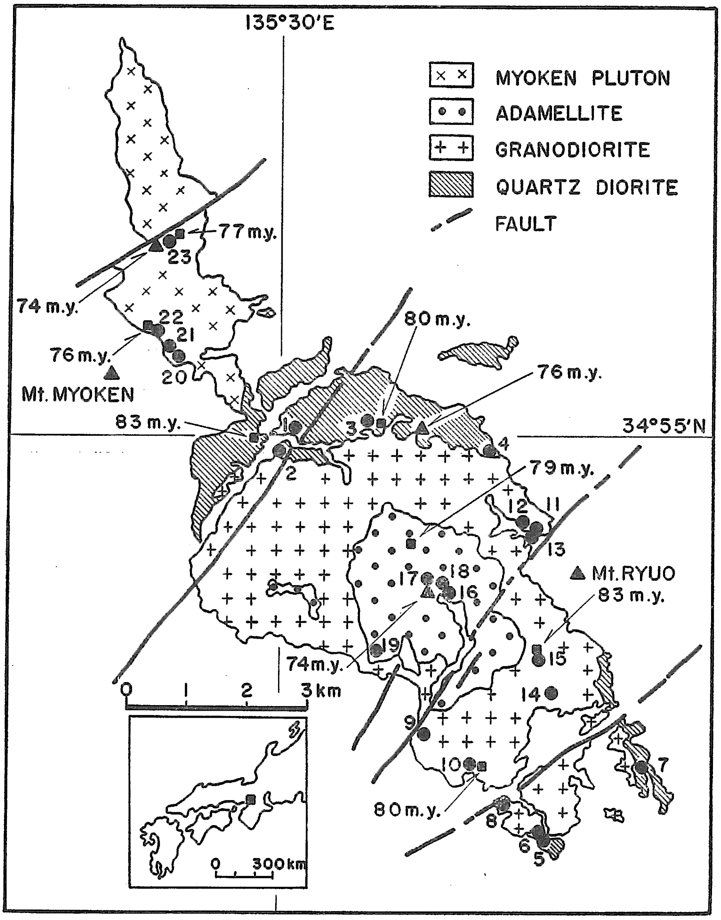

Fig. 1. Geological sketch map of the Ibaragi granitic complex (after Tainosho, 1971). Sampling localities for radiometric dating are indicated by the closed square (after Ishizaka, 1971) and closed triangle (after Shibata, 1971). Sampling sites for paleomagnetism are shown by full circles.

diameter and 2.4 cm in length were drilled from a hand sample using drill machine in the laboratory.

3) Measurements of NRM and stability tests

The direction of NRM have been initially measured with an astatic magnetometer at the Shimane University and then with a spinner magnetometer at the Rock Magnetism Laboratory of the University of Pittsburgh. Alternating field (AF) demagnetization to 100 oe was done for core samples by tumbling the sample about two axes simultaneously in the three cylindrical μ-metal boxes in which the ambient field was maintained at less than 0.01 per cent of the earth's field.

Results of measurements of the NRM after AF demagnetization of 100 oe are listed in Table 1. Site-mean directions of the NRM are also shown in Fig. 2. Initial

Table 1.

Locality	N	D (°E)	I (°)	I_r (emu/cc)	K	α_{95}	Pole position Lat.	Long.	dp	dm
1 Yono	5	70	+53	18.00×10^{-5}	118.2	7.1	34°N	158°W	6.8	9.8
2 Yono	5	106	+42	11.10	106.2	7.5	0°	163°W	5.6	9.2
3 Kirihata	5	268	−74	9.47	165.3	6.0	31°S	9°W	9.8	10.8
4 Zenihara	5	9	+59	10.28	130.3	6.7	81°N	171°W	7.5	10.0
5 Kamimura	5	253	−26	0.31	17.7	18.7	22°S	44°E	10.9	20.2
6 Kamimura	10	230	−34	0.67	71.7	5.7	43°S	52°E	5.6	6.5
7 Daimonji	3	225	−68	0.98	116.7	9.6	54°S	5°E	12.7	15.1
8 Sabo	10	82	+71	4.10	154.6	3.9	32°N	177°E	5.9	6.8
9 Sabo	11	243	−60	2.53	74.5	5.3	41°S	19°E	6.1	8.0
10 Sabo	5	249	−54	5.52	102.7	7.6	35°S	25°E	7.5	10.7
11 Shimootoba	5	263	−58	9.42	178.0	5.8	26°S	15°E	6.3	8.5
12 Shimootoba	5	259	−63	23.07	58.7	12.0	31°S	9°E	16.9	20.1
13 Shimootoba	22	270	−54	5.37	77.8	3.5	19°S	16°E	3.4	4.9
14 Minoyama	5	221	−48	1.85	9.3	26.4	55°S	44°E	22.5	34.5
15 Minoyama	5	260	−61	4.28	6.8	31.7	29°S	13°E	37.2	48.6
16 Tarumi	5	107	+75	0.43	54.2	10.5	23°N	165°E	17.5	19.2
17 Tarumi	5	68	+50	0.40	56.1	10.3	34°N	151°W	9.4	14.0
18 Tarumi	6	23	+66	0.38	76.0	7.7	68°N	180°E	10.3	12.6
19 Izumihara	5	233	−51	4.12	146.0	6.4	46°S	34°E	5.9	8.7
20 Noma-toge	4	16	+70	2.98	71.0	11.0	68°N	161°E	16.3	18.9
21 Noma-toge	4	351	+66	2.54	13.2	26.3	75°N	159°E	35.2	43.0
22 Noma-toge	3	63	+62	0.71	18.2	29.8	42°N	164°W	35.9	46.2
23 Noma Ohara	5	40	+53	0.45	18.5	18.3	58°N	149°W	17.5	25.3

N : Number of samples measured.
D : Declination.
I : Inclination.
I_r : Intensity of NRM after demagnetization of 100 oe.
K : Fisher's precision parameter.
α_{95}: Semi-angle of cone of 95% confidence.
dp, dm: Semi-axes of ovals of 95% confidence.

directions of the NRM of some core samples were well grouped, and the directions of remanent vectors after demagnetization of 100 oe were almost fixed in situ without great change. The directions of normal NRM of quartz diorite from the outer part of the Nose pluton are northeasterly, and reversely magnetized rocks are southwesterly. Samples of granodiorite from the middle part are reversely magnetized, except for one site (site 8), and the directions of NRM show obviously intermediate. Acidic adamellite placed at the central part has the normal NRM with directions which are slightly northeasterly, except for one site (site 13). All samples from the Myoken pluton (sites 20 to 23) are normally magnetized and the directions of remanent vector deviate still significantly from the present field direction.

After thermal demagnetization for some core samples, change in direction of the NRM was nothing significantly. Both the directions of magnetic vector after thermal and AF treatments for two core samples from a hand sample tended to agree well. Curie temperatures were between 550° to 570°C in all samples investigated. Reflected light microscopy showed that the titanomagnetite is in one generation with large grains of up to several hundred microns. Samples collected at Tarumi included only a little ferromagnetic mineral so long as we observed under the reflected light. This is likely to be the cause that the intensity of NRM of the samples at Tarumi is very weak as compared with that of the other localities. There are no obvious microscopic difference among ferromagnetic minerals in the samples taken from the outer, middle and central parts of the complex.

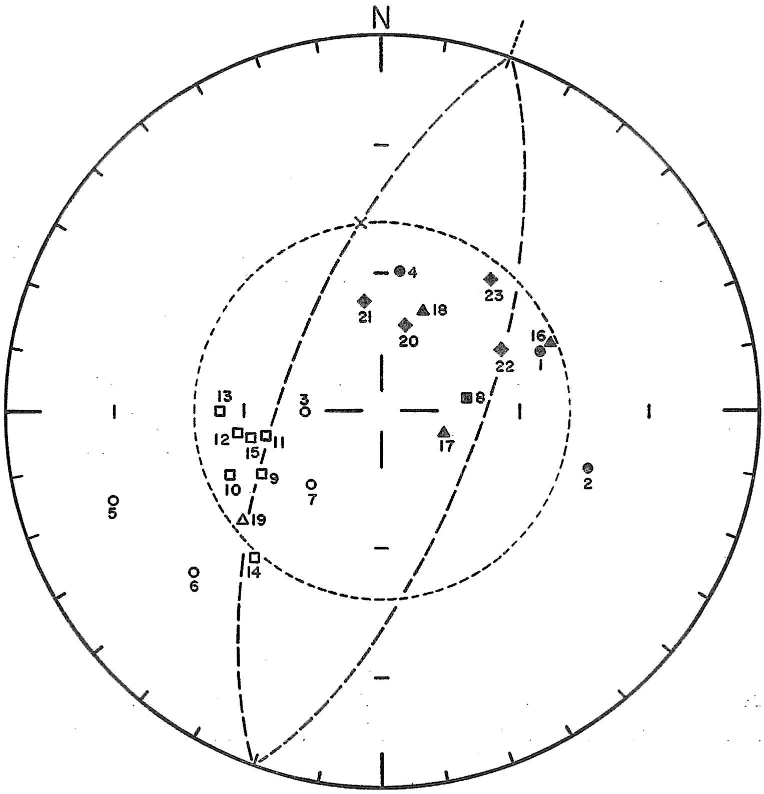

Fig. 2. Site-mean directions of NRM after demagnetization of 100 oe.

4) Directions of the NRM

Presently available paleomagnetic data from the Kinki and Chugoku districts indicate that normal samples of the Cretaceous and early Tertiary have northeasterly directions and reversed ones southwesterly directions (Nagata et al., 1959; Sasajima and Shimada, 1966; Sasajima et al., 1968; Kawai et al., 1971; Domen, 1971; Ito and Tokieda, 1972; Kono et al., 1974; Ito and Tokieda, in press). The overall mean direction of NRM for the normal samples is 46° in declination and 56° in inclination and that for the reversed ones is 232° and −48° respectively (Ito and Tokieda, in press).

Site-mean directions of the NRM of the Ibaragi granitic complex are shown on the equal net in Fig. 2. As seen in Fig. 2, the intermediate normal directions and the intermediate reversed ones cluster around two points about 180° apart from each other along the great circle. The mean direction of NRM for the normal samples of the Nose pluton is 68° in declination and 64° in inclination and that for the reversed ones is 246° and −56° respectively. However, the Myoken pluton has only the normal NRM and the mean direction is 31° in declination and 65° in inclination. Thus the paleomagnetic data from the Ibaragi complex are apparently in accord with those from Southwest Honshu.

The most important question is whether the ancient magnetic field had an axial geocentric dipole that it is now in geological time. The available paleomagnetic data from all over the world indicate that the geomagnetic field is nearly dipolar since the upper Cretaceous and that the north seeking pole is close to the present geographic north pole (Strangway, 1970; McElhinny, 1973). Therefore, remanent vectors which were acquired in a period of reversed polarity are roughly opposed to the present field direction. It is also assumed that intermediate directions of the NRM were acquired in a field of transitional dipole. On the other hand, there will be changes in direction of remanent vector caused by tectonic movements after the formation of rocks.

The NRM of the Nose pluton are normal by half in the outer part (oldest), almost reversed in the middle part, and normal in the central part (younger). This shows that the pluton which is intermittent intrusions differentiated from basic quartz diorite to acidic adamellite was partly emplaced at some period of time of polarity transition, during which time the pole moves to and from south. The Myoken pluton whose age appears to be younger than the Nose pluton has been normally magnetized. It shows that the pluton intruded at the time of a normal polarity subsequent to the field transition.

5) Discussion

The paleomagnetic results as described above would be interpreted as follows.

It is not that the geomagnetic field direction itself has largely changed from the upper Cretaceous to the present except a period of polarity transitions. The NRM of the Myoken pluton emplaced at the time of a normal polarity was directed mainly along a geomagnetic field nearly parallel to the present field, but the directions of NRM have been deflected from the original one by some tectonic movement after the formation. The deflection in direction of remanent vectors of the Nose pluton was originally acquired at the time of a polarity transition of the field and after the acquisition of remanence more deflected by the same tectonic movement as changed the directions of NRM of the Myoken pluton. Accordingly, it is expected that all of the remanent vectors of the Nose and Myoken plutons are uniformly affected by such a tectonic movement. Site-mean declinations of NRM at each sampling site are schematically shown in Fig. 3.

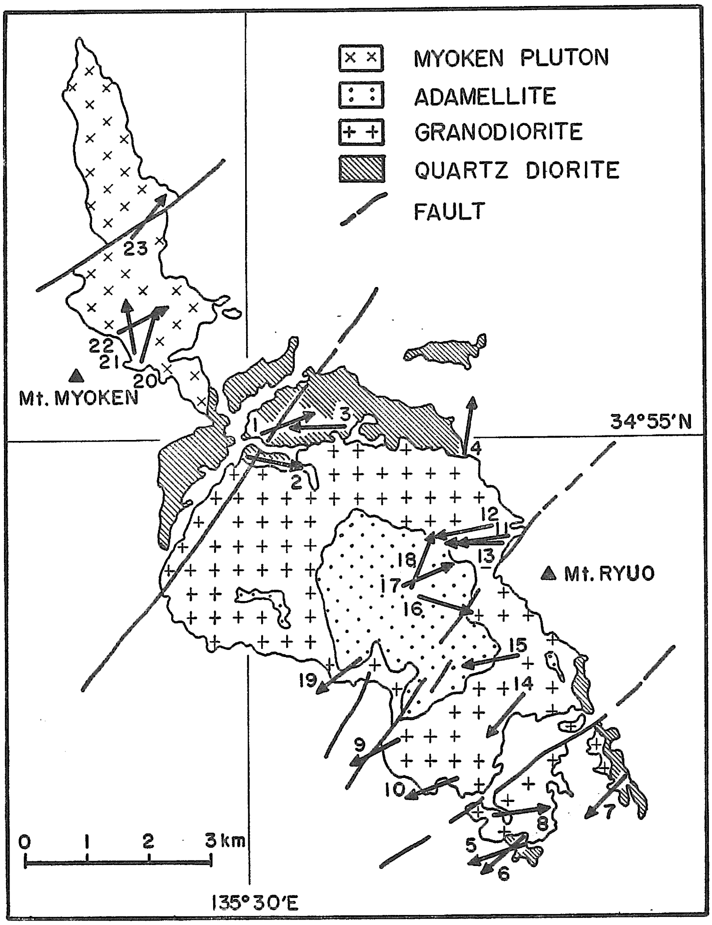

Fig. 3. Declinations of NRM at each sampling site.

The following basic procedures are considered in order to seek a primary direction of NRM from the measured NRMs (Ito and Tokieda, in press): (1) to rotate the magnetic vector about a vertical axis, (2) to rotate the magnetic vector about an axis in the horizontal plane or in a tilted plane from the horizontal plane, (3) to drift the observed rock body in the horizontal plane.

As described in the previous section, the mean declination of normal samples of the Nose pluton is N68°E and that of reversed samples is S66°W. It may be important that these two vectors in the same pluton are nearly antipodal to each other. Fig. 4 shows a case that all the site-mean directions of NRM have rotated 31° (this angle corresponds to the deviation in declination of NRM of the Myoken pluton) anti-clockwise about a vertical axis at the sampling locality. This means that the deviation in direction has been corrected by the declination only and that the pluton was subjected to a clockwise rotational movement in the horizontal plane.

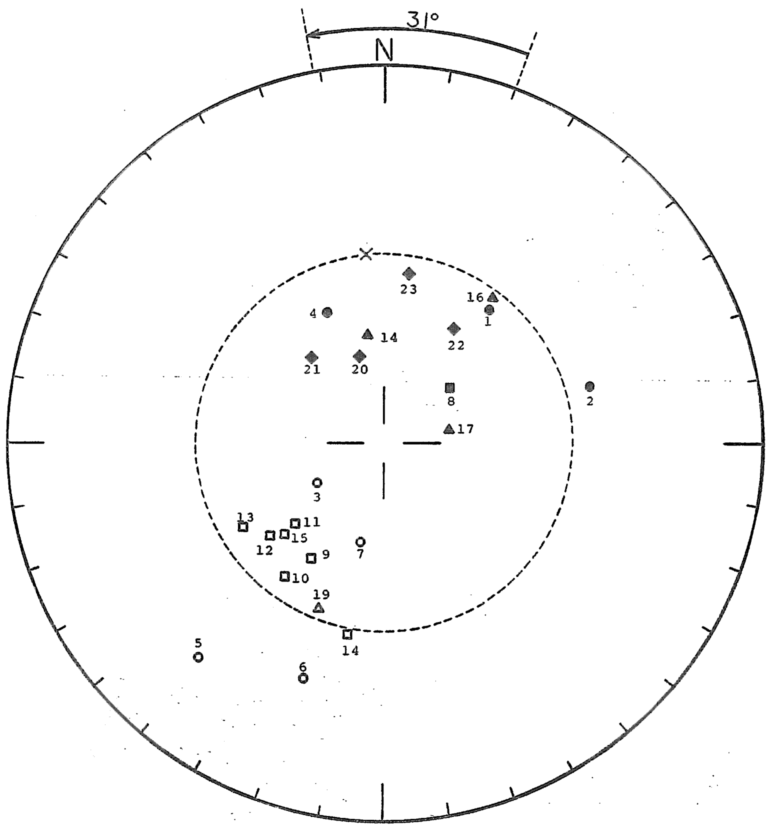

Fig. 4. Site-mean directions of NRM after a rotation about a vertical axis at the sampling site.

Fig. 5a shows to have restore the observed magnetic vectors to original positions by a rotation about an axis in the horizontal plane. In this case the rotation angle is approximately 20° and a direction of its rotational axis should be N20°E. This means that the pluton has been subjected to a tilting movement of 20° to the west-side. In these two cases, however, the difference in inclination between the present field and the observed NRM is inevitably disregarded.

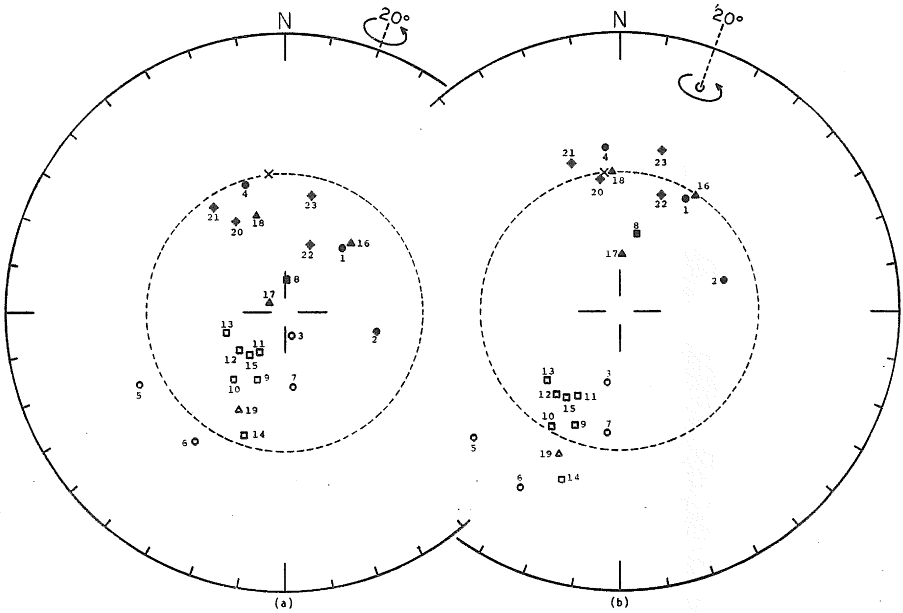

Fig. 5. (a) Site-mean directions of NRM after a rotation about a bisector in the horizontal plane. (b) Site-mean directions of NRM after a rotation about a bisector in a plane tilted 15° from the horizontal plane.

The present field direction at the sampling locality is 6°W in declination and 48° in inclination. The observed mean inclinations of the normal and reversed samples of the Nose pluton are 64° and −56° respectively and that of the Myoken pluton is 65°. Thus the mean inclinations of NRM of the complex are clearly different from that of the present field. The difference in inclination is about 15°. Fig. 5b shows an example of a rotation about an axis in a tilted plane of about 15° upward from the horizontal plane. In this case, it is seen that the directions of NRM approach the present field direction thoroughly. This may indicate that both the declination and inclination of NRM are successfully restored. On the assumption that the principle of minimum movement is applied, it will be reasonable to choose a rotation of magnetic vectors about an axis in a tilted plane from the horizontal plane corresponding to tilting movement of the pluton.

According to the geomagnetic reversal time scale (Larson and Pitman. 1972), the interval between 85 and 110 m.y. is a time of normal polarity representing the Cretaceous smooth zone as seen in Fig. 6. The fact that the middle part of the Nose pluton is reversely magnetized suggests that magnetic ages of the pluton are close to both the Rb–Sr ages (79 to 83 m.y.) by Ishizaka (1971) and the K–Ar ages (74 and 76 m.y.) by Shibata (1971). However, it will be able to emphasize that magnetic ages of the pluton are not older than 85 m.y.

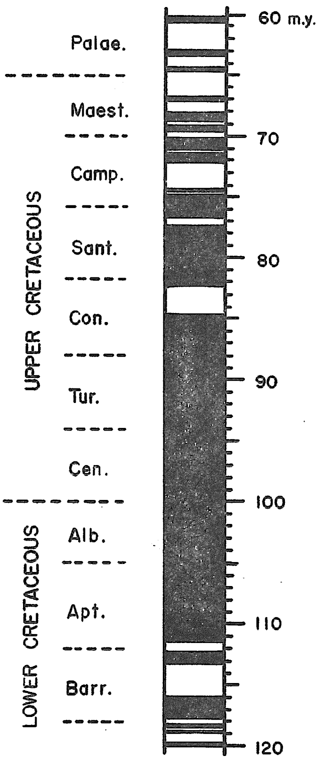

Fig. 6. Geomagnetic reversal time scale from 60 to 120 m.y. (after Larson and Pitman, 1972).

In short, most of the Nose pluton was formed for a short part of a transitional period in a few field reversals taken place for the interval from 85 to 75 m.y. In contrast, the Myoken pluton was emplaced at a period of normal polarity subsequent to a polarity change encountered with the intrusion of the Nose pluton. The directions of NRM of the Myoken pluton may have no record of the polarity transition. Accordingly, the observed deviation in direction of NRM of the Myoken pluton should be mostly caused by some tectonic movement after the intrusion. It is therefore concluded that the Ibaragi granitic complex was tilted about 20° to the west-side about an axis with N20°E direction in a tilted plane of about 15° upward from the horizontal plane.

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