A Paleomagnetic Reconnaissance of Permian to Cretaceous Sedimentary Rocks in Southern Part of Korean Peninsula

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Paleomagnetic results have been obtained from ten Korean sedimentary rock formations ranging in age from Permian to Cretaceous. The magnetizations of almost all the rocks from Permian to Jurassic formations have been severely overprinted. Estimation of paleomagnetic direction of the period between Permian and Jurassic is hindered by this. The Cretaceous rocks from the Gyeongsang Supergroup, however, have recorded the paleomagnetic direction at the period of formation of sedimentary rocks during Cretaceous. Some strata in the Hasandong Formation of lower part of the Gyeongsang Supergroup show the reversed magnetization which is presumably ascribed to reversed magnetic polarity epoch of M-series in Mesozoic polarity scale. Paleomagnetic direction of the upper part of the Gyeongsang Supergroup (Middle to Late Cretaceous) is estimated to be Dec=28.4°, Inc=58.2° and ø95=6.4°. The pole position of Middle to Late Cretaceous obtained for the Korean Peninsula (202°E, 67°N) is in good agreement with other Cretaceous data for the Asian continent, implying that the Korean Peninsula has not been subjected to rotational movement relative to the Asian continent since Cretaceous.

1. Introduction

The Korean Peninsula is situated between North China platform and trench-island arc-back arc basin systems of Japan and Ryukyu. The former behaves as a stable craton subjected to only epeiric movements for over a thousand million years. The latter is one of the most active areas at present on the earth; while new igneous products are added and allochthonous terrains are accreted on the island arc, older geological phenomena have been obscured. In the peculiar situation of the Korean Peninsula, the igneous and sedimentary rocks have been fairly continuously produced from Archaeozoic age to Quaternary, and they have been preserved on the peninsula (UM and REEDMAN, 1975). The Korean Peninsula is, therefore, a rare area where the apparent polar wandering path (APWP) can be expected to be traced back to 2700 Ma. Our ultimate objective is to obtain the paleomagnetic direction change during 2700 Ma from the Korean Peninsula. The aim of the present work is to estimate the paleomagnetic direction for the period between Permian and Cretaceous.

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In addition, paleomagnetic work of the Korean Peninsula can be useful for detection of the relative movement of island arcs of Japan and Ryuku as well as for consideration on the origin and accretionary history of the Korean Peninsula.

2. Sampling Locality

Figure 1 shows the sampling localities for sedimentary strata described below (see Table 1). Our paleomagnetic sampling is concentrated on the Cretaceous to Permian sedimentary rocks distributed in Danyang, Daecheon and Daegu areas.

2.1 Danyang

2.1.1. The Gobangsan Formation (Permian)

The Gobangsan Formation is one of those in the Pyeongan Group which is lying disconformably above the Cambro-Ordovician Joseon sequence and unconformably below the Jurassic Daedong System in South Pyeongan province. The Gobangsan Formation consists of a thick sequence of non-marine sands and muds containing the abundant thick leaved Gigantopteris flora. The Gobangsan Formation has been assigned either Permian or Triassic in age on the basis of a Gabangsan flora (KAWASAKI, 1927; CHANG, 1972; UM and REEDMAN, 1975).

2.1.2. The Nogam Formation

The Nogam Formation overlies the Gobangsan Formation, and is composed of red feldspathic medium-grained, greenish grey sandstones, having about 400 m in
thickness. Most researchers consider the Nogam Formation being early Triassic in age but this is not yet definitely proved (UM and REEDMAN, 1975).

2.1.3. The Bansong Group (Late Jurassic)
The basal beds of the Bansong Group are conglomerates which were deposited as deltaic fans in fluvio-lacustrine environments. Sandstones and shales overlie the basal conglomerates and some thin coal seams are intercalated. A rich flora is found in some of the shaly horizons and has been identified by KAWASAKI (1925) as the Late Jurassic.

2.2 Daechon
2.2.1. The Nampo Group (Late Jurassic)
Nampo Group crops out in the Chungnam Coalfield of Chungnam province. It comprises a thick sequence of mainly coarse grained, clastic sedimentary rocks which were formed in a fresh water. KIM (1976) assigned the Late Triassic to Late Jurassic on the basis of floral assemblage found in Chungnam Coalfield.
2.3 Daegu

2.3.1. The Gyeongsang Supergroup (Cretaceous)

The Gyeongsang Supergroup is a major unconformity-bounded unit of non-marine sedimentary and igneous rocks of about the whole span of the Cretaceous System. The Gyeongsang Supergroup is divided into three groups (CHANG, 1975): The Sindong, Hayan and Yuchon Groups in ascending order. The Singdong Group consists of sediments of prevolcanic phase, the Hayan Group comprises nonvolcanic sediments with some volcanic horizons, and Yuchon Group consists of volcanic formation. Of the seven formations of the Sindong and Hayan Groups, four of them (Haman, Silla, Chilgog and Hasandong Formations) contain red beds of mudstone and siltstones, whereas the other two (Jindong and Jinju Formations) consists mainly of black shale and one (Nagdong Formation) consists of dark grey mudstone.

3. Sampling and Technique

More than three block samples were obtained at each site. The sites were located only in strata with well-defined bedding. In all cases block samples were oriented by a magnetic compass. Forty five examples at 13 sites were collected from Permian strata, 44 samples at 10 sites were from Triassic ones, 91 samples at 23 sites were from Jurassic ones, and 290 samples at 65 sites were from Cretaceous. Two or more specimens 25 mm in diameter and 25 mm long were prepared from each sample in the laboratory.

Natural remanent magnetization (NRM) was measured with a two component SCT cryogenic magnetometer. The stability of remanent magnetization was investigated through progressive demagnetization treatment by both thermal and alternating field (AF) methods. The progressive AF demagnetization was made with a magnetically shielded three axis tumbler and thermal one was with a non-inductively wound electric furnace enclosed in a cylindrical mu-metal shield. One specimen in each site was cleaned as a pilot specimen in a stepwise progression with alternating peak field ranging from 5 mT to 50 mT. One or more specimens in each formation was progressively demagnetized with thermal method up to 400°-600° C. Zijderveld component plots (ZIJDERVELD, 1967) were used to assess the directional stability and coercivity spectrum of each specimen.

4. Paleomagnetic Results

4.1 Permian

Magnetic stability of NRM of Permian rocks depends on their remanent intensity (Fig. 2A). Samples with intensity larger than $7 \times 10^{-10}$ Am$^2$ show a stable NRM with respect to AF demagnetization. On the other hand, NMRs with intensity less than $7 \times 10^{-10}$ Am$^2$ from five sites show erratic cleaning behaviour during progressive demagnetization runs. Nine sites were recognized to have characteristic direction. Stable behaviour of the NRM is also recognized by trial thermal demagnetization for the sample stable in response to AF demagnetization. The remainder of the specimens for nine sites showing the magnetically stable behaviour were cleaned to eliminate soft viscous magnetism by AF demagnetization at peak field of 5 mT or 10 mT using a “tumbling” magnetic field demagnetization system.
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(MATSUDA et al., 1981). Statistical analysis of the characteristic direction for each site gave within-site circles of confidence with average radius ($\alpha_{95}$) of 12.8°.

Characteristic directions for nine sites have only normal polarity. After bedding correction, they have westerly declination and shallow inclination (Fig. 3).

4.2 Triassic

The pilot specimens from nine sites showed a stable behaviour during progressive demagnetization (Fig. 2C). Their characteristic direction after bedding correction shows the westward deflection in declination (Fig. 3).

4.3 Jurassic

Only nine sites have stable magnetization (Fig. 2B). The westerly declination value of about $-50^\circ$ is recognized in the mean direction of characteristic direction after AF cleaning and bedding correction (Fig. 3).

4.4 Cretaceous

Except for the Hasadong Formation, all characteristic directions have normal polarity (Fig. 2D). The NRM intensity of the grey sandstone of the Nagdong Formation is weak, which is about $5 \times 10^{-5}$ Am$^2$, and their characteristic directions for each site have a fairly large average circle of confidence ($\alpha_{95}$), which is 18°. Other formations, consisting of shale, siltstone and red sandstone, have strong NRM intensity; more than ten times larger than that of the Nagdong Formation. The NRM intensity of some samples from the Chilgog Formation is up to $2 \times 10^{-7}$ Am$^2$. The within-site circles of confidence with average radius is less than ten degrees for these sites. Regardless of variety in NRM intensity for the formation in the Gyeongsang Supergroup, statistical analysis for formation mean directions has a small 95% confidence circles; less than eight degrees after bedding correction. The formation mean directions are characterized by the easterly declination about thirty degrees with normal polarity (Fig. 3).

The NRM directions with reversed polarity were discovered in some specimens of red sandstone and red shale from four site in the Hasandong Formation (Fig. 4). The NRM direction before demagnetization shows, in general, eastward declination with steep inclination. During the AF progressive demagnetization runs, the NRM direction changes its polarity at more than 20 mT. During the thermal progressive demagnetization, there is also a great shift of the NRM directions. The AF demagnetization technique was appeared to be more effective than the thermal one for erasing the overprinting component with normal polarity. Although almost all specimens in each site did not change their polarity after AF demagnetization, the reversed mangetization appears to be a characteristic direction for sedimentary rocks from four sites of the Hasandong Formation. Because magnetic grains have an inhomogeneous distribution in sedimentary strata, some specimens may include many magnetic particles with secondary magnetic component of hard coercivity which conceals the primary component with reversed direction.
Fig. 2. Direction change during progressive alternating field (AF) and thermal demagnetization (Th). (A, B) Lower hemisphere equal area plots of magnetization change together with normalized intensity decay of specimens from Permian (A) and Jurassic (B). (C, D) Orthogonal projections of magnetization vectors of specimens from Triassic (C) and Cretaceous (D) strata, following the method outlined by Zijderveld (1967). Solid (Open) symbols refer to the horizontal (vertical) plane.
5. Discussion

The paleomagnetic directions of the Pre-Cretaceous and Cretaceous periods after bedding correction are compared in Fig. 5. Abrupt change of the paleomagnetic direction is clearly observed between the Jurassic and Cretaceous periods. The westerly direction of the period from Permian to Jurassic changes to easterly one at Cretaceous: The amount of the change is larger than 50°.

We interpret that the anomalous westerly direction before Cretaceous is ascribed to the secondary component which was acquired after the rocks had been tilted. The NRM directions before bedding correction from Permian to Jurassic formations correspond to both the present field and the present axial dipole within error (Fig. 3). In especial, the NRM direction of Permian deflects only by 4.2° from the present field direction and by 1.9° from the axial dipole field. This indicates that the NRMs
Fig. 3. Equal area plot of site mean magnetization directions after alternative field demagnetization (the closed star) and 95% confidence limits of four period from the Permian to Cretaceous strata: (A) before bedding correction and (B) after bedding correction. The solid (open) symbols refer to the lower (upper) hemisphere. The open star and circled star represent the axial dipole and present field directions, respectively.
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Fig. 4. Equal area plot of magnetization direction change during (A) alternating field demagnetization and (B) thermal demagnetization of specimens of the Hasandong Formation. (C) Equal area plot of sample magnetization directions for sites CR6 and CR9 of the Hasandong Formation after alternating field demagnetization at 10 mT. Solid (Open) symbols refer to the lower (upper) hemisphere.

observed in the Permian to Jurassic period were acquired after tectonic movement. In addition, all NRM s showed the normal polarity. The evidence suggests that the timing of acquisition is sometime in a normal polarity epoch, probably during the Brunhes chron. Because the formations of Permian to Jurassic are tilted westward, the westerly deflection of the NRM between Permian and Jurassic is possibly due to accidental results after simple bedding correction for the secondary magnetization.

The NRM direction before bedding correction of the Cretaceous period has northerly direction closer to the present field direction than that after correction (Fig. 3). The NRM direction after tilt correction is, however, a realistic estimate for the paleomagnetic field direction of the Cretaceous period, on the basis of the following evidence. (1) Comparing the NRM directions of the Haman Formation before and after bedding correction, a closer grouping is observed after bedding correction. The precision of the directions after bedding correction, \( k_a = 285.3 \) contrasts with the precision in situ, \( k_i = 47.6 \) (See Table 2). (2) Since scarce change in paleomagnetic direction is expected for the period between 60 Ma and 100 Ma on the basis of the apparent polar wander path from Eurasia (Irving, 1977), it is worthwhile to compare the mean directions calculated from three formation mean directions of upper part of Gyeongsang Supergroup (Jindong, Haman and Chilgog) before and after bedding correction. The precision increases from \( k_i = 61.1 \) to \( k_a = 376.2 \) after bedding correc-
Fig. 5. Lower hemisphere equal area plots of mean magnetic directions and 95% confidence limits of three periods of Permian (P), Triassic (Tr) and Jurassic (J1), and five formations of the Gyeongsang Supergroup of Cretaceous (Nagdong (N), Jinju (J), Chilgog (C), Haman (H), and Jindong (Jin) in ascending order). Directions are after bedding correction.

...tion (see Table 2). (3) The directions of the present earth's field and the geocentric axial dipole field both lie outside the α95 circles of confidence of all NRM mean directions before bedding correction from the Gyeongsan Supergroup except for the Nagdong Formation. (4) The virtual geomagnetic pole (VGP) position of the Gyeonsang Supergroup is close to that of the North Korea of the Cretaceous age (GURARII et al., 1966) (Fig. 6A).

Systematic movements are observed in the distribution of the VGP positions for five formations as shown in Fig. 6A. The VGP position drifts northward during the Cretaceous period. This northward drift of the apparent polar wandering path (APWP) between 120 Ma and 60 Ma is clearly observed on the paleomagnetic data set from Northern Eurasia (IRVING, 1977), Western Europe (ACHACHE et al., 1983) and North America (IRVING, 1979; HARRISON and LINDH, 1982). The northward drift appeared in the APWP derives the further support for the reliability of the NRM directions from the Gyeongsang Supergroup as a paleomagnetic record during the Cretaceous period.

Thermal demagnetization test up to 700°C (OTOFUJI et al., 1983) indicated that the magnetization of lower part of the Gyeongsang Supergroup (Chilgog, Jinju and Hasandong Formations) resided in hematite. The colour of some sandstones of the Gyeongsang Supergroup is reddened due to the presence of hematite. On the basis of
Table 2. Summary of paleomagnetic results.

<table>
<thead>
<tr>
<th>Period</th>
<th>Formation</th>
<th>Locality</th>
<th>before bedding correction</th>
<th>after bedding correction</th>
<th>V G P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lat(°)</td>
<td>Lon(°)</td>
<td>N(n)</td>
<td>Polarity</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Jindong</td>
<td>35.9</td>
<td>128.6</td>
<td>13(132)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Hanan</td>
<td>35.8</td>
<td>128.5</td>
<td>6(57)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Chilgo</td>
<td>35.9</td>
<td>128.5</td>
<td>16(213)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>mean(upper part)</td>
<td>36.0</td>
<td>128.5</td>
<td>3</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Jinju</td>
<td>35.8</td>
<td>128.4</td>
<td>10(84)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Hasandong</td>
<td>35.8</td>
<td>128.6</td>
<td>7(80)</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Nagdong</td>
<td>36.0</td>
<td>128.5</td>
<td>8(79)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>mean(lower part)</td>
<td>36.0</td>
<td>128.5</td>
<td>2</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>mean(cretaeous)</td>
<td>36.0</td>
<td>128.5</td>
<td>5</td>
<td>N</td>
</tr>
<tr>
<td>Early Jurassic</td>
<td>Bansong</td>
<td>37.0</td>
<td>128.0</td>
<td>9(108)</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Nampo</td>
<td>38.4</td>
<td>126.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triassic</td>
<td>Nogam</td>
<td>37.0</td>
<td>128.0</td>
<td>9(62)</td>
<td>N</td>
</tr>
<tr>
<td>Permian</td>
<td>Gobangsan</td>
<td>37.0</td>
<td>128.0</td>
<td>9(63)</td>
<td>N</td>
</tr>
</tbody>
</table>

N is number of sites and n is number of specimens. Demag is alternating peak field intensity during demagnetization. D and I are mean declination and inclination, K and α95 are Fisher statistic parameter, dp and dm are semiaxes of the oval of 95% confidence around the pole.
Fig. 6. (A) Virtual geomagnetic pole positions of five formations for the Gyeongsang Supergroup (Nagdong (N), Jinju (J), Chilgog (C), Haman (H), and Jindong (Jin) in ascending order) together with Cretaceous pole position for the North Korea (square). (B) Cretaceous pole positions for the Korean Peninsula (Poles for three periods are drawn; upper Cretaceous [KU], Lower Cretaceous [KL] and Cretaceous [K]) and neighbouring regions; Siberia, Kolyma, North China block (NCB KU and KL) and South China block (SCB KL).

the microscopic study (CHOI, 1979), the red pigment of the Gyeongsang strata is identified to be finely divided hematite; it is notable that red pigment is restricted to fine sediment of clay size, whereas the sands and coarser clastics are non-red. The pigment is not probably formed diagenetically in situ after deposition but is detrital materials derived from red tropical soils (Um et al., 1978; Choi, 1979). Therefore, the NRM of the Gyeongsang Supergroup is not ascribed to a CRM (chemical remanent magnetization) in its origin but either a DRM (detrital remanent magnetization) or a PDRM (post depositional remanent magnetization) of the pigment of hematite in the vacancy among coarser grains (Walker et al., 1981). We believe the above lines of evidence indicate that the acquisition of remanent magnetization of the Gyeongsang Supergroup took place just after deposition of sediment during the Cretaceous period.
Predominant distribution of normally magnetized formations in the Gyeongsang Supergroup is possibly ascribed to the dominance of normal polarity in the middle to late Cretaceous period. The Sindong Group, the lower part of the Gyeongsang Supergroup, is extensively fossiliferous and it is documented as lower Cretaceous in age (Yabe, 1905; Kawasaki, 1928; Chang, 1975; Um and Reedman, 1975). Recent paleontological study (Yang, 1976, 1978) suggested that the Nagdong Formation could be correlated to the period of Aptin–Albian. The K–Ar data of 79.4±4.0 Ma and 68.1±3.4 Ma were obtained from basalt on the Hagbong volcanic members in the Hayang Group (Min et al., 1982; Ototuji et al., 1983). The K–Ar data for granitic plutons intruding the Gyeongsang Supergroup range from 58 Ma and 115 Ma (Kim, 1971; Lee, 1980). These data indicate that the Gyeongsang Supergroup was formed within the whole span of Cretaceous. On the basis of the magnetic polarity time scale (Harland et al., 1982), more than 75 percent of normally magnetized rocks are expected for those of the Gyeongsang Supergroup. The reversed magnetization discovered in the Hasandong Formation (Fig. 4) may be attributed to some reversed
magnetic polarity epoch in M-series in Mesozoic polarity scale before the "Cretaceous quiet zone" between 118 Ma and 83 Ma.

The Cretaceous paleomagnetic data of the present study are compared with those of the previous works in South Korea. The NRM direction after bedding correction of the upper part of the Gyeongsang Supergroup of sediment layers corresponds to the NRM direction of igneous rocks (Kienzle and Scharon, 1966) within 95% confidence limit, although the declination value from sediment layers of the present work is fairly larger in easterly declination than that of the igneous rocks \((D=28.4^\circ, I=58.2^\circ, \alpha_{95}=6.4^\circ)\) vs. \((D=19.5^\circ, I=53.3^\circ, \alpha_{95}=9.5^\circ)\). The igneous rocks were collected at localities where no local and major structural features were observed. The paleomagnetic direction of the present work is quite close to that of previous work from the Gyeongsang Supergroup (Otofuji et al., 1983); \((D=33.0^\circ, I=60.9^\circ, \alpha_{95}=5.5^\circ)\) vs. \((D=26.6^\circ, I=62.3^\circ, \alpha_{95}=8.3^\circ)\). Both directions are obtained after bedding correction. The easterly declination about 20 to 30 degrees previously estimated is confirmed by our detailed paleomagnetic results.

The NRMs of the granites with the Cretaceous age intruding in the Gyeongsang Basin (Ito and Tokieda, 1980), however, have northward direction \((D=3.5^\circ, I=57.3^\circ, \alpha_{95}=8.3^\circ)\) which deviates far apart from that of the Gyeongsang strata. Discrepancy of directions between granites and Gyeongsang strata may be due to either (1) lack of information about the tilt of granites, (2) overestimate of tilt of the bedding of the Gyeongsang Supergroup or (3) inefficiency of demagnetization for either samples from granites or the Gyeongsang strata. Future work on paleomagnetism of the volcanic materials from the well defined bedding plane in the Gyeongsang Supergroup (the Chaeyagsan Formations and the Hagbong volcanic member) can explain the reason for this discrepancy.

6. Conclusions and Implication

Paleomagnetic work of Permian to Cretaceous rocks from 111 sites in the Korean Peninsula provides the following conclusions:

(1) The NRMs of the Permian to Jurassic rocks were acquired after the formations had been tilted. Primary component acquired between Permian and Jurassic was not unveiled by using ordinary AF and thermal demagnetization technique (up to 50 mT and a small number of steps of progressive thermal demagnetization) because of the presence of the hard secondary magnetic component.

(2) The paleomagnetic direction at the Cretaceous period is recorded in sedimentary rocks of the Gyeongsang Supergroup. Paleomagnetic direction of upper part of the Gyeongsang Supergroup (Middle to Late Cretaceous) is estimated to be \(D=28.4^\circ, I=58.2^\circ\) and \(\alpha_{95}=6.4^\circ\).

Our data of the Cretaceous period can represent the Cretaceous paleomagnetic direction of the Korean Peninsula. It is compared with the Cretaceous poles of neighbouring regions of the Korean Peninsula in Fig. 6B. The Korean Peninsula pole is statistically indistinguishable from those from North China (Lin et al., 1985), Kolyma (Otofuji et al., 1983), and Siberia (Achache et al., 1983), implying that the Korean Peninsula has not been subjected to rotational movement relative to the Asian continent since Cretaceous.
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