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# Paleomagnetism of Cambrian to Jurassic Sedimentary Rocks from the Ogcheon Zone, Southern Part of Korean Peninsula

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A paleomagnetic study was performed on sedimentary rocks in the Ogcheon zone. The area is unique in the southern part of the Korean Peninsula for the existence of a sequence of sedimentary rocks from the Cambrian through the Jurassic periods. Although the rocks were strongly overprinted with a secondary magnetization, detailed thermal demagnetization was effective in isolating a component with a very high blocking temperature in a few sites. This component is thought to be the primary magnetization. The paleomagnetic directions from these sites, which are Carboniferous, Permian and Triassic in age, suggest that the Ogcheon zone had belonged to the South China Block rather than the North China Block.

## 1. Introduction

Recent studies suggest that the eastern part of the Eurasian plate was fragmented in the pre-Cretaceous age (MITCHELL, 1981; MCELHINNY *et al.*, 1981; KLIMETZ, 1983). Two of the blocks now sharing a large part of eastern Eurasia are the North China Block (NCB) and the South China Block (SCB). The boundary of these blocks are, however, still controversial in the east border area. MCELHINNY *et al.* (1981) drew the boundary between the NCB and SCB to the south of the Korean Peninsula. In contrast, LIN *et al.* (1985) located the line in the midst of the Korean Peninsula. In order to give some restriction to the position of the boundary, we made a paleomagnetic study on several pre-Cretaceous sedimentary rocks from the Ogcheon zone, which is situated in the middle of South Korea.

In the northeastern part of the Ogcheon zone are deposits of Cambrian, Ordovician, Carboniferous, Permian, Triassic and Jurassic sedimentary rocks (REEDMAN and UM, 1975). In other regions in the southern part of the Korean Peninsula, pre-Cretaceous rocks are either granitic intrusion or metamorphic rocks, although some Jurassic sediments are distributed sporadically. Therefore, paleomagnetic measurements for the Ogcheon zone are indispensable in discussing the pre-Cretaceous tectonics of the Korean Peninsula.

## 2. Sampling and Measurements

Samples were collected in the Jangseong and Mungyeong areas (Fig. 1). The samples range in age from Cambrian to Jurassic in the Jangseong area, and from Ordovician to Jurassic in the Mungyeong area (REEDMAN and UM, 1975). Silurian and Devonian samples were absent in both these regions. Latitude, longitude, number of hand samples, rock type, and age of the strata of each site are summarized in Table 1.

Several, usually more than five, oriented block samples were collected at each site using a magnetic compass. A few cores 25 mm in diameter were drilled from each block sample and were cut to a height of about 25 mm.

Measurements of remanent magnetization were carried out using an ScT C-112

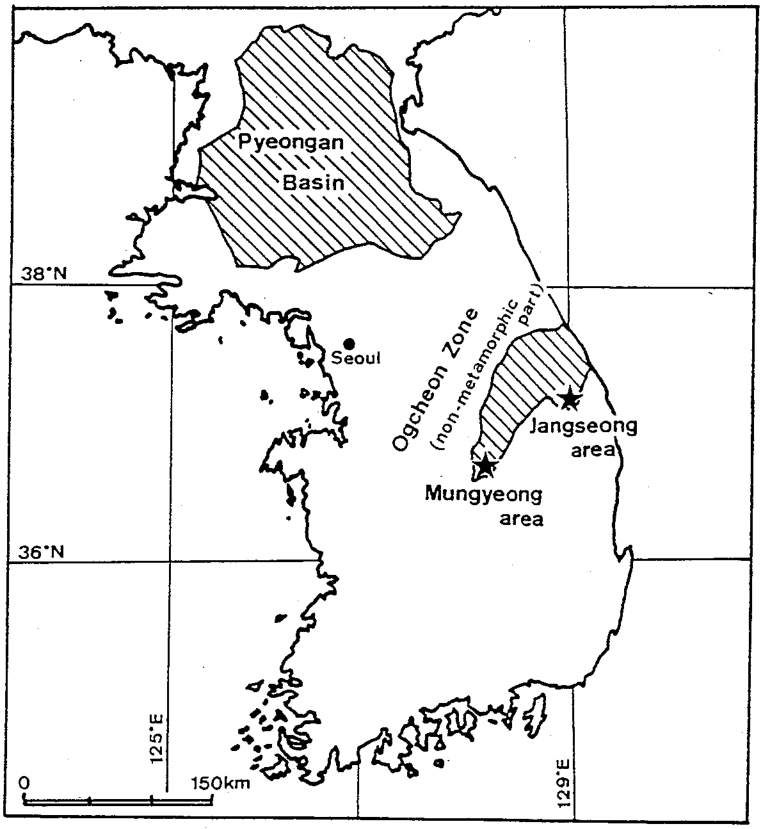


Fig. 1. A map showing the studied area. The stars are studied areas. Shaded areas are where pre-Jurassic non-metamorphic sedimentary rocks are distributed.

Table 1. Sampling sites. $N_s$: number of block samples. Lat. and Long.: Latitude and longitude, respectively. Fm.: Formation. Cm, O, Cr, P, Tr and J in the age column indicate Cambrian, Ordovician, Carboniferous, Permian, Triassic and Jurassic, respectively.

Jangseong area

| Site | $N_s$ | Lat. (37°N) | Long. (129°E) | Age (Fm.) | Rock type |
|---|---|---|---|---|---|
| 12 | 3 | 4′40″ | 3′15″ | Cm (Jangsam) | quartzite |
| 13 | 5 | 4′40″ | 3′02″ | Cm (Myobong) | slate |
| 14 | 6 | 4′48″ | 2′54″ | Cm (Pungchon) | limestone |
| 15 | 6 | 4′54″ | 2′53″ | Cm (Pungchon) | limestone |
| 16 | 8 | 4′57″ | 2′53″ | Cm (Sesong) | slate |
| 17 | 8 | 5′20″ | 5′39″ | O (Dumugol) | limestone |
| 18 | 8 | 5′34″ | 2′21″ | O (Dumugol) | limestone |
| 19 | 6 | 5′45″ | 1′22″ | Cr (Hongjeom) | sandstone |
| 20 | 8 | 6′05″ | 0′42″ | Cr (Hongjeom) | sandstone |
| 21 | 5 | 6′06″ | 0′14″ | P (Sadong) | black shale |
| 22 | 8 | 6′11″ | 0′11″ | P (Sadong) | sandstone |
| 23 | 8 | 6′28″ | 0′12″ | P (Gobangsan) | red sandstone |
| 24 | 9 | 6′31″ | 0′12″ | P (Gobangsan) | red sandstone |
| 25 | 9 | 7′06″ | 0′08″ | Tr (Nogam) | red sandstone |
| 26 | 5 | 7′06″ | 0′08″ | Tr (Nogam) | red sandstone |
| 27 | 11 | 7′58″ | 0′21″ | Tr (Nogam) | red shale |

Mungyeong area

| Site | $N_s$ | Lat. (36°N) | Long. (128°E) | Age (Fm.) | Rock type |
|---|---|---|---|---|---|
| 28 | 10 | 39′12″ | 8′03″ | P (Gobangsan) | sandstone |
| 29 | 2 | 39′13″ | 8′07″ | P (Gobangsan) | sandstone |
| 30 | 8 | 39′17″ | 8′01″ | J (Daedong) | shale |
| 31 | 8 | 39′24″ | 7′56″ | P (Gobangsan) | sandstone |
| 32 | 11 | 39′35″ | 7′35″ | Tr (Nogam) | red shale |
| 33 | 10 | 39′43″ | 7′50″ | J (Daedong) | sandstone |
| 34 | 4 | 40′25″ | 8′34″ | J (Daedong) | black shale |
| 35 | 8 | 40′24″ | 8′37″ | J (Daedong) | black shale |
| 40 | 5 | 37′33″ | 8′59″ | O (Dumugol) | limestone |
| 41 | 5 | 37′33″ | 8′59″ | O (Dumugol) | limestone |
| 42 | 10 | 37′53″ | 9′06″ | O (Dumugol) | limestone |
| 43 | 8 | 37′33″ | 7′30″ | Cr (Hongjeom) | silty sandstone |
| 44 | 8 | 38′46″ | 8′50″ | P (Sadong) | black shale |
| 45 | 9 | 39′22″ | 8′31″ | P (Gobangsan) | sandstone |

cryogenic rock magnetometer at Kyoto University. The magnetometer is connected to an NEC PC8001mkII microcomputer for stacking data and calculating the magnetic direction. Thermal demagnetization was accomplished in a non-inductively wound electric furnace contained within a three layered mu-metal shield (ITOH and TORII, 1984). The accuracy of the demagnetization temperature is about ±10°C. During the cooling cycle, the furnace was withdrawn from the region where specimens were placed so as to reduce the stray magnetic field. The mu-metal shields were frequently demagnetized by the alternating field method such that the stray field in the sample space was maintained at less than 10 nT during the cooling cycle. Progressive demagnetization was performed in 10 or more steps up to the point that the remanence either becomes too weak for meaningful measurement or becomes masked by excessive buildup of VRM (viscous remanent magnetization) acquired between the field free spaces of demagnetizer and magnetometer.

## 3. Results

Orthogonal diagrams for the thermal demagnetization of the pilot specimens show three different types of behavior of the remanent magnetizations of the samples. One type of behavior (Class A) is for the specimen with no stable component. This behavior was found with most of the limestone and sandstone samples (Fig. 2(a)). We will not say anything further about these samples. Another type of behavior (Class B) shows one stable component (Fig. 2(b)). Although the blocking temperature ($T_b$) ranges of the stable component vary from site to site, some specimens show a high $T_b$ of more than 600°C. The last type of behavior (Class C) shows two stable components (Fig. 2(c)). The $T_b$ of the high-$T_b$ component is very high (more than 650°C) and the ranges are very narrow. The low-$T_b$ component (the word 'low'-$T_b$ was used relatively) also shows a $T_b$ portion higher than 600°C.

The $T_b$ ranges of the stable component of Class B specimens and the low-$T_b$ component of Class C specimens overlap. The similarities of these two components are not only the $T_b$ ranges but also the directions. The in-situ magnetic directions of these components are shown in Fig. 3. It can be clearly seen that the directions are very well clustered in spite of various individual bedding plane tilting, and they are close to the present geocentric dipole field direction. The components are, therefore, concluded to be secondary. These specimens have a common, very stable secondary magnetization.

In order to determine the site mean direction in the other component of the Class C specimens, several additional specimens in each Class C site were demagnetized at 670°C. The magnetic directions on some of the samples were difficult to determine. This is because the internal consistency of a measurement became very poor due to either very weak intensity or the sample becoming so viscous that even very short exposure to earth's magnetic field was enough to get spurious VRM. We are using, as an index of the internal consistency of a measurement, the standard deviation of measurements of vector component intensity. As the $i$-th component was measured several times, the standard deviation of the $i$-th component, $\sigma_i$, was defined as usual. Then the total $\sigma$ was calculated by $\sigma^2=\sigma_1^2+\sigma_2^2+\sigma_3^2$. When the sigma was larger than 10% of the total intensity, the measurement was thought to be inconsistent and was abandoned.

The directions after the treatment at 670°C are shown in Fig. 4. These samples show significant scatter on several sites. In these sites, the remanent intensities after the treatment were very widely distributed and divided into two groups, strong and

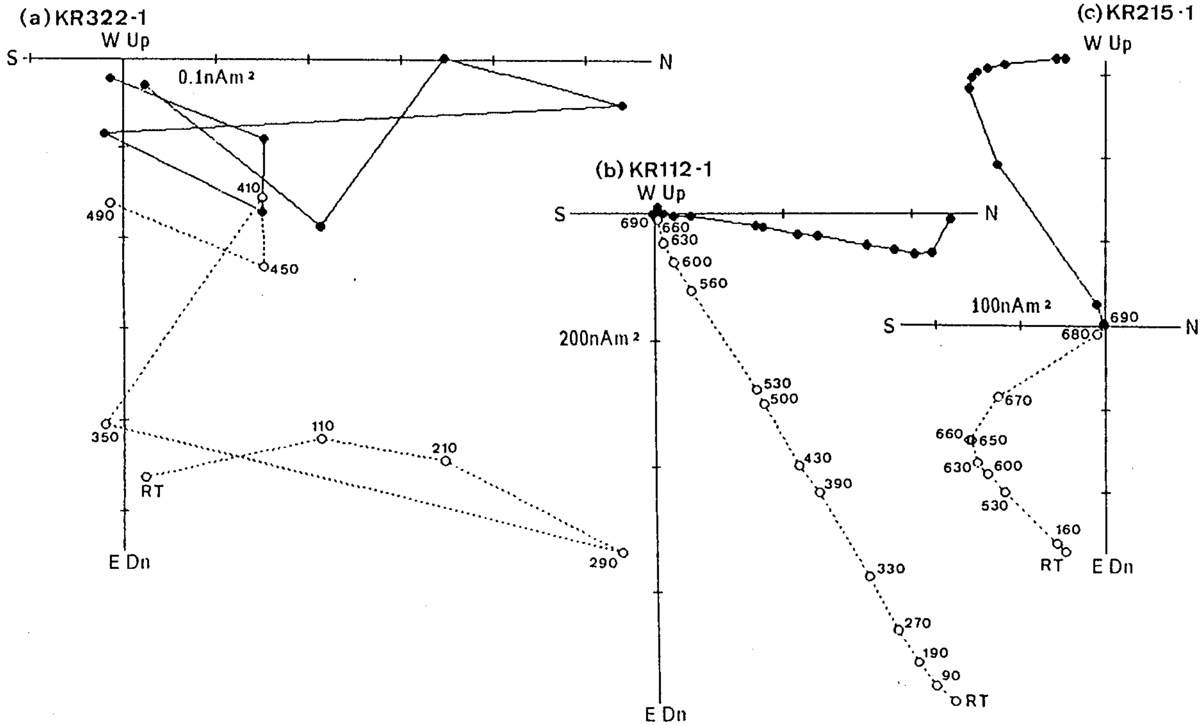


Fig. 2. Orthogonal diagrams of three representative examples of stepwise thermal demagnetization experiments. (a), (b) and (c) are examples of pilot specimens with no, one and two stable components, respectively. Numerals in the figure indicate the demagnetization temperature in degrees Celsius. Open and solid circles denote the projection onto vertical and horizontal planes, respectively. SHIBUYA *et al.* (1985) should be referred to for demagnetization diagrams of all the pilot specimens.

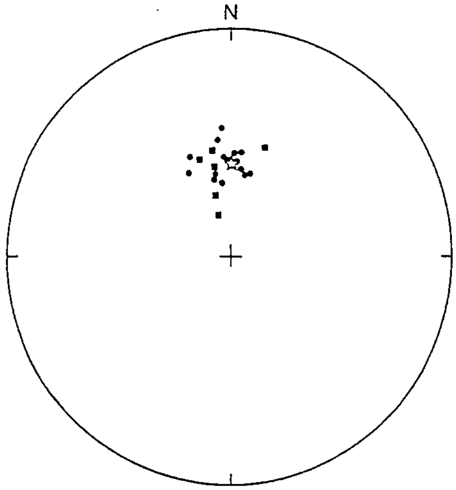


Fig. 3. Directions of low-$T_b$ component of pilot specimens in equal area projection. Circles and squares are from sites in the Jangseong and Mungyeong areas, respectively. Star indicates the present geocentric dipole field direction. All directions are in the lower hemisphere.

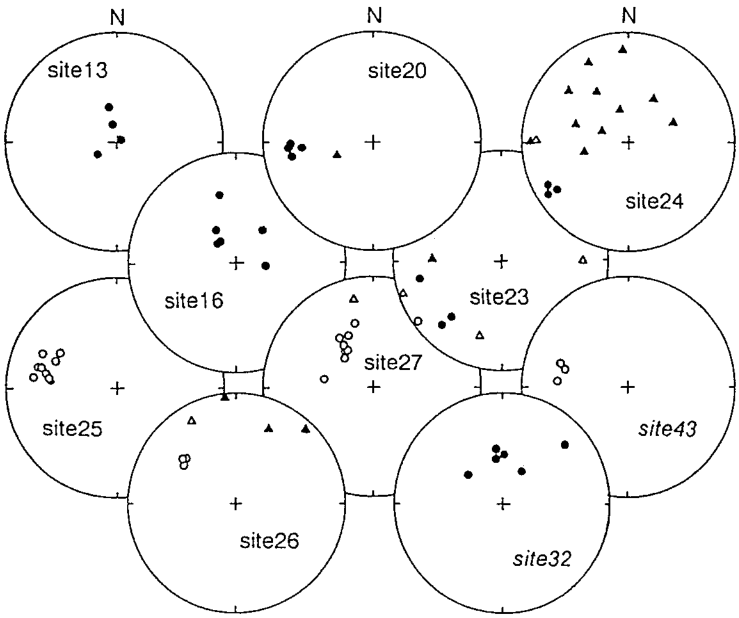


Fig. 4. Equal area projection diagram showing the individual magnetic direction of each specimen after a treatment of 670°C. Open and solid symbols are projection of upper and lower hemispheres, respectively. Triangles indicate specimens judged as unreliable (see text).

weak (Fig. 5). The magnetic directions of the strong specimens, including the progressively demagnetized pilot specimen of their site, were well clustered, while those of weak specimens were scattered. A progressive demagnetization experiment for one of the weak specimens indicates that they did not have enough magnetization of the high $T_b$ component to be measured and the excessive build up of VRM after demagnetization treatment masked this component. The weak specimens were, therefore, judged to have few magnetic minerals with a $T_b$ higher than 670° C, and were abandoned.

The site mean directions and their 95% confidence circles for high-$T_b$ component surviving are shown in Fig. 6(a) and Table 2. Even after the intensive treatment, three mean directions could not be distinguished from the present geocentric magnetic field direction (site 16, site 19 and site 32). These sites were also characterized by large $\alpha_{95}$. Because of this, we rejected these sites for further tectonic discussion. Six sites in the Jangseong area (two Carboniferous, one Permian and three Triassic in age) and one site in the Mungyeong area (Permian) did not show this behavior. These sites are used in the tectonic discussion below. The surviving sites were corrected for tilting (Fig. 6(b) and Table 1). The corrected directions are grouped for each geological epoch.

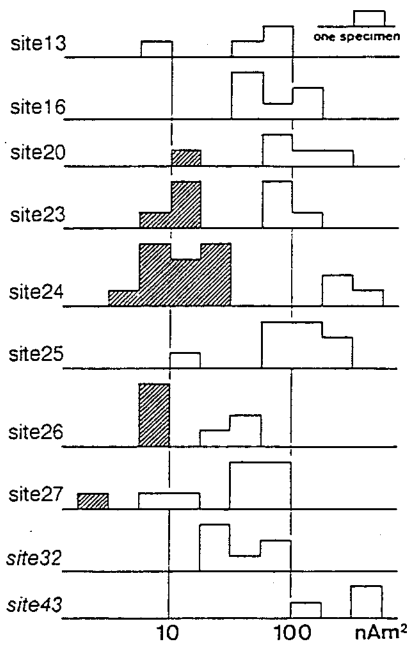


Fig. 5. A histogram of the remanence intensity after a thermal treatment of 670° C in each site. Shaded specimens correspond to the triangles in the Fig. 4.

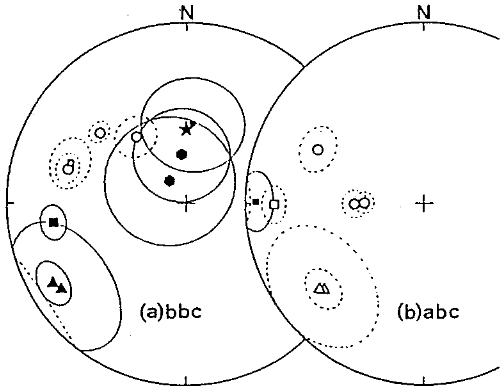


Fig. 6. Equal area projection diagram showing site mean directions before (left) and after (right) bedding correction. Hexagons, squares, triangles and circles indicate Cambrian, Carboniferous, Permian and Triassic sites, respectively. Larger and smaller symbols show sites in Jangseong and Mungyeong areas; open and solid symbols are projection of upper and lower hemispheres, respectively.

Table 2. Site mean directions of high-$T_b$ component. Abc, bbc, $\alpha_{95}$ and VPP denote magnetic direction before and after bedding correction, radius of confidence circle of 95% and virtual geomagnetic pole position, respectively. Dec, inc, lat, lon are declination, inclination, latitude and longitude, respectively. Abbreviations in age column are the same as Table 1.

| Site | bbc | | abc | | $\alpha_{95}$ | VPP | | Age |
|---|---|---|---|---|---|---|---|---|
| | dec (°) | inc (°) | dec (°) | inc (°) | (°) | lat (°N) | long (°E) | |
| Jangseong area | | | | | | | | |
| 13 | −37.3 | 77.5 | | | 29.3 | | | Cm |
| 16 | −5.7 | 68.0 | | | 21.3 | | | Cm |
| 20 | −98.5 | 27.3 | −90.6 | −17.0 | 6.9 | 5.7 | −147.6 | Cr |
| 23 | −124.7 | 18.0 | −129.2 | −25.8 | 25.8 | 39.2 | −127.3 | P |
| 24 | −121.4 | 16.0 | −130.3 | −27.4 | 8.5 | 40.6 | −127.5 | P |
| 25 | −73.6 | −32.8 | −90.8 | −58.4 | 6.0 | 22.9 | −173.6 | Tr |
| 26 | −50.6 | −38.1 | −89.6 | −62.8 | 4.7 | 24.6 | −179.0 | Tr |
| 27 | −37.3 | −51.9 | −63.4 | −34.0 | 9.4 | −8.4 | −172.1 | Tr |
| Mungyeong area | | | | | | | | |
| 32 | 4.7 | 53.6 | | | 22.2 | | | Tr |
| 43 | −70.9 | −32.9 | −89.5 | 6.6 | 10.2 | −2.4 | −139.5 | Cr |

## 4. Discussion

Very stable secondary magnetization has already been reported not only in the Ogcheon zone (OTOFUJI *et al.*, 1986) but also in lower Cretaceous rocks in the Gyeongsang supergroup (LEE *et al.*, 1987). LEE *et al.* (1987) claimed another early

Cretaceous paleomagnetic result in the Gyeongsang supergroup (OTOFUJI *et al.*, 1983) to be of secondary origin. The common features of the secondary magnetization are a high, usually more than 550°C, maximum blocking temperature, and all normal polarity. Although there is no definite evidence to determine the age of the secondary magnetization, we think that it was acquired either very recently or in the Cretaceous normal superchron. The direction of the component seems to show that it was acquired near the present, but several works have shown that the paleomagnetic direction in the Korean Peninsula has not significantly changed since the late Cretaceous (KIENZLE and SCHARON, 1966; ITO and TOKIEDA, 1980). Therefore, the direction does not conflict with any age of remagnetization after the late Cretaceous. There is indeed a controversy about the reliability of Cretaceous paleomagnetic results (LEE *et al.*, 1987, OTOFUJI *et al.*, 1986). What we can say at least is that the direction does not restrict the remagnetization time. The other fact that the polarity of all the sites are normal, however, suggests that the secondary component was not acquired in a mixed polarity time. If the remagnetization occurred at a normal polarity chron in the recent mixed polarity superchron, we have to assume that the secondary magnetization was acquired simultaneously over a rather wide area, including the Jangseong, Mungyeong and Gyeongsang areas, within a short time interval. Therefore, the primary candidate for the time of the acquisition is the Cretaceous normal superchron. The fact that the age of the last intensive granitic intrusion in Korea was the late Cretaceous (LEE, 1987) is another support for the late Cretaceous acquisition of the secondary component.

Very severe Cretaceous remagnetization has also been reported from Northeast and Southwest Japan (FUJIWARA and MORINAGA, 1983; SHIBUYA and SASAJIMA, 1986). Since the Japanese Islands were likely next to the Korean Peninsula before the opening of the Japan Sea, the secondary components on both sides of the Japan Sea may be due to a single event.

Two facts are suggestive for the primary origin of the high-$T_b$ component: 1) The tilt-corrected directions were grouped within each geological epoch and different between the epochs; 2) the Carboniferous sites, one from the Jangseong area and the other from the Mungyeong area, coincide with each other despite these sites being fairly distant from each other.

Although the polarity of the Earth's magnetic field corresponding to these site mean directions is ambiguous, it is probably reversed, since the reversed polarity was dominant during the Carboniferous and Permian (HARLAND *et al.*, 1982). Table 3 shows the differences of declination and paleolatitude compared to those expected from virtual pole positions (VPPs) either of the SCB or the NCB, for two assumptions of both polarities. Looking at paleolatitude differences, reversed polarity of these sites is much more preferable in either assumption of belonging to the SCB or the NCB. Since it is very hard for paleolatitudes to be changed by tectonic deformation, the polarity of these sites must be reversed.

On the other hand, the declination differences are clearly smaller with the SCB than with the NCB in all ages. This is also seen in Fig. 7, in which the virtual north poles for each site are compared to the apparent polar wander paths for the NCB

Table 3. The differences of declination (Dec) and paleolatitude (PLat) compared to those expected from VPPs, either the SCB or the NCB for two assumptions of polarities. N- and R-VPP calculated assuming normal and reversed polarity, respectively. Since no VPP is available for Carboniferous in NCB, comparison with Permian (1) and Ordovician (2) VPP are presented. All are in degrees.

| Age | Compared with SCB | | | | Compared with NCB | | | |
|---|---|---|---|---|---|---|---|---|
| | R-VPP | | N-VPP | | R-VPP | | N-VPP | |
| | Dec | PLat | Dec | PLat | Dec | PLat | Dec | PLat |
| Tr | 55 | −2 | −125 | −68 | 163 | 12 | −17 | −54 |
| P | −3 | 9 | 177 | −20 | 93 | 12 | −88 | −17 |
| C | 21 | −8 | −159 | −13 | 127 | 0 | −53 | −5 (1) |
| | | | | | 107 | 9 | −73 | 4 (2) |

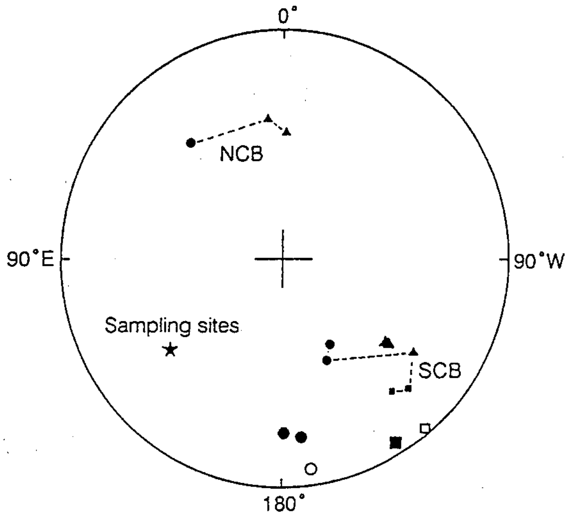


Fig. 7. Virtual geomagnetic north pole positions of site means of high-$T_b$ components in equal area projection, on an assumption of reversed polarity. The VPP paths for the NCB and the SCB (LIN *et al.*, 1985) are also indicated. Squares, triangles, and circles show Carboniferous, Permian and Triassic sites, respectively. Smaller square is from Mungyeong area and the others are from Jangseong area. Open and solid symbols indicate the projection of southern and northern hemisphere, respectively. Note that the VPP path of Ogcheon zone is much closer to that of the SCB than the NCB.

and the SCB (LIN *et al.*, 1985). In general, it is risky for a tectonic discussion to depend solely on declinations, since they are easily altered by local tectonic deformation. In the present VPP, the trajectory also agrees well with poles from the SCB. We concluded, therefore, that the Ogcheon zone was a part of the SCB in the period from the Carboniferous to the Triassic.

If the Ogcheon zone was a part of the SCB, a contradiction arises. The review articles on the geology of the Korean Peninsula (REEDMAN and UM, 1975; LEE, 1987) mentioned that the strata in the Ogcheon zone are well correlated with those in the Pyeongan basin (Fig. 1). Since the correlation suggests that they were deposited on one tectonic block, the Pyeongbug massif on which the Pyeongan basin was developed should also be a part of the SCB. However, the Pyeongbug massif is thought to belong to the NCB (KIM, 1987), as another name for the NCB, the Sino-Korean Block, indicates. To solve this contradiction, either of the following is required: 1) The correlation of the Pyeongan basin and the Ogcheon zone is wrong and the boundary between the NCB and the SCB is situated between the Ogcheon zone and the Pyeongan basin, or 2) the Pyeongbug massif had belonged to the SCB and the boundary runs to the north of the Pyeongbug massif.

## 5. Conclusion

A paleomagnetic study of sedimentary rocks occurring in the Ogcheon zone ranging from Cambrian to Jurassic in age unraveled the following:

1) All the sedimentary rocks studied were remagnetized by a strong secondary magnetization with an in-situ direction close to the present geocentric dipole field.

2) A few sites with ages of Carboniferous, Permian and Triassic had another component with higher $T_b$ than the secondary component. This component seems primary.

3) The virtual pole positions calculated with the high-$T_b$ component suggest that the Ogcheon zone belonged to the SCB from the Carboniferous to Triassic age.

Sampling was performed with assistance from the Jangseong Coal Mine of the Dae Han Coal Corporation, the Mungyeong Coal Mine of the Daesung Mining Development Co. Ltd., and Dr. T. Matsuda of Himeji Institute of Technology. We could not complete this work without their cooperation. Thanks are also due to Dr. M. Torii for valuable discussions. R. McCabe and an anonymous reviewer were helpful in improving the manuscript. This work was partly supported by the Ministry of Education, Science and Culture of Japan under Grant-in-Aid for Overseas Scientific Survey 5904341.

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