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ON THE REVERSAL PROCESS OF THE EARTH'S MAGNETIC FIELD IN TERTIARY

by

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Abstract

Only a few examples of rocks have been found which have intermediate direction likely to indicate transitional stage of the earth's magnetic field. Most of the sequences of rocks with the intermediate magnetization are reported from Japan, North America and Iceland. Fortunately, these parts are away from one another about 120° in longitude. Although data to demonstrate the same transition zone are not found in papers published so far, a rough comparison between different parts of the world gave us some informations about the earth's magnetic field during the transition. Important points of the informations are that the earth's magnetic field during a reversal process is probably to have shifted along a path on the globe, and that each path seems to be dissimilar to each other between different parts of the world and between different ages.

1) Introduction

A fundamental assumption of paleomagnetism is that the natural remanent magnetization (NRM) of rocks is parallel to the ambient field that induced it. Results of paleomagnetic survey for younger rocks than the Miocene indicate that about half of rocks have the normal directions of magnetization parallel to the present field direction and approximately equal number is magnetized in just opposite to the normal direction. However, it is generally accepted that the earth's magnetic field during the Tertiary and Quaternary closely approximated a geocentric axial dipole (Doell and Cox, 1961). Cox et al (1964) have strongly demonstrated a field reversal pattern during a period of last 4 million years by using potassium-argon dating. Since then extensive paleomagnetic survey of much older rocks have been made for igneous rocks or sedimentary rocks in the world (Dagley et al, 1967 ; Cox, 1968, 1969 ; Heirtzler et al, 1968). It seems now to be well established that the reversal pattern in the late Tertiary was quite similar to that of the last 4 million years.

If the field reversal is correct and if self-reversals, as found in Haruna dacite (Uyeda, 1958), are rare in rocks of the Teriary and Quaternary, then the same magnetic polarity should be found in rocks of the same age all over the world. Therefore, if the intermediate NRM is found in rocks of the same age, it should generally show the change in direction of the ambient field even if self-reversals occurred. The intermediate direction of NRM is the most important factor to know the nature of the main dipole field during the transition. Although the earth's magnetic field reversed itself many times since the Miocene, a few data of the intermediate NRM which demonstrates the polarity transition have been reported only from Japan (Momose, 1958, 1963 ; Nomura, 1967 ; Ito, 1963, 1965), North America (Watkins, 1965 ; Goldstein et al, 1969 ; Ito and Fuller, 1970) and Iceland (Sigurgeirsson, 1957 ; Brynjolfsson, 1957). By using the paleomagnetic data published so far, it is possible to scrutinize whether exists a characteristic transition pattern during the polarity changes. In this paper it will be made a comparison between results of measurements of the intermediate rocks obtained from Japan and those from the other continents.

2) Reversals of the earth's magnetic field

An early important evidence for the field reversal was found in volcanic rocks in Japan and Korea by Matuyama (1929). Then, in Japan, reversely magnetized rocks are reported from many localities and on all kinds of rocks (Kawai, 1951 ; Nagata et al, 1957 ; Momose, 1958, 1963 ; Hirooka, 1963 ; Nomura, 1963, 1967 ; Ito, 1963, 1965 ; Nishida et al, 1967). On the other hand, many investigators have found consistent evidence on a worldwide basis to show that reversals took place simultaneously around the world. Momose(1958) reported that the change in direction of the earth's magnetic field from the normal to reversed polarity is traced contineously. Kawai(1963) suggested that a reversal pattern of the earth's magnetic field from Cretaceous to Quaternary was not in a strict periodic way. The most significant evidence of the field reversal have been produced by the combined study of paleomagnetism and potassium-argon dating (Cox et al, 1963a, 1963b, 1964 ; Cox, 1969 ; McDougall and Tarling, 1963). Recently, a reversal pattern of the earth's magnetic field less than 4.5 million years old is given by Cox (1969). According to this pattern, it is likely that the earth's magnetic field changed its polarity direction about twenty times. This shows that there is every probablity that we shall find about the twenty transition zones in younger rocks than 4.5 million years old, but the intermediate rocks are not always found in between the normally and reversely magnetized rocks.

Paleomagnetic survey for older rocks than 4.5 million years old has been carried out in Japan (Ito, 1965, 1970 ; Nagata et al, 1970), North America (Cox, 1968 ; Ito and Fuller, 1670) and Iceland (Dagley et al, 1967). Heirtzler et al (1968) have estimated the reversal sequence over the last 80 million years based on sea-floor spreading pattern. According to these results, the earth's magnetic field changed its direction many times since the early Tertiary. The reversal pattern of the Tertiary also is improbable to have been in a strict periodic way, but seems to be random with time, and it is likely to have been quite similar to that of the last 4.5 million years. Thus, the earth's magnetic field reversed the polarity direction many times, but it has approximated a geocentric axial dipole except the reversal process (Doell and Cox, 1961). This generalized information on the earth's magnetic field is available for making a study of the transition zones during the Tertiary and Quaternary.

3) Transition zones

As mentioned above, although the earth's magnetic field reversed the polarity many times during the Tertiary, the intermediate samples to indicate the transition have been rarely found because of a very difficulty in taking rocks which were formed in the reversal process. Therefore, it is not so easy to trace a reversal process of the field or to estimate the length of time required for the transition. A few results of the paleomagnetic survey suggest that positions of the paleomagnetic pole were located in a definite zone (Momose, 1958 ; Ito, 1965) and that the time required for the transition is approximately of the order of 10^3 to 10^5 years (Ito, 1970).

Table 1

	Reference	Rock type	Age	Note
Japan	Momose (1958)	Andesite	Pliocene	N−R
	Nomura (1967)	Andesite	Miocene	N−R−N
	Ito (1965, 1970)	Granodiorite and lavas	Miocene (13-14 m. y.)	R−N Reversing time : $<10^5$ years
North America	Watkins (1965)	Basalt	Miocene	N−R
	Goldstein et al (1969)	Lava flows	Miocene (15.1 m. y.)	N−R
	Ito and Fuller (1970)	Granodiorite	Pliocene (8.2 ± 0.5 m. y.)	R−N Reversing time : $\sim10^3$ years
Iceland	Sigurgeirsson (1957)	Basalt	Tertiary	N_4-R_3, R_3-N_3, R_2-N_2, N_2-R_1. Reversing time : A few thousand years
	Brynjolfsson (1957)	Basalt	Pliocene	R−N Reversing time : 1000-3000 years

N : Normal field
R : Reversed field

Samples with the intermediate NRM has been reported from Japan (Momose, 1958 ; Nomura, 1967 ; Hirooka, 1963 ; Ito, 1963, 1965, 1970), North America (Watkins, 1965 ; Goldstein et al, 1969 ; Ito and Fuller, 1970) and Iceland (Sigurgeirsson, 1957 ; Brynjolfsson, 1957). The rock kinds, ages and some notes of the intermediate samples are tabulated in Table 1. Informations about the intermediate magnetization are essential for revealing the nature of the earth's magnetic field during the transition. The known paleomagnetic data may not give us detailed and exact informations about the reversal process of the earth's field, but it will be a clue to find a behavior of the earth's magnetic field during the transitions in the Tertiary. In order to follow the change in direction of the earth's magnetic field during the transition, it is, of course, necessary to make an exact comparison between the intermediate rocks, belonging to the same transition zone, which were obtained from different parts of the world. The transition zones being exactly at the same time in the past are not yet found in different part sof the world. Fig. 1 shows a rough comparison between the pole positions estimated from the intermediate NRM of some transition zones. The pole positions are shown in the figure without regard to age of the transition zones and direction that the pole shifted.

The positions of the paleomagnetic pole at various times, which were obtained from the same continent, are not always located in the same zone around the globe. Although apparent shifted direction of the pole is not so clear with time, the pole positions taken from one locality appear to distribute in a definite zone around the earth. There exists no significant difference between inversions of the field from the normal to reversed and from the reversed to normal.

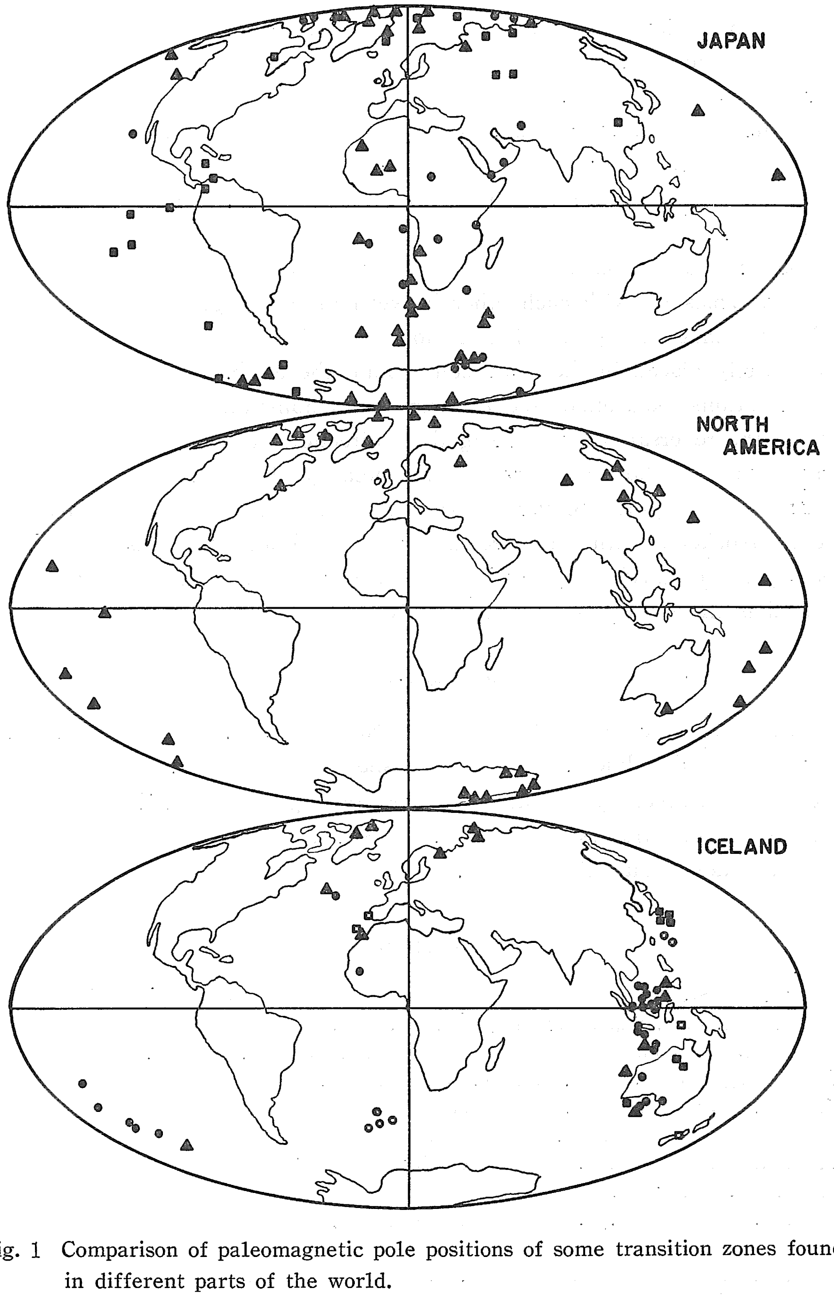

Fig. 1 Comparison of paleomagnetic pole positions of some transition zones found in different parts of the world.

Japan
- ● : Momose (1958)
- ■ : Nomura (1967)
- ▲ : Ito (1965, 1970)

North America
- ▲ : Ito and Fuller (1970)

Iceland
- ● : R_3-N_3 } Sigurgeirsson (1957)
- ○ : R_2-N_2 } Sigurgeirsson (1957)
- ■ : N_4-R_3 } Sigurgeirsson (1957)
- □ : N_2-R_1 } Sigurgeirsson (1957)
- ▲ : Brynjolfsson (1957)

4) Conclusions

As has been indicated above, the rough comparison between the transition zones gives us some informations about the earth's field during the reversal process. The important points are summarized as follows :

a) Directions of the intermediate NRM taken from a part are likely to demonstrate to have shifted along a path on the earth. In other words, the positions of the paleomagnetic pole are distributed in a definite zone along a great circle around the globe.

b) Paths of the paleomagnetic pole estimated from the same continent are not always consistent with each other between different ages.

c) The paleomagnetic poles of transition zones in different parts of the world are not strictly placed in the same belt around the earth.

The informations mentioned above seem to demonstrate that the earth's magnetic field during the reversal process changed its direction in order within a short period. This may show that the field reversed the polarity direction rapidly without strong disturbance of non-dipole component or under the influence of a steady non-dipole component associated with the decreasing main dipole field as described in the previous paper (Ito, 1970). A detailed comparison between the same transition zones of the world is the subject for a future study.

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