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Paleomagnetic and Rock-Magnetic Studies of Cretaceous Sedimentary Rocks in the Poongam Basin

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풍암분지에 분포하는 백악기 퇴적암류에 대한 고지자기 및 암석자기 연구

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강원도 풍암(갑천)분지에 분포하는 백악기 퇴적암류에 대한 고지자기 및 암석자기 연구를 수행하였다. 13개 지점으로부터 총 128개의 정향시료를 착공하였다. 지점별 고지자기 방향은 지층경사보정 후에 D/I=353.1°/55.6°, k=21.5, α_{95}=10.1°, 보정 전에 D/I=10.5°/56.9°, k=73.9, α_{95}=5.3°로 나타났으며, 지층경사보정 후에 분산도가 증가하였다. 단계별 경사보정에 따른 정확도상수(k)도 20% 경사보정시 최대값을 보였다. 전자현미경 관찰결과에서는 이차적으로 생성된 적철석이 녹니석 등의 점토광물들과 함께 나타났다. 이러한 결과들은 연구지역의 특성잔류자화가 지층경사 이후에 생성된 적철석에 의하여 기록된 재자화 성분임을 지시한다. 연구지역의 재자화 작용은 주변에 열수맥광상을 형성시킨 마그마수/천수 혼합 유체와 관련된 것으로 해석하였다. 재자화 방향으로부터 계산한 고지자기극의 위치(214.3°E, 81.6°N, A_{95}=7.4°)는 한반도에서 기 보고된 후기 백악기와 제 3기의 고지자기극의 위치와 가깝다. 이 시기의 화학잔류자화에 의한 재자화 현상은 옥천대 경계부에 위치한 다른 백악기 소분지들(예, 음성분지, 공주분지, 영동분지)과 옥천비변성대의 고생대 지층에서도 보고된 바 있기 때문에 옥천대에 광역적으로 일어난 것으로 생각된다.

주요어 : 고지자기학, 암석자기학, 재자화, 화학잔류자화, 풍암분지

Paleomagnetic and rock-magnetic investigations have been carried out for the Cretaceous sedimentary rocks in the Poongam (also called Gapcheon) Basin in the eastern South Korea. A total of 128 independently oriented core samples were drilled from 13 sites for this study. The mean direction after bedding correction (D/I=353.1°/55.6°, k=21.5, α_{95}=10.1°) is more dispersed than the mean direction before bedding correction (D/I=10.5°/56.9°, k=73.9, α_{95}=5.3°), and the stepwise unfolding of the characteristic remanent magnetization (ChRM) reveals a maximum value of k at 20% unfolding. Secondary authigenic hematite accompanied by altered clays such as chlorite was identified by the electron microscope observations. These results collectively imply that the ChRM is remagnetized due to the formation of the secondary authigenic hematite after tilting of the strata. It is interpreted that the chemical remagnetization was connected to the introduction of mixed magmatic-meteoric fluids, which formed hydrothermal vein deposits near the study area. The paleomagnetic pole position (214.3°E, 81.6°N, A_{95}=7.4°) of the Cretaceous sedimentary rocks calculated from remagnetized directions is close to those of the Late Cretaceous and Tertiary poles of the Korean Peninsula. This Late Cretaceous to Tertiary remagnetization seems to be widespread over the Okcheon Belt because the chemical remagnetization is previously reported to be found in rocks from other Cretaceous small basins (e.g., Eumseong, Gongju and Youngdong basins) along the Okcheon Belt and some Paleozoic strata from the Okcheon unmetamorphosed zone.

Key words : paleomagnetism, rock-magnetism, remagnetization, chemical remanent magnetization, Poongam Basin

1. Introduction

The Okcheon Belt is bounded by two major NE-SW trending strike-slip faults, Gongju Fault System to the north and Gwangju Fault System to the south (Fig. 1a). During Cretaceous, the northward subduction of the Kula/Pacific Plate under the Eurasian Plate caused sinistral, brittle shearing accom-

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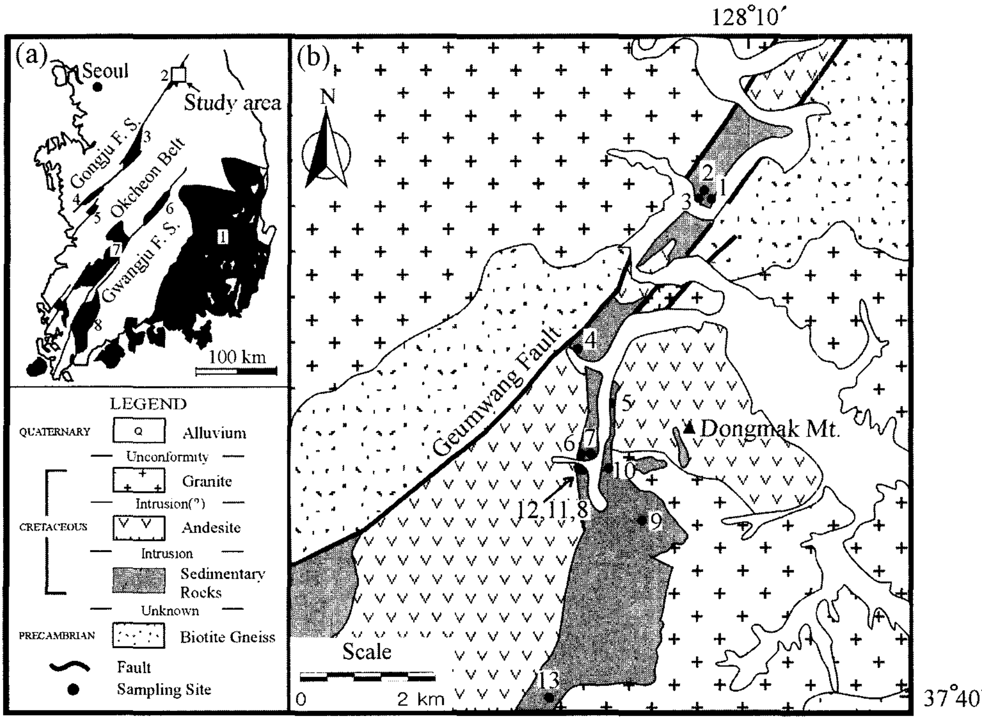


Fig. 1. (a) Distribution of the Cretaceous sedimentary basins and major fault systems in the Korean Peninsula (after Ryang, 1998); 1, Gyeongsang; 2. Poongam; 3, Eumseong; 4, Gongju; 5, Buyeo; 6, Youngdong; 7, Jinan; 8, Neungju; 9, Haenam basins. (b) Geologic map of the Poongam Basin, showing the locations of the paleomagnetic sampling sites.

panied by a number of transtensional basins within the Korean Peninsula (Chun and Chough, 1992). The Cretaceous non-marine sedimentary rocks and volcanics are mainly distributed in the southeastern part (Gyeongsang Basin), and in the several small basins along the boundary of the Okcheon Belt (Fig. 1a). These faults were active not only during the basin forming stage but also after the sedimentation, caused many brittle or ductile deformation (e.g., fault, fold and joint) within Cretaceous basins (Lee, 1998).

Several paleomagnetic studies for the Cretaceous clockwise tectonic rotation of the Korean Peninsula with respect to Eurasia were reported (e.g., Ma *et al.*, 1993; Uchimura *et al.*, 1996; Zhao *et al.*, 1999; Uno, 2000; Doh *et al.*, 2002). Because most paleomagnetic directions for Cretaceous in Korea were obtained from the Gyeongsang Basin, it is not unclear whether the Korean Peninsula rotated entirely or the only Gyeongsang Basin rotated regionally. Therefore, more paleomagnetic studies for the other Cretaceous basins outside the Gyeongsang Basin are essential to verify the rotation problem in Korea. Only one paleomagnetic study for the Poongam Basin has been done by Lee *et al.* (1992). In the study by Lee *et al.* (1992), paleomagnetic results were obtained from 11 samples (two sites) of andesitic rocks, and can hardly be considered as representative directions of the study area. Previous paleomagnetic studies for Youngdong Basin (Doh *et al.*, 1996), Eumseong Basin (Doh *et al.*, 1999) and Gongju Basin (Doh *et al.*, 2002) were reported that the sedimentary rocks in those basins had been remagnetized chemically during or after the tilting of the strata. In this study, paleomagnetic results from the Cretaceous sedimentary rocks in the Poongam Basin are presented by comparing the results with those from the Gyeongsang Basin and other Cretaceous basins in order to clarify the tectonic and geochemical processes of the Korean Peninsula as well as the study area since Cretaceous.

2. Geologic Setting

The Poongam Basin is one of the Cretaceous sedimentary basins distributed along the northwestern boundary of the Okcheon Belt (Fig. 1a). The Poongam Basin is a transpressional basin formed by the sinistral movement during Cretaceous. The basin is interpreted to be formed at a gentle restraining bend (the Geumwang Fault). The transpressional movement resulted in uplift near the fault zone and sedimentation in other region (Lee, 1998).

The study area is mainly composed of gneiss, granite, sedimentary rocks, andesite, and quartz porphyry (Fig. 1b). Precambrian gneiss and age-unknown granite comprise the basement of the Poongam Basin. The Cretaceous sedimentary rocks (reddish shale, siltstone and feldspathic sandstone with minor component of conglomerate), being correlated with the late Early Cretaceous Hayang Group of the Gyeongsang Basin, cover unconformably the basement in the basin. These are intruded by andesite and granite, which may have the similar intrusion ages to the volcanic rocks of the Late Cretaceous Yucheon Group of the Gyeongsang Basin (Kang and Jin, 1972; Won *et al.,* 1989). The Geumwang Fault, a northwestern boundary of the Poongam Basin, is a sinistral strike slip fault zone with a width of up to 400 m, and extends to the Gongju Fault System to the southwest (Fig. 1). The Geumwang fault zone with well-developed cataclastic foliation is interpreted as a reactivated transpressional fault zone, which resulted in forming many faults, folds and joints after deposition of the sedimentary rocks in the study area (Lee, 1998).

3. Experimental Methods

The samples were cored with a gasoline-powered portable rock drill and oriented with a magnetic compass in the field. Andesitic and granitic rocks, which do not show any structural information for the tilting correction, were excluded in sampling. A total of 128 paleomagnetic samples from 13 sites of red bed were collected (Fig. 1). In the laboratory, all the samples were stored in μ-metal boxes to prevent subsequent acquisition of viscous remanence by the external magnetic field. After measuring natural remanent magnetization (NRM) for each sample using a Molspin spinner magnetometer and a FITM SQUID-Based spinner magnetometer (model HSM2), the samples were demagnetized by stepwise thermal and alternating field (AF) demagnetizations. The ASC Scientific thermal demagnetizer (model TD-48) and the Molspin AC demagnetizer were used for the thermal and AF demagnetizations, respectively. To avoid acquisition of systematic parasitic remagnetization during thermal demagnetization, the samples were turned over at each step. Thermal demagnetization was performed at 100, 200, 300, 350, 400, 450, 500°C, and at intervals of 20°C from 520°C to 700°C. To detect any chemical alteration of magnetic carriers on heating, magnetic susceptibility was measured at each stage of thermal treatment using a Bartington magnetic susceptibility meter (model MS2). AF demagnetization was performed at the field strength of 5~30 mT with 5 mT intervals, and 40~90 mT with 10 mT intervals. The paleomagnetic data from all samples were projected on the orthogonal vector diagram (Zijderveld, 1967), and the direction of characteristic remanent magnetization (ChRM) of each sample was determined using the principal component analysis (PCA) with anchored line fit method from at least three or more points(Kirschvink, 1980).

Isothermal remanent magnetization (IRM) acquisition experiments for representative samples were performed using an ASC Scientific impulse magnetizer (model IM-10), and hysteresis parameters were measured with a Molspin vibrating sample magnetometer (model VSM Nuvo). Small cylindrical samples of 7 mm in diameter and 10 mm in height were prepared for hysteresis measurements. The electron microscope observations were also performed for selected samples to confirm the characteristic size, shape and composition of magnetic carriers.

4. Paleomagnetic Results

The NRM directions (directions before any demagnetization treatments) of the sedimentary rocks are predominantly northerly positive, clustering more closely about the mean axial dipole field (D/I=0°/56.3°) than the present-field direction at the sampling site (D/I=352.6°/52.9°, Fig. 2). This result suggests that the NRMs are merely dominated by the secondary NRM components

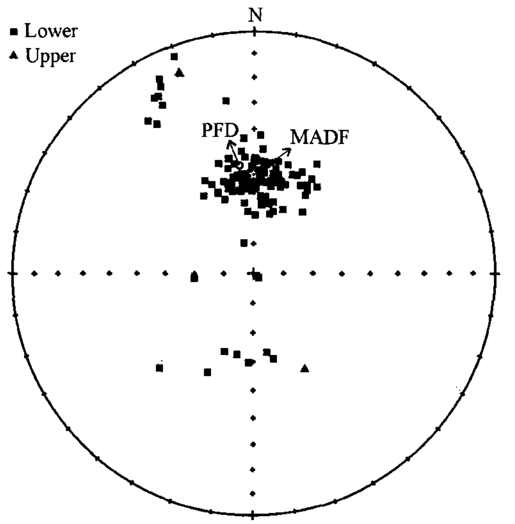


Fig. 2. Total NRM directions of 128 samples from the Poongam Basin in geographic coordinates. Lower (upper) hemisphere plots are shown as squares (triangles). Equal area projection. Open circle, present-field direction (PDF); star, mean axial dipole field (MADF).

acquired for a fairly long time. The NRM intensities vary from 2.93 to 63.61(mA/m).

The demagnetization of pilot samples shows that the thermal demagnetization method isolates the characteristic component more effectively, while the AF demagnetization method, even at the field strength of 90 mT, cannot remove the remanent magnetization successfully (Fig. 3a). The thermal demagnetization method was therefore applied to the remaining samples for this study to isolate ChRMs. Samples in the study area reveal two distinctive types of thermal demagnetization behaviors. Most samples show a simple decay of remanences toward the origin up to 660°C heating step (Fig. 3b). Samples from site PA1 reveal two components of magnetization. The low temperature component, a viscous remanent magnetization (VRM) component, is removed at or below 400°C, and then a high temperature component is mainly isolated in the range of 500~660°C heating steps (Fig. 3c). Both types of thermal demagnetization behaviors show that the direction starts to randomize with the increase of intensity and susceptibility above 660°C (Fig. 3b and c).

The mean direction of the ChRM calculated from eleven site-mean directions except site PA2 and PA13, which show anomalously shallow inclination and large α_{95} value, respectively, is D/I =10.5°/56.9° (k=73.9, α_{95}=5.3°) before tilt correction and D/I=353.1°/55.6° (k=21.5, α_{95}=10.1°) after tilt correction (Table 1).

Table 1. Paleomagnetic results from the sedimentary rocks in the Poongam Basin.

Site	n/N	Locality		D_g	I_g	D_s	I_s	k	α_{95}	Paleomagnetic pole		dp	dm
		Long.	Lat.							Long.	Lat.		
PA1	8/11	128.16	37.74	36.4	68.3	48.0	50.4	116.8	5.1	178.0	61.1	7.2	8.6
PA2*	11/11	128.16	37.74	332.6	5.4	334.4	5.2	27.5	8.9	350.4	46.9	4.5	8.9
PA3	7/7	128.16	37.74	344.2	55.9	7.1	48.4	77.8	6.9	37.1	77.3	7.1	9.9
PA4	17/17	128.14	37.72	354.3	52.8	288.2	73.6	64.3	4.5	356.7	83.6	4.3	6.2
PA5	12/12	128.15	37.71	9.9	56.1	338.7	58.8	155.4	3.5	222.8	82.0	3.6	5.0
PA6	10/10	128.14	37.70	6.3	58.7	327.1	54.8	329.7	2.7	196.8	84.8	3.0	4.0
PA7	11/11	128.14	37.70	15.3	55.1	337.8	55.8	249.5	2.9	223.1	77.6	2.9	4.1
PA8	7/7	128.14	37.70	11.7	51.1	4.3	40.6	72.4	7.1	246.3	78.7	6.5	9.6
PA9	11/11	128.15	37.69	357.8	57.6	3.7	47.6	258.9	2.8	56.2	88.2	3.0	4.1
PA10	9/11	128.14	37.70	17.6	53.6	344.9	58.1	90.0	5.5	226.8	75.3	5.3	7.7
PA11	3/7	128.14	37.70	16.5	56.4	345.9	53.9	29.9	23.0	216.3	76.9	24.0	33.2
PA12	8/8	128.14	37.70	31.4	51.6	351.8	42.4	155.0	4.5	220.6	63.8	4.2	6.1
PA13*	5/5	128.14	37.66	250.4	74.7	294.8	74.3	5.2	37.3	98.4	24.1	61.7	67.8
Mean	11/13			10.5	56.9			73.9	5.3	214.3	81.6	K=38.7	
						353.1	55.6	21.5	10.1			A_{95}=7.4	

*PA2 and PA13 sites are excluded from the calculation for mean direction; n/N: number of samples used in average/measured; D_g and I_g: declination and inclination in geographic coordinates; D_s and I_s: declination and inclination in stratigraphic coordinates; k: Fisherian precision parameter; α_{95}: radius of cone of 95% confidence interval; dp: the semi axis of the confidence ellipse along the great-circle path from site to pole; dm: the semi axis of the confidence ellipse perpendicular to that great-circle path; K: the best-estimate of the precision parameter k for the observed distribution of paleomagnetic poles; A_{95}: the radius of the 95% confidence circle about the calculated mean pole.

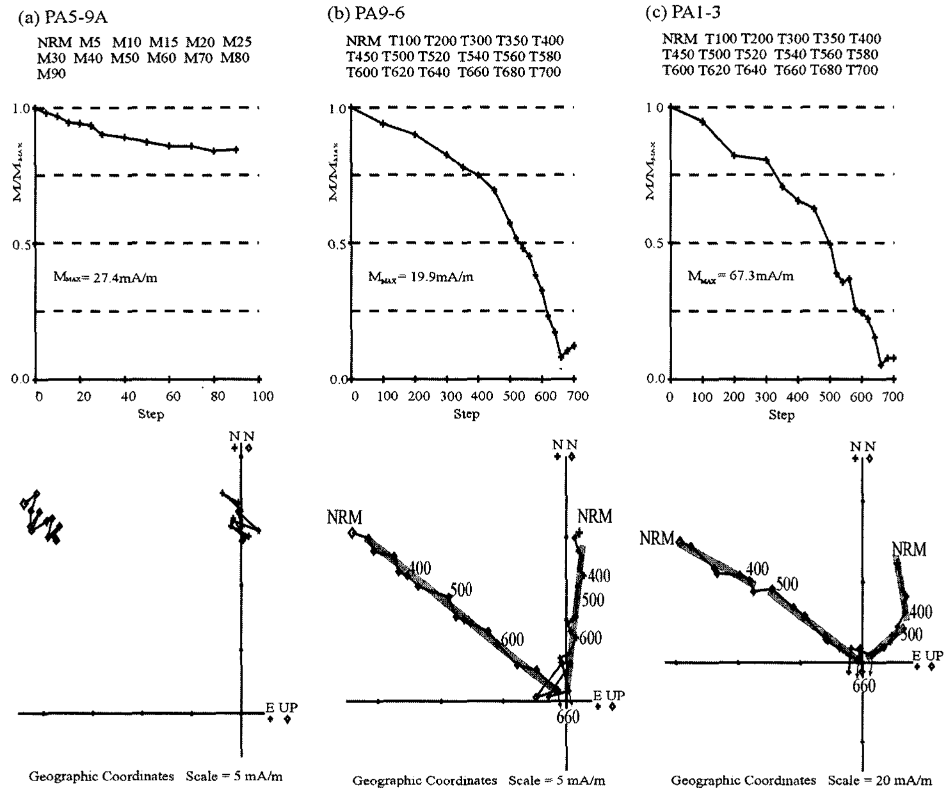


Fig. 3. Typical (a) AF demagnetization and (b and c) thermal demagnetization results of the samples from the sedimentary rocks of the study area: normalized intensity curve and Zijderveld diagram in geographic coordinates. Demagnetization steps are shown below the sample number.

5. Rock Magnetic Results

IRM acquisition experiment is performed to distinguish the magnetic phase that contributes to the magnetization of the samples (Fig. 4). Samples of this study can be grouped into two types on the basis of the IRM acquisition behavior, even though all of them are reddish colored rocks (shale, siltstone and sandstone). First, samples from six sites (PA5, PA8, PA9, PA11, PA12 and PA13) show a continuous increase in IRM intensity with increasing field up to 1 Tesla (Fig. 4a), indicating that high coercivity hematite is the dominant magnetic phase contributing to the IRM acquisition. Secondly, samples from seven sites (PA1, PA2, PA3, PA4, PA6, PA7 and PA10) reach 80~90% of saturation at 500 mT and then increases gradually without saturation (Fig. 4b), indicating that both low coercivity magnetite and high coercivity hematite contribute to the IRM acquisition.

Hysteresis loops were measured from the representative samples of this study. Typical Hysteresis

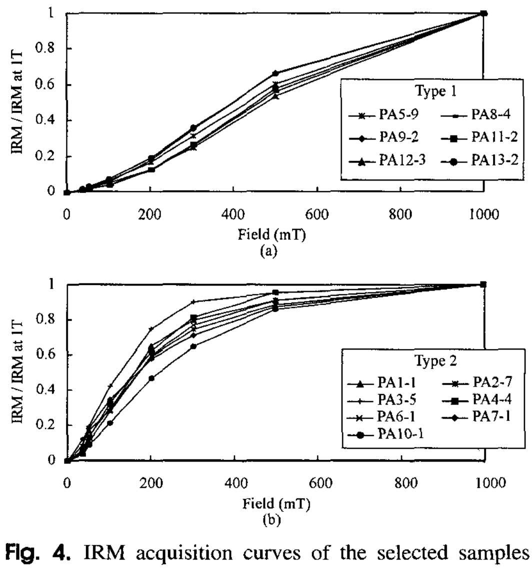


Fig. 4. IRM acquisition curves of the selected samples from the study area.

loops for type 1 and type 2 indicate the hematite dominant phase (Fig. 5a), and the mixture of mag-

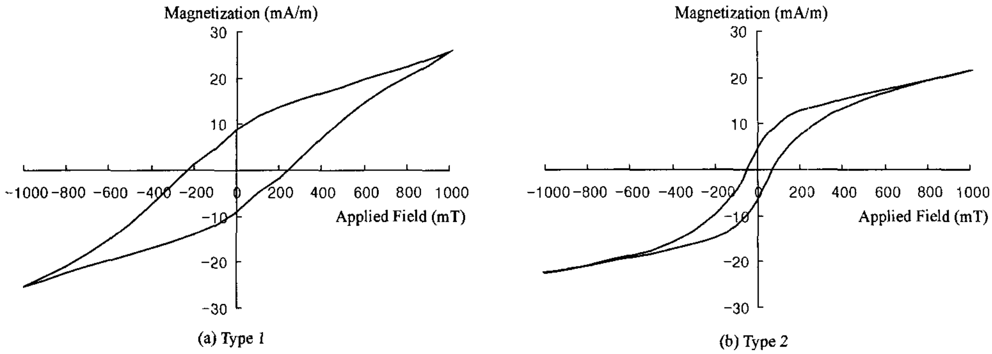


Fig. 5. Typical hysteresis loops from sedimentary rocks in the study area, showing (a) type 1 and (b) type 2.

Table 2. Coercivity of remanence (H_{cr}) of selected samples.

	Sample No.	H_{cr} (mT)	Rock Type
Type 1	PA5-9	405	Red Shale
	PA8-4	497	Red Siltstone
	PA9-2	404	Red Siltstone
	PA11-2	407	Red Shale
	PA12-3	493	Red Shale
	PA13-2	404	Red Shale
Type 2	PA1-1	139	Red Shale
	PA2-7	155	Red Siltstone
	PA3-5	95	Red Shale
	PA4-4	145	Red Shale
	PA6-1	163	Red Shale
	PA7-1	167	Red Siltstone
	PA10-1	227	Red Siltstone

netite and hematite (Fig. 5b), respectively. Remanent coercivity (H_{cr}) was obtained from stepwise back field IRM acquisitions and listed in Table 2. The H_{cr} values are commonly used to identify magnetic minerals in a way that minerals of the spinel structure (e.g., magnetite) have H_{cr} below 50 mT while minerals of the corundum structure (e.g., hematite) have H_{cr} above 200 mT (Thompson *et al.*, 1980). Samples of type 1 in the figure 4 and 5 show H_{cr} above 403.6 mT, while those of type 2 have H_{cr} of 94.5~226.8 mT range. The grouping on the basis of values of H_{cr} is well matched with the grouping based on the IRM acquisition curves. Day plot (Day *et al.*, 1977) for diagnosing the domain state of magnetite in samples was not applied to red beds in this study.

6. Electron Microscope Observations

Electron microscope observations were carried out for representative samples of red beds from the study area. Compositional analyses using energy dispersive spectroscopic (EDS) system for X-ray analysis were performed to identify iron oxide and adjacent grains or matrix of magnetic carriers. In order to distinguish the magnetic phase between magnetite and hematite, the morphological characteristics and the iron-oxygen ratio determined by optical and electron microscopic observations, the results of the rock magnetic experiments and thermal demagnetization behavior of samples were collectively used.

Hematite grains of submicron to 20 μm in size are the most frequently observed iron-oxides in association with quartz, K-feldspar, albite, calcite and chlorite. Detrital hematite showing the severe corrosion feature or ilmenite lamellae are not observed. Some submicron-size hematite grains are filling the cleavages of chlorite (Fig. 6a), while others are distributed in the form of aggregates of about 20~30 μm diameter in pore space (Fig. 6b). Most pigmentary hematite grains are distributes along microcracks or around grains of quartz and K-feldspar (Fig. 6c). Some grains are in interlocked contact with adjacent quartz and chlorite grains, and contains quartz inclusions (Fig. 6d), which imply that the hematite is a younger phase than the inclusions (Suk *et al.*, 1990). The results of the electron microscope observations suggest that the major magnetic carrier in samples of the study area is hematite that is secondary in origin. Altered clay minerals such as chlorite are frequently observed around presumably authigenic hematite grains, indicating that secondary hematites were formed by precipitation from Fe-bearing fluids, for which Fe is enriched during the processes of alteration of Fe-bearing minerals to clays (Walker *et al.*, 1981).

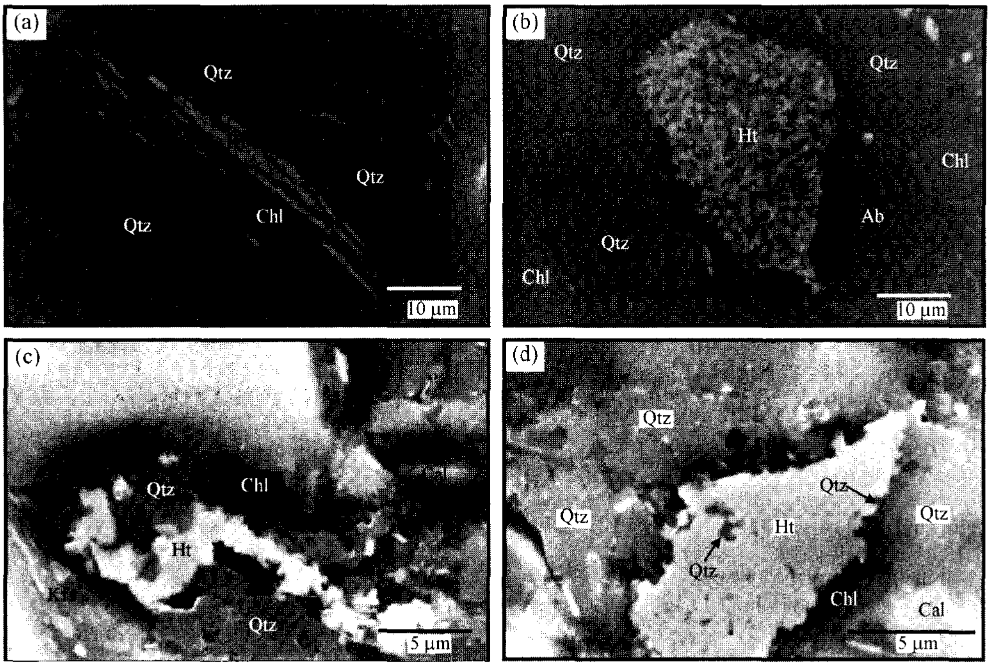


Fig. 6. Scanning electron microscopy photographs of hematite grains observed in red bed. Sympols are Ht, hematite; Qtz, quartz; Kfs, K-feldspar; Chl, chlorite; Cal, calcite; Ab, albite. (a) hematite formed along the cleavages of chlorite; back-scattered electron image(BEI). (b) authigenic hematite as aggregates of individual grains in a void; BEI. (c) hematite grains formed in a void showing the relation to K-feldspar; secondary electron image(SEI). (d) Void-filling hematite with quartz inclusions(arrows); SEI.

7. Discussion and conclusions

The gently to moderately dipping (8°~36°) sedimentary rocks revealed more dispersed paleomagnetic mean direction after tilt correction, which do not pass the fold test (McElhinny, 1964) at the 95% confidence level (Fig. 7a and b). Stepwise untilting test shows that the maximum clustering of ChRM directions occurs at 20% untilting (Fig. 7c). The parameter estimating fold test (Watson and Enkin, 1993) gives the maximum k value at 20.3% untilting, when the number of parametric resampling was 1000, which is in fairly good agreement with the results of the stepwise untilting test. The paleomagnetic direction of the sedimentary rocks at 20% untilting is D/I=7.1°/57.1° (k=89.4, α_{95}=4.9°). The maximum k value sometimes does not occur at 0% or 100% untilting due to an incomplete isolation of characteristic component. But this explanation can be discarded because the demagnetization results indicate successful isolation of ChRMs (Fig. 3b and c). The stepwise untilting test and the parameter estimation fold test, showing more tightly clustered mean direction at 20% untilting, clearly suggest that the ChRM of the sedimentary rocks in the Poongam Basin is not a primary component but a remagnetized one, although it is hard to determine whether the magnetization was acquired during tilting of the strata or not. This is also supported by the fact that the characteristic direction in this study is significantly different from the directions obtained from the Early Cretaceous strata in the Gyeongsang Basin (Doh *et al.*, 1994; Kim *et al.*, 1993; Lee *et al.*, 1987) (Fig. 7d). All of samples from eleven sites show only normal polarity without reversed one (Table 1), implying that the remagnetized component had been acquired during the period of normal polarity interval.

The paleomagnetic pole calculated from the characteristic direction in geographic coordinates is at 214.3°E, 81.6°N (K=38.7, A_{95}=7.4°). When this paleomagnetic pole position is compared with the paleomagnetic poles of middle Early Cretaceous to Quaternary in Korea, it is close to those of the Tertiary and Quaternary poles while it is significantly far from those of middle and late Early Cretaceous poles (Fig. 8a). Figure 8a shows that

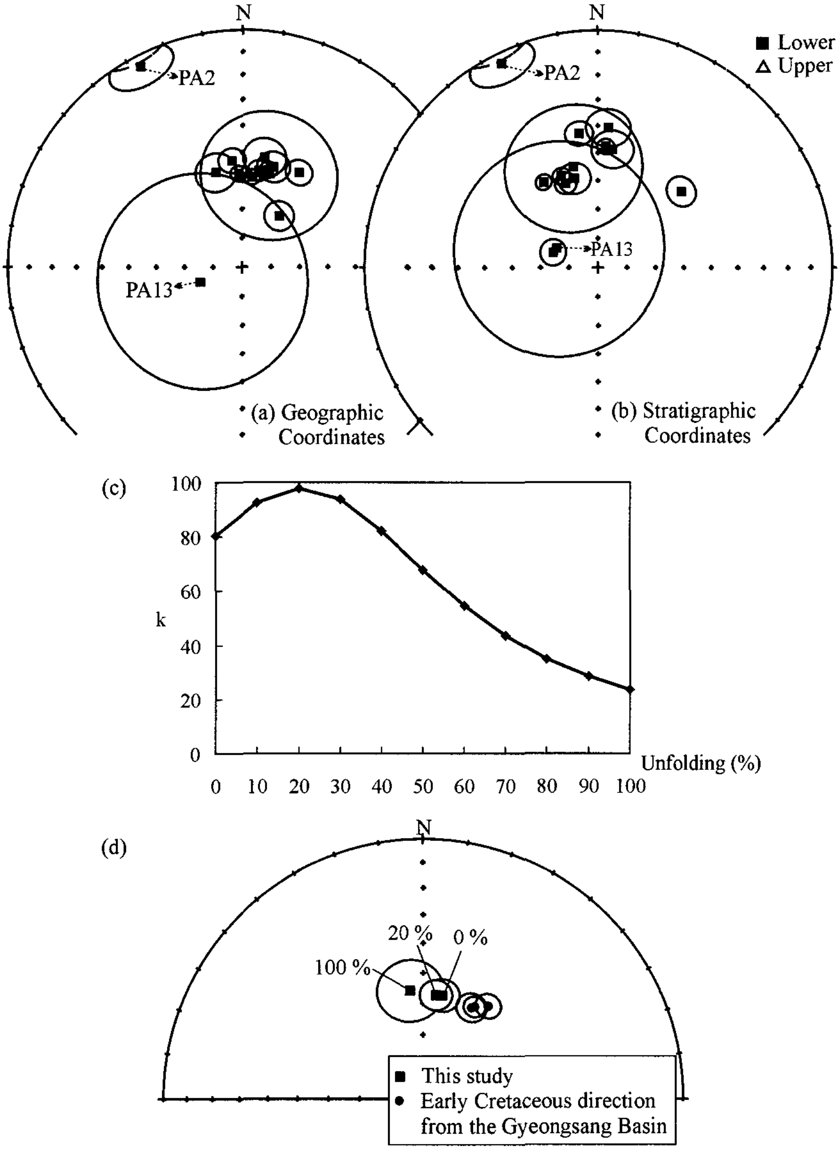
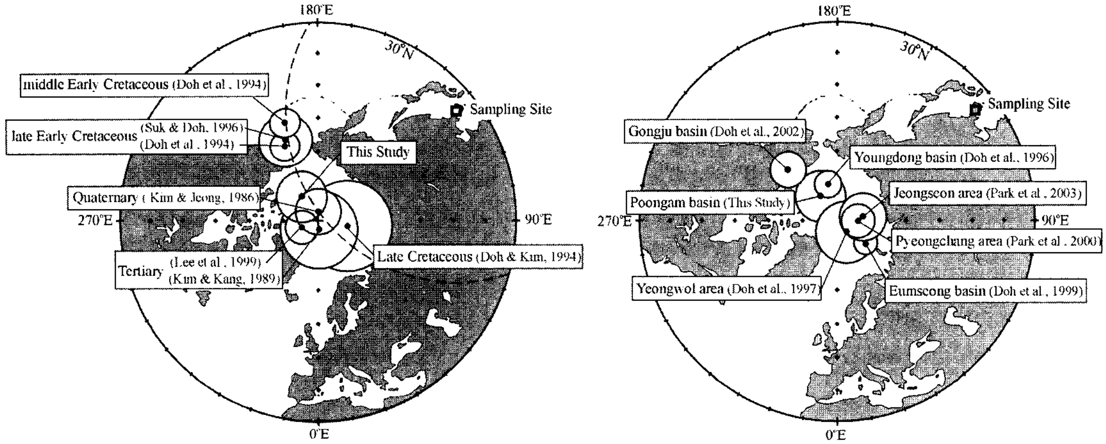


Fig. 7. Equal-area projections of the site-mean directions with 95% confidence limits of Poongam Basin (a) before and (b) after tilt correction. (c) Stepwise unfolding test, plotting Fishers precision parameter(k) versus percent unfolding. (d) Comparison of characteristic directions at 0%, 20% and 100% untilting with Early Cretaceous paleomagnetic directions reported from the Gyeongsang Basin (Lee *et al.*, 1987; Kim *et al.*, 1993; Doh *et al.*, 1994).

the middle Early and late Early Cretaceous poles are displaced westward with respect to the pole positions of the Late Cretaceous to Quaternary, indicating that the Korean Peninsula rotated (c.a., 30°) clockwise about the vertical axis while it was located at similar latitude to the present during the Cretaceous Period. This interpretation is consistent with the Cretaceous clockwise rotation of the Korean Peninsula with respect to the North China Block (Zhao *et al.*, 1999; Doh *et al.*, 2002). Thus, it can be interpreted that the remagnetization occurred after the clockwise rotation of the Korean Peninsula. Because any remarkable geologic events, which might cause the remagnetization, after Tertiary are not recognized, the timing of remagnetization can be assigned to the Late Cre-



(a) (b)

Fig. 8. Paleomagnetic pole of the sedimentary rocks in the Poongam Basin compared to (a) Cretaceous to Quaternary poles of Korea, and (b) those from remagnetized areas.

taceous to Tertiary. K-Ar ages from the intruding andesite, volcanoclastics and volcanic fragments in the sedimentary rocks show a range of 84 Ma to 70 Ma (Cheong and Kim, 1999), indicating that the extrusion and intrusion of volcanic rocks occurred during the Late Cretaceous in the study area. Some K-Ar age dating data from several hydrothermal vein deposits near the study area (79 Ma and 94 Ma from the Dongyang Hongcheon mine and Munhyun mine, Shin and Jin, 1995; 82 Ma from the Byungjibang mine, So *et al.*, 1999), indicating that the fluid-mediated processes were active during the Late Cretaceous in the study area. It is assumed that the Late Cretaceous igneous activities and/or fluid-mediated mineralizations were possibly connected to the remagnetization in the study area.

There are several possible mechanisms responsible for the remagnetization. Many authors suggested a chemical remanent magnetization (CRM), acquired by the formation of authigenic magnetic minerals, as the mechanism of remagnetization (e.g., McCabe *et al.*, 1983; Oliver, 1986; Hagstrum and Johnson, 1986; Elmore *et al.*, 1993; Banerjee *et al.*, 1997; Katz *et al.*, 2000). Another mechanism has been suggested that prolonged exposure to elevated temperature below the Curie temperature affecting the ability of rocks to retain a primary NRM is responsible for the acquisition of thermoviscous remanent magnetization (TVRM, e.g., Kent, 1985). Strain-related remagnetization (e.g., Hudston *et al.*, 1989) and surface weathering (e.g., Otofuji *et al.*, 1989) can also cause the remagnetization.

The remagnetized directions of this study have extremely well clustered (α_{95}=4.9°). Such a well-clustered direction is hard to be acquired by weathering process, and magnetic grains found in the electron microscope observations cannot be produced by weathering processes. Therefore the weathering process is the most unlike mechanism for the remagnetization. Strain-related remagnetization can be also denied because the strata are gently tilted without severe deformation. Andesitic rocks and granite, which extruded and intruded, in turn, after formation of the sedimentary rocks, are distributed widely around the study area. This feature raises a possibility that the TVRM is the major remagnetization mechanism in the study area. The maximum estimated paleotemperature of 355°C, as determined by fluid inclusion studies of several hydrothermal veins in adjacent areas (Won *et al.*, 1989), is significantly lower than temperatures (c.a., above 550°C for, at least, 10 My) required to have activated the remagnetization for hematite with an unblocking temperature of 640~660°C, as determined by the blocking temperature-relaxation time curves for hematite (Pullaiah *et al.*, 1975). Although this maximum paleotemperature of 355°C is high enough to produce a TVRM in hematite with an unblocking temperature below 520°C, the TVRM model can be ruled out because the stable single ChRM component residing in hematite was isolated mainly in the 500~660°C range, indicating that both magnetizations with unblocking temperatures below and above 520°C are the same component (Fig. 3b and c). This interpretation can be supported by that the strata in the study area do not show any signs of the metamorphism due to high temperature, despite that such temperature condition (above 550°C) should have resulted in considerable degree of contact metamorphism in rocks. Based on rock magnetic studies and electron microscope observations, the major magnetic carriers are hematite of secondary (authigenic) in origin. Therefore, the CRM is most likely to be the major process of remagnetization in the study area.

The CRMs can be acquired in association with various fluids such as the lateral migration of orogenic/basinal fluids (Oliver, 1986) or the introduction of meteoric and/or magmatic fluids (Hagstrum and Johnson, 1986) or the in situ pore waters released by tectonic pressure(Elmore *et al.*, 1993), as well as with burial diagenesis such as clay alteration (Katz *et al.*, 2000) and organic matter maturation (Banerjee *et al.*, 1997). Generally, burial diagenesis of clay is connected to the magnetite authigenesis. Considering that the major magnetic carrier in this study is hematite and there are many hydrothermal vein deposits formed during the Late Cretaceous near the study area, the acquisition of CRM might be associated with fluid-mediated processes rather than the burial diagenesis. So *et al.* (1999) reported that the hydrogen and oxygen isotope compositions of hydrothermal fluids from the Byungjibang Au-Ag mine near the study area indicate mixed magmatic (dominant)-meteoric fluids. Thus, we speculate that the CRM in the study area is related to the mixed magmatic-meteoric fluids at present, although there is no direct evidence that these mineralizing fluids circulated the host rocks pervasively.

Similar aspects of the chemical remagnetization by the fluid-mediated process are observed in other Cretaceous basins such as Youngdong Basin (Doh *et al.*, 1996), Eumseong Basin (Doh *et al.*, 1999) and Gongju Basin (Doh *et al.*, 2002) (Fig. 1a). Moreover, the late Paleozoic strata in several areas (e.g., Yeongwol, Doh *et al.*, 1997; Pyeongchang, Park *et al.*, 2000; Jeongseon, Park *et al.*, 2003) in the eastern Korea (the Okcheon unmetamorphosed zone) are also reported to be chemically remagnetized during the Late Cretaceous to Tertiary. Comparisons of the paleomagnetic pole positions of the remagnetized areas are shown in figure 8b. Paleomagnetic pole position of the study area is not distinguishable statistically to that of the Youngdong Basin, but it is significantly different from those of the Gongju Basin, the Eumseong Basin and Okcheon unmetamorphosed zone. The discrepancy of paleopole positions from remagnetized areas can give two alternative interpretations. One possible explanation is that small basins distributed along the Okcheon Belt were relatively rotated about vertical axis after the acquisition of CRMs at the almost same time. In a view of this explanation, the Gongju Basin and the Eumseong Basin experienced relative clockwise and counterclockwise, respectively, rotations with respect to the Poongam and Youngdong basins. The other explanation is that the discrepancy of the paleomagnetic pole positions indicates the temporal difference of the remagnetizations among these areas. The timing of the remagnetizations of the study area is not distinguishable statistically to that of the Youngdong Basin, which is later than that of the Gongju Basin and earlier than those of the Eumseong Basin and Okcheon unmetamorphosed zone. It can be interpreted that fluid-mediated chemical process possibly due to reactivation of the Gongju Fault System and Gwangju Fault System affected these basins at different time. At present, the second hypothesis seems to be more preferable, because it is hardly imagine that the remagnetizing fluids, related to the hydrothermal fluids, affected both the boundaries of the Okcheon Belt and the Okcheon unmetamorphosed zone at the same time. Also, it is still unclear whether the temporal difference of remagnetizations reflects the large-scale migration of remagnetizing fluids of similar origin along the Okcheon Belt or the intermittent and local hydrothermal activities during the Late Cretaceous to Tertiary. Further detailed studies with the structural syntheses, geochemical analyses and systematic absolute age determinations for remagnetized areas may give better information on these problems.

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