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A Study on the Paleomagnetism of Southern Korea since Permian

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Abstract: Oriented hand samples were collected from Gobangsan Formation and Nogam Formation in the north of Danyang and south of Yeongchun, from Bansong Group in and around Danyang, from Nampo Group in Chungnam Coalfield, from Gyeongsang Supergroup distributed from Waegwan through Daegu to Gyeongsan and from Daegu to Goryong, and from volcanic flows in Jeongog area and Jeju Island to study the paleomagnetism of southern Korea since Permian.

Stepwise alternating field and thermal demagnetization experiments were carried out to determine optimum fields and temperatures.

Observed mean paleomagnetic directions are as follows:
D=331.5°, I=25.1°, a95=12.8° for Permian,
D=325.6°, I=46.1°, a95=11.8° for Triassic,
D=313.4°, I=43.1°, a95=16.0° for early Jurassic,
D=41.3°, I=64.6°, a95=4.5° for early Cretaceous,
D=28.3°, I=58.1°, a95=2.3° for late Cretaceous,
D=2.0°, I=55.8°, a95=6.6°for Quaternary.

To describe the tectonic translocation of southern Korean block, northern Eurasian continental block was used as a reference frame. For each age since Permian the expected northern Eurasian field directions in terms of paleolatitude and declination were calculated. The paleolatitudes of Permian (13.2°N) and early Jurassic (25.1°N) obtained from the study area are quite different from those of Permian (66.0°N) and early Jurassic (68.1°N) which are expected for northern Eurasia. The declinations of Permian (331.5°) and early Jurassic (313.4°) are also quite different from those of the Permian (56.6°) and the early Jurassic (47.5°) expected for northern Eurasia. The Cretaceous paleolatitude is similar to the expected within error limit, but the declination for the same period is significantly different from that of the expected for the northern Eurasia.

From the above evidences it is suggested that the south Korean land mass had moved from low latitude in Permian to north and sutured to northern continental block since early Jurassic.

The relative rotations of early Cretaceous(27.4°) and late Cretaceous(10.8°) to northern Eurasian continent reveal that the Korean land mass might be rotated clockwise in two different times, probably in late Early Cretaceous and in Tertiary.

INTRODUCTION

To test the hypothesis that the Korean Peninsula has been stable and to obtain an apparent polar wander path (APWP) from the Korean Peninsula, a paleomagnetic study was made use of sedimentary rocks from the Permian-Cretaceous suites of the southern part of the Korean Peninsula and Quaternary volcanic rocks.

Upto 1984, several researchers have studied paleomagetism of the Cenozoic and the Cretaceous rocks from southern Korea. Kim (1964) carried out the paleomagnetic study for the Cenozoic lavas distributed in Jeongog and Pohang for the first time in Korea. Kinzle and Scharon (1966), Ito and Tokieda (1980) and Otofujj et al. (1982)

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conducted paleomagnetic studies from Cretaceous rocks of southern Korea, and reported that the VGPs of the Cretaceous and post-Cretaceous rocks of Korea are similar to those obtained from the northern Eurasian continent, and suggested that the Korean Peninsula had been stable tectonically since the Cretaceous. Lee et al. (1983) presented a paper "the Geotectonic Interpretation of Choogaryong Rift Valley, Korea". In their research, paleomagnetic study was also carried out simultaneously using the astatic magnetometer constructed by Kim (1983). The result of the paleomagnetic measurement was that the magnetic directions of Cretaceous basalts are scattered and quite different from that of the Quaternary basalts distributed along the Hantan River.

GEOLOGIC SETTINGS OF THE STUDIED AREAS

The Korean Peninsula occupies the eastern margin of the North China block, the Sino-Korean paraplatform of Huang (1978). The Precambrian basement of Korea is tectonically related to that of Manchuria and China (Lee, 1974). Pyeongbuk-Gyema massif forms the southern part of the Liao-Gyema massif, and Gyeonggi and Sobaeksan massifs can be correlated to Shantung and Fukien massifs of China (Kobayashi, 1957; Lee, 1972), respectively. Kobayashi and Lee suggested that Pyeongan basin and Ogcheon geosyncline of Paleozoic sediments rest upon these massifs (Fig.1).

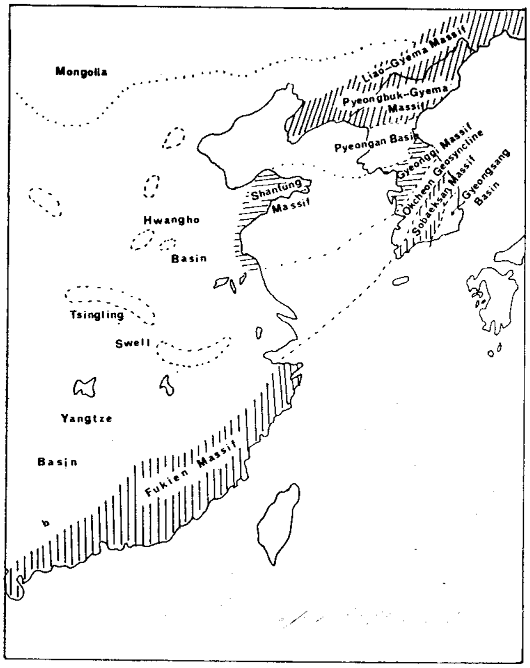
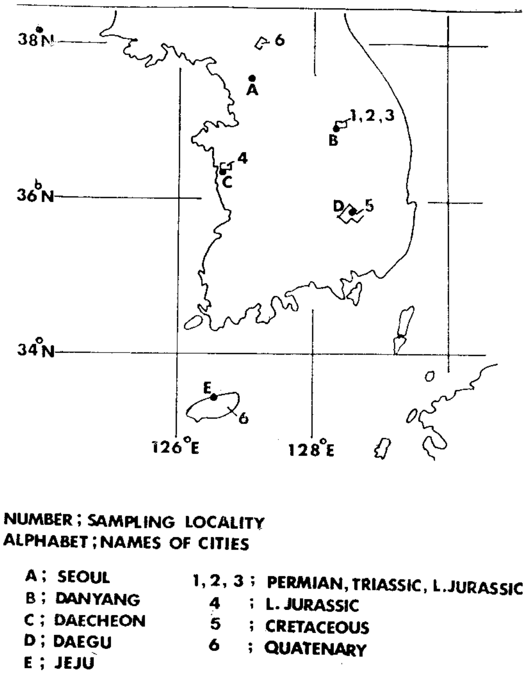


Fig. 1 Korea-Chinese Heterogen, after Kobayashi (1953, 1957) and Lee (1972).



NUMBER ; SAMPLING LOCALITY
ALPHABET ; NAMES OF CITIES

A ; SEOUL
B ; DANYANG
C ; DAECHEON
D ; DAEGU
E ; JEJU

1, 2, 3 ; PERMIAN, TRIASSIC, L.JURASSIC
4 ; L. JURASSIC
5 ; CRETACEOUS
6 ; QUATENARY

Fig. 2 Sampling localities.

Fig.2 shows the sampling localities. Oriented hand samples were collected from 1) Gobangsan Formation of Permian 2) Nogam Formation of Triassic 3) Bansong Group of lower Jurassic. The above sampling localities 1, 2 and 3 are located in the north of Danyang and south of Yeongchun, Chungbuk Province. 4) Nampo Group of lower Jurassic distributed in Chungnam Coalfield, Chungnam Province. 5) Gyeongsang Superoup of Cretaceous distributed in Gyeongsang basin in and around Daegu 6) volcanic rocks of Quaternary distributed in Jeju Island and Jeongog area.

Gobangsan Formation (Permian)

The sampling localities and sites from the Gobangsan Formation are shown in Figs. 2, 3. Non-marine sandstones and shales containing the abundant *Gigantopteris* flora constitute the Gobangsan Formation. The white sandstones forming the basal units are in sharp contact with underlying coal measures of the Sadong Formation. In places quartzite pebbles and shale fragments are found in the basal beds and locally an unconformity may be present (Reedman and Um, 1975). In the Samcheog and the Danyang Coalfield, Cheong (1969, 1971) reclassified the Gobangsan sequence into the Hambaeg, Dosagog and Gohan Formations, but elsewhere the term Gobangsan Formation is commonly used.

The Gobangsan Formation was considered by Kawasaki (1927) to be Triassic using the Gobangsan flora but Kobayashi (1953) reported that the flora is mainly that of late Permian. Son (1966) considered the Gobangsan Formation to be Permian in relation to the time of the crustal disturbance. Chang (1972) collected typical Gobangsan flora from the type Gobangsan Formation and located the Gobangsan Formation to the early Upper Permian.

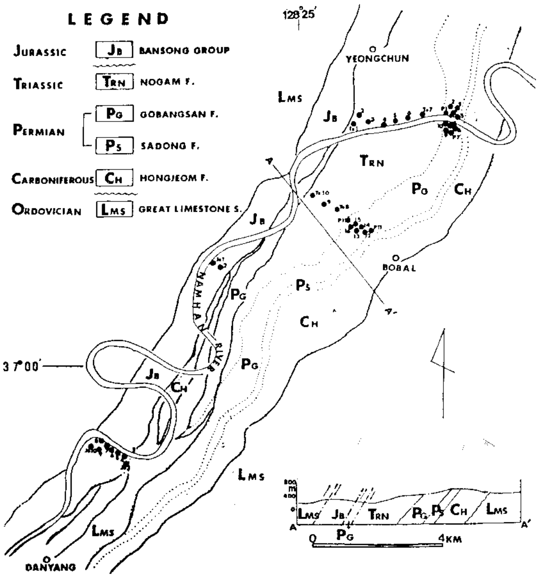


Fig. 3 Sampling sites from the Gobangsan, Nogam Formations and Bansong Group.

Nogam Formation (Triassic)

The sampling localities and sites from the Nogam Formation are shown in Figs. 2, 3. This Formation overlies the Gobangsan Formation, and is composed of red feldspathic medium-grained, greenish grey sandstones, having about 400 meters in thickness (Park, 1963). In the center part of the Baegunsan Syncline, near Donggo Mine, the Nogam Formation is in contact with the Sadong and the Hongjeom Formations and Son et al. (1967) believed it to lie unconformably upon the younger units. Shiraki (1940) and Cheong (1967) interpreted the relationship as a fault and in general the Nogam Formation appears to rest conformably upon the Gobangsan Formation.

No fossils have been reported from the Nogam Formation and only broad limits can be set on its age; it predates the Songrim distribance. Most researchers considered the Nogam Formation to be early Triassic in age but this is not definitely proved yet.

Bansong Group (lower Jurassic)

The sampling locality and sites of the Bansong Group are shown in Figs. 2, 3. The basal beds of the Bansong Group are conglomerates which were deposited as deltaic fans in a fluvio-lacustrine environment. Sandstones and shales overlie the basal conglomerates and some thin coal seams are intercalated. A rich flora was found in some of the shaly horizons and was identified by Kawasaki (1925) as Triassic in age.

The succession of the Bansong Group is best known in Danyang and Mungyeong Coalfields. In the Danyang Coalfield, three formations have been recognized (Son et al., 1967; Cheong, 1971): the Sapyeongri, the Hyeoncheonri and the Deogcheonri Formations.

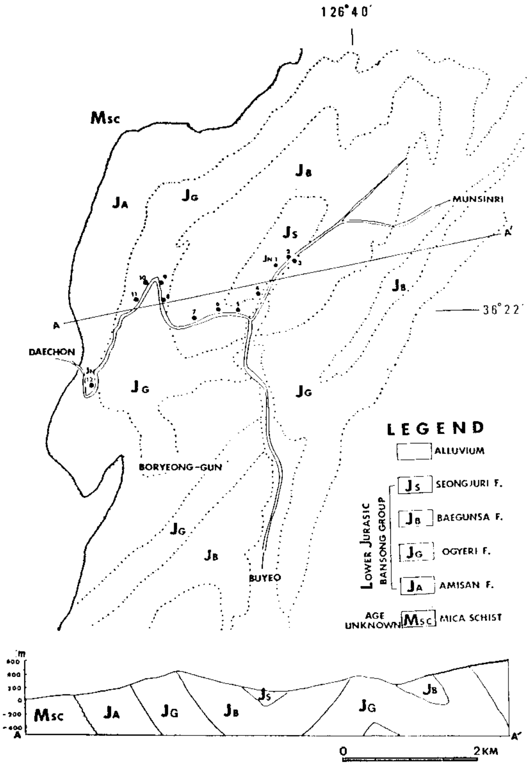


Fig. 4 Sampling sites from the Nampo Group.

Nampo Group (Lower Jurassic)

The sampling locality and sites from the Nampo Group are shown in Figs. 2 and 4. Nampo Group crops out in the Chungnam Coalfield in Chungnam Province. It comprises a thick sequence mainly of coarse grained, clastic sedimentary rocks which were formed in a fresh water lake. The sedimentary sequence is divided into Hajo, Amisan, Jogyeri, Baegunsa and Seongjuri Formations in ascending order (Kim, 1976).

An adundant flora has been obtained from the shales of the Amisan and the Baegunsa Formations. Kawasaki (1925) assigned an early Jurassic age (Liassic) to the floral assemblage but Kobayashi (1951), on the basis of fossil *Estherians*, concluded that lower part of the succession was deposited in late Triassic Period. Kim (1976) reported that the Amisan and the Baegunsa Formations could be placed in late Triassic-early Jurassic using the new flora found in the Chungam Coalfield. Samples were collected from the four formations except the Hajo.

Gyeongsang Supergroup (Cretaceous)

The sampling locality and sites from Gyeongsang Supergroup are shown in Figs. 2 and 5. Gyeongsang Supergroup is an unconformity-bound unit of non-marine sedimentary and igneous rocks of about the whole span of the Cretaceous System (Chang, 1975).

Minato et al. (1965) reported that the lower part of the Gyeongsang Supergroup could be correlated with the Berriasian by the non-marine fossil assamble. Suzuki (based on the animal remains) and Qishi (based on the plant remains) correlated the upper part of the Hayang Group with the Mihune Group (Suzuki, 1940), and reported that the age of the Hayang Group appeared to span from Aption-Albian to Cenomanian-Turonian. Yang (1976) reported that Nagdong Group is correlated to the Akaiwa Subgroup (Aption to Albian) of the Tetori Group from the new genus *Nagdongia* which he discovered. Yang (1978) also confirmed that Nagdong Formation could be correlated to Sebayashi Formation (Aption-Albian) from the discovery of *Nipponoanania ryosekiana* in Nagdong Formation.

Volcanic Rocks (Quaternary)

Volcanic rocks distributed in Jeju Island (Won, 1976; Lee, 1982) and Jeongog area (Kim, 1964; Lee et al., 1983) are included in this study. Won and Lee reported that eruptions occurred during the Pleistocene up to historic time and that about 14 eruptions or extruded episodes were identified from the Jeju volcanic rocks. It was reported that maximum six different eruption episodes were identified from the basalt flows in Jeongog (Lee et al., 1983). The times of these eruptions was reported to be about 0.27 m.y. (Choi, 1980).

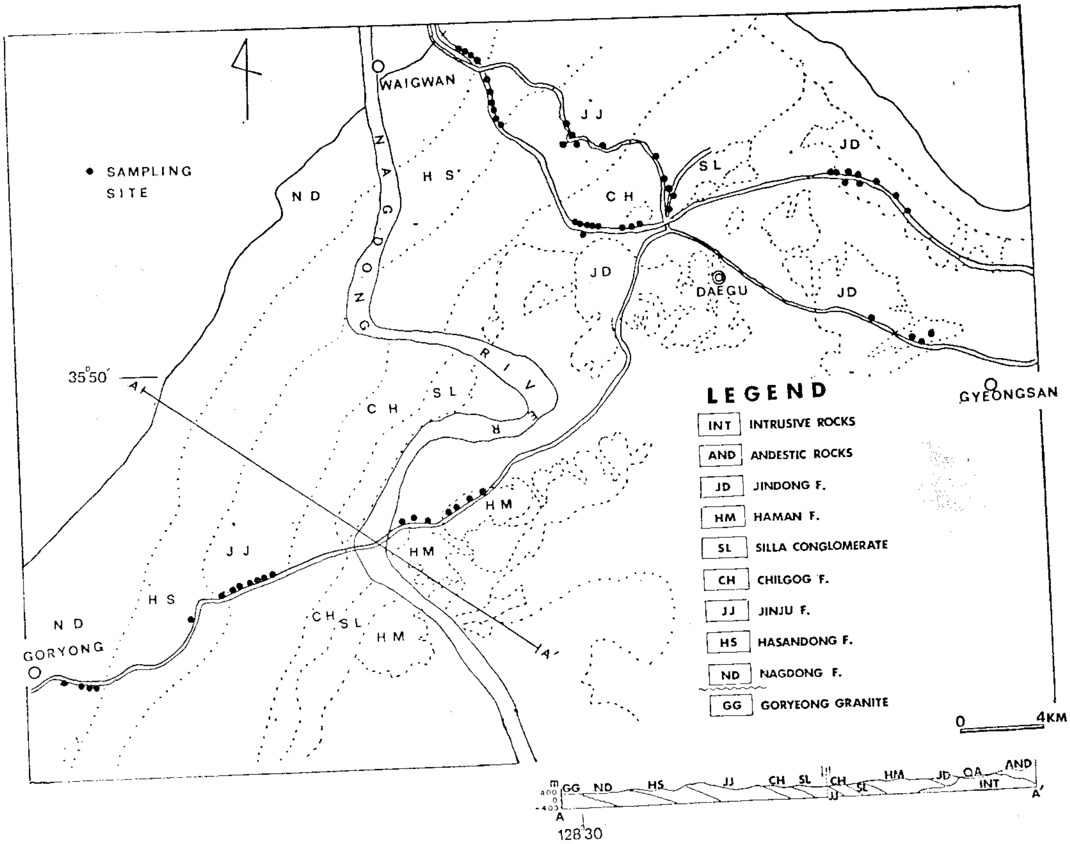


Fig. 5 Sampling sites from the Gyeongsang Supergroup.

SAMPLE COLLECTION AND PALEOMAGNETIC MEASUREMENTS

Sample collection

For paleomagnetic study of southern Korea, collection and laboratory measurements of samples were undertaken from August, 1982 to August, 1984. Most of the samples collected were sedimentary rocks which cover from the Permian to the Cretaceous distributed in southern Korea.

Oriented hand samples were collected with tripod and clinocompass from newly or recently cut road sides. Three to six samples were collected from each site (Table 1). To check probable errors and to compare paleomagnetic data, two different sampling routes in the same sedimentary basin were chosen far from each other in the localities of Permian, Triassic and Cretaceous ages. Different sedimentary basins were also chosen for the localities of the Jurassic, that is, the Bansong Group in Danyang basin and Nampo Group in Chungnam basin were selected to compare the data. Quaternary samples were collected from Jeongog area and Jeju Island. In Jeongog area samples were collected from vertical sections where maximum six lava flows were identified. In Jeju Island samples were collected from different lava flows erupted in different times.

Paleomagnetic measurement

Oriented hand samples collected were drilled to be cores of 2.4cm in diameter, 2.4cm in height. Measurements of remanent magnetization were made on two-component cryogenic magnetometer and spinner magnetometer of the Department of Earth Science, Kobe University,

Table 1 Number of sampling sites for each formation.

Age	Formation	Number of sites	Number of samples
Quaternary	Jeju Basalts	16	70
	& Jeongog Basalts	6	37
	Total	22	107
Cretaceous	Jindong Fm.	14	54
	Haman Fm.	7	31
	Chilgog Fm.	17	97
	Jinju Fm.	12	43
	Hasandong Fm.	7	31
	Nagdong Fm.	8	34
	Total	65	290
Early Jurassic	Nampo Group	11	36
	Bansong Group	8	55
	Total	23	91
Triassic	Nogam Fm.	10	44
Permian	Gobangsan Fm.	17	45
Total		133	577

Japan. Volcanic rocks were measured with the spinner.

Three or more pilot specimens from independently oriented samples in each site were progressively demagnetized in alternating field (a.f.) in steps of 50 oersted up to maximum field of 500 oersted. Progressive thermal demagnetization was also done in air on three or more specimens from each site in steps of 100°C or 150°C to Curie Temperature, each run covering for 30 minutes. To determine a characteristic direction of magnetization for each site, Zijderveld component plots were used to identify a characteristic direction of each site (Zijderveld, 1967).

Permian

NRM and result of a.f. demagnetization show that speciments from eight sites of the Gobangsan Formation have very weak and unstable magnetization. At the remaining nine sites, the specimens are magnetically strong and stable and display intrasite and intersite consistency in their magnetic directions (Fig. 6, Table 2).

Progressive thermal demagnetization was also carried out on two pilot specimens from each the stable site and shows that the specimens are unstable and the directions change randomly as temperature increases (Fig. 6).

Triassic

Triassic samples from the Nogam Formation apper to be magnetized stably. Although the magnetic direction of individual specimen is stable on stepwise a.f. and thermal demagnetization (Fig. 6) and the magnetic directions reveal intrasite consistency, the site mean directions

Table 2. Paleomagnetic directions from stably magnetized Permian samples.

Site No.	Locality Lat. (°N)	Locality Long. (°E)	N	Level of Demag.	D (°)	I (°)	Int. ($\times 10^{-6}$)	k	a95 (°)	Rock type
P 1	37.0	128.0	9	100	302.8	33.0	2.0	113.8	4.8	shale
P 7	37.0	128.0	6	100	324.7	35.4	1.0	2.9	47.9	slate
P10	37.0	128.0	6	50	318.8	35.9	3.5	56.4	12.3	shale
P11	37.0	128.0	6	100	339.2	−6.0	6.3	12.7	19.5	sandstone
P12	37.0	128.0	7	100	348.7	18.0	7.9	67.7	7.4	sandstone
P13	37.0	128.0	9	50	319.7	18.5	4.0	21.4	11.4	sandstone
P14	37.0	128.0	6	50	356.9	27.0	40.6	54.3	9.2	sandstone
P16	37.0	128.0	8	100	340.8	29.0	152.1	108.4	5.3	red s.s.
P17	37.0	128.0	6	100	326.3	27.2	25.0	21.6	14.7	sandstone

Parameters are as follows; N, number of specimens; D, declination; I, inclination; a95, radius of 95% confidence; k, precision parameter

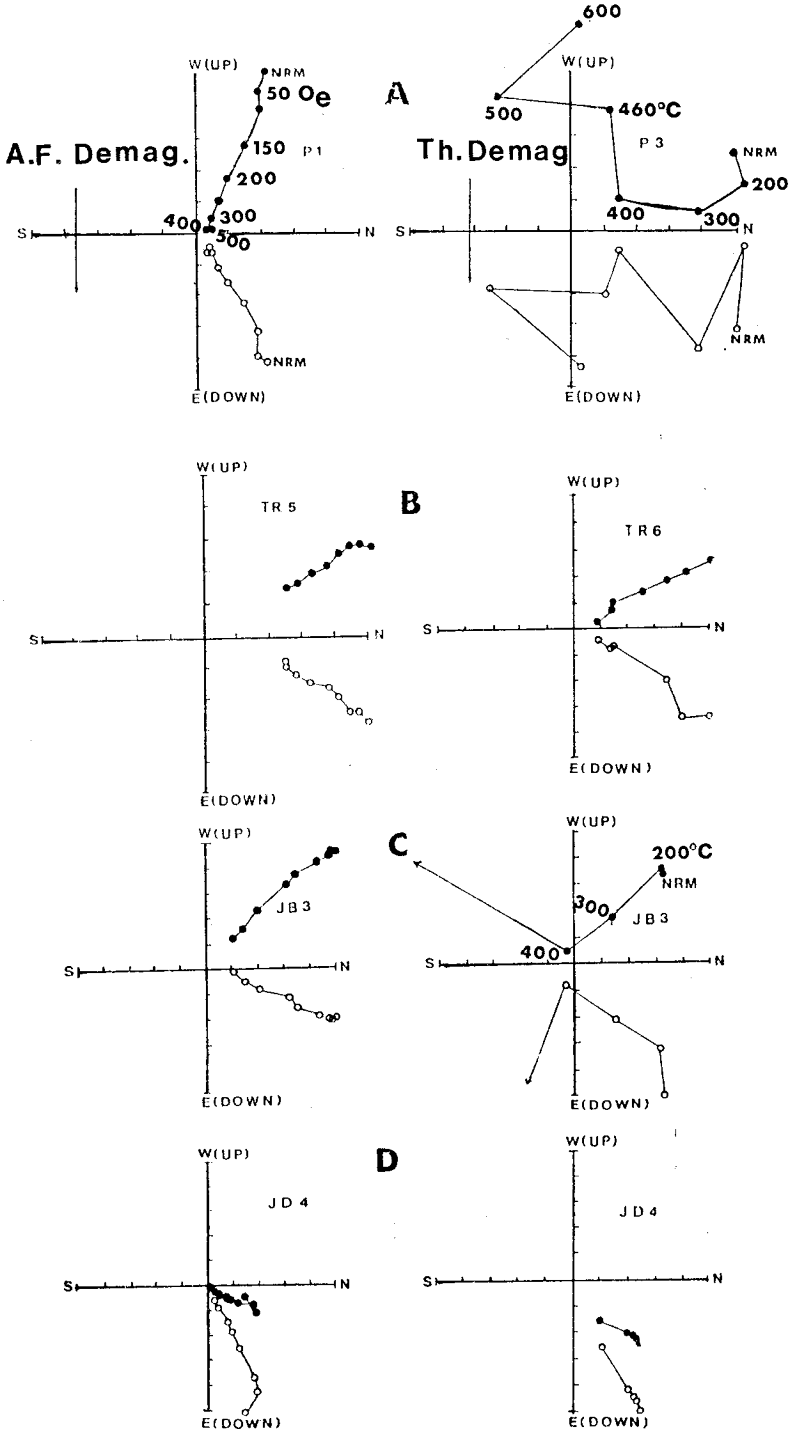


Fig. 6 Zijderveld plot of direction change during alternating field (A.F.) and thermal (Th.) demagnetization of specimens from A : Permian, B : Triassic, C : early Jurassic, D : Cretaceous strata.
Solid (open) circles refer to projections on the horizontal (vertical) plane.

Table 3 Paleomagnetic directions from Triassic sites.

Site No.	Locality Lat. (°N)	Locality Long. (°E)	N	Level of Demag. (Oe)	D (°)	I (°)	Int. ($\times 10^{-6}$)	k	a95(°)	Rock type
TR 2	37.0	128.0	6	100	284.1	61.1	24.1	54.9	12.5	sandstone
TR 3	37.0	128.0	6	100	320.2	51.7	44.4	101.3	7.6	sandstone
TR 4	37.0	128.0	9	100	332.7	59.7	15.8	91.8	5.4	sandstone
TR 5	37.0	128.0	10	100	331.2	33.6	10.4	74.8	5.6	sandstone
TR 6	37.0	128.0	6	100	1.0	40.4	38.6	101.4	7.6	sandstone
TR 7	37.0	128.0	6	100	299.6	45.2	357.3	69.7	8.0	red s.s.
TR 8	37.0	128.0	5	100	331.8	41.9	15.6	298.5	5.3	shale
TR 9	37.0	128.0	8	100	326.9	33.1	33.2	57.4	7.4	sandstone
TR10	37.0	128.0	6	100	323.8	34.0	2.7	155.4	7.3	shale
Mean					325.9	46.5		19.9	11.8	

Table 4 Stably magnetized sites of early Jurassic.

Site No.	Locality Lat. (°N)	Locality Long. (°E)	N	Level of Demag. (Oe)	D (°)	I (°)	Int. ($\times 10^{-6}$)	k	a95(°)	Rock type
JB 1	37.0	128.0	23	100	333.5	19.0	6.5	15.1	8.0	sandstone
JB 2	37.0	128.0	21	50	336.9	17.0	10.3	18.3	7.6	sandstone
JB 3	37.0	128.0	12	100	318.0	21.6	5.4	26.4	8.6	sandstone
JB 4	37.0	128.0	5	50	302.2	49.0	0.9	12.8	26.6	sandstone
JB 5	37.0	128.0	10	100	297.0	44.2	784.5	12.2	14.1	sandstone
JB 8	37.0	128.0	10	100	323.6	53.1	17.7	87.7	5.2	sandstone
JN 5	36.4	126.6	8	100	311.6	70.6	2.0	14.5	15.0	sandstone
JN 8	36.4	126.6	6	100	287.4	35.7	2.4	10.9	21.2	sandstone
JN 9	36.4	126.6	13	100	286.0	65.2	1.9	25.3	8.3	sandstone
Mean					313.4	43.1		11.2	16.0	

from the Triassic sites are poorly converged (Table 3).

Early Jurassic

At two sites from the Bansong Group and eight sites from the Nampo Group it was impossible to obtain any reliable magnetic direction for one of the two reasons: 1) Although the magnetic directions of each specimen are stable in a.f. demagnetization, the magnetic directions within a site would not converge. At two sites from the Nampo Group and at one site from the Bansong Group, the specimens are found to have reversed and scattered magnetization. 2) The site mean directions show quite different from the overall mean direction which were calculated from all of the lower Jurassic sites even if these site mean directions have relatively good intrasite consistencies after a.f. demagnetization.

At the remaining nine sites the specimens are not only magnetically stable in a.f. demagnetization (Fig. 6) but also, on the whole, display intrasite and intersite consistency (Table 4).

Progressive thermal demagnetization experiment on pilot specimens shows that the specimens from the Jurassic sites are unstable and the directions change randomly as the temperature increases (Fig. 6).

Cretaceous

Both a.f. and thermal demagnetization expe-

Table 5 Summary of paleomagnetic directions since the Permian.

Era	Period	Formation or Group	Before bedding correction				After bedding correction			
			D(°)	I(°)	a95(°)	k	D(°)	I(°)	a95(°)	k
Cenozoic	Quaternary	Jeju and Jeongog	2.0	55.8	6.6	69.5	2.0	55.8	6.6	69.5
Mesozoic	Cretaceous	Jindong	15.4	48.4	4.4	71.1	28.6	53.5	4.9	71.5
		Haman	11.2	66.0	11.3	47.6	27.6	59.5	3.9	285.3
		Chilgog	6.4	49.0	2.8	147.5	28.9	61.5	2.9	152.8
		Mean					28.3	58.1		
		Jinju	21.8	67.8	7.8	38.2	44.0	64.6	6.5	55.6
		Hasandong								
		Nagdong	6.5	60.8	8.4	56.4	38.6	64.6	7.0	62.6
		Mean					41.3	64.6		
	Early Jurassic	Bansong and Nampo	−23.6	52.9	25.3	5.0	−46.6	43.1	16.0	11.2
	Triassic	Nogam	−9.2	49.9	15.3	12.2	−34.1	46.1	11.8	19.8
Paleozoic	Permian	Gobangsan	−3.1	54.7	7.2	51.4	−28.5	25.1	12.8	16.9

D, declination; I, inclination; a95, radius of 95% confidence;

riments for pilot specimens from all the Cretaceous sites, excepting from the Hasandong Formation, show that the magnetic directions are nearly consistent during stepwise demagnetization (Fig. 6, Table 5).

It is impossible to obtain any consistent magnetic direction from the Hasandong sites and the specimens reveal reversed directions as maximum a.f. field or temperature increases. The specimens, excepting from the Hasandong sites, are characterized by normal polarity.

The magnetic directions within a site are poorly converged at some sites from the Nagdong Formation, but the Formation mean direction is grouped well about the overall mean direction. At the remaining all sites the specimens are magnetically stable and display intrasite and intersite consistency in their magnetic directions.

Paleomagnetic directions for each age

The Permian and Triassic directions before bedding correction are close to the present field direction, and the early Jurassic direction is definitely different from the present field direction. It is inferred that the magnetic directions of each formation are primary from the following reasons: 1) declination changes gradually from the Permian to early Jurassic and from early to late Cretaceous (Fig. 7A). 2) inclination changes gradually from the Permian to Quaternary (Fig. 7B). 3) although the precision parameter (k) decreases after bedding correction in the case of the Gobangsan Formation, those of the other formations increase after bedding corrections. 4) the Bansong and Nampo Groups of lower Jurassic are different sedimentary formations which were deposited in different tectonic depressions separated about 160km apart each other, but the magnetic directions of the two groups are approximately same after bedding corrections.

The similar directions of the Permian and the Triassic to the present field direction, therefore, may be the result of tectonic rotation of the Korean Peninsula in the Jurassic.

The paleomagnetic directions for each formation (Table 5) and their change with age (Fig. 7) reveal that there is big gap in declination between early Jurassic and early Cretaceous, and gradual change in inclination from shallow to high. It

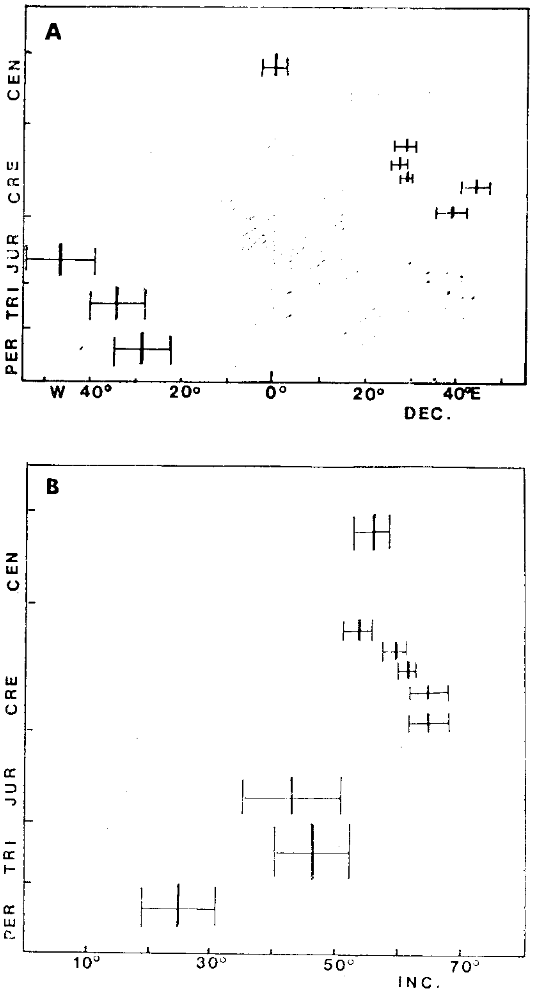


Fig. 7 Change of paleomagnetic directions since the Permian.
A: declination, B: inclination, thick vertical bars: mean declinations (inclinations) of each age, thin vertical bars: error limits (a95) about the mean

is noticed that there were gradual changes in declination from the Permian to the early Jurassic and from early to late Cretaceous, whereas abrupt change from late Cretaceous to Quaternary. It is also noticed that the inclination decreased graduallly from early to late Cretaceous.

PLATE TECTONIC INTERPRETATION OF RESULTS

Reasonably reliable APW path for the northern Eurasian continental block can now be drawn for the middle Carboniferous onwards, and are given in Fig. 9 (Irving, 1977).

The assumption required for plate tectonic interpretation is that the mean paleomagnetic directions of rock units represent the direction of the field averaged over a period of time long enough to average out the secular variation. The calculations were made assuming that the geomagnetic field averaged to an axial geocentric dipole.

Analysis of the mean directions

The time variations in the results for each geologic age are expressed in terms of the change of the directions relative to the present geocentric axial dipole field. The mean direction of any age (Dm, Im) may be compared with that of the earth's field over the past several thousand years ($D'm, I'm$), that is, with the direction of the geocentric dipole field. The differences ΔIm and ΔDm are defined as follows:

$$\Delta Im = Im - I'm$$

$$\Delta Dm = Dm - D'm$$

$Rp = Dm$ or $Rp = Dm - 360°$ if $180° < Dm \leqq 360°$. Rp defines the angle between the present meridian and paleomeridian, the rotation. The values Rp and Im are combined into a single angle ϕ (divergence) which is the angle between the mean direction for any age (Dm, Im) and that of the geocentric axial dipole field ($D'm, I'm$), and is calculated from the following relation:

$$\cos\phi = \cos Rp \cos Im \cos I'm + \sin Im \sin I'm$$

From the calculation of ϕ using above formula a systematic increase of ϕ is noted from the Quaternary to the Permian excepting the Triassic (Table 6, Fig. 8). It is suspected, therefore, that the mean direction obtained from the Nogam sites might be secondary.

The average rate of change of ϕ is about 1.4cm/year. When the Gobangsan Formation is considered to be deposited in the upper Triassic,

Table 6 Rotation (R_p) and divergence (ϕ) calculated from the paleomagnetic directions for each age from southern Korea since Permian.

Period	Formation or Group	D (deg.)	Relative R_p (deg.)	ϕ (deg.)	Average increasing rate of ϕ
Quaternary	Jeju B. and Jeongog B.	2.0		3.6	0.13°/10^6 years or 1.4cm/year
			26.3		
Late Cretaceous	Hayang Group	28.3		15.4	
			18.2		
Early Cretaceous	Sindong Group	46.5		21.9	
			−93.1		
Early Jurassic	Bansong and Nmapo Group	−46.6		32.1	
			12.5		
Triassic	Nogam Formation	−34.1		23.4	
			5.6		
Permian	Gobangsan Formation	−28.5		37.1	

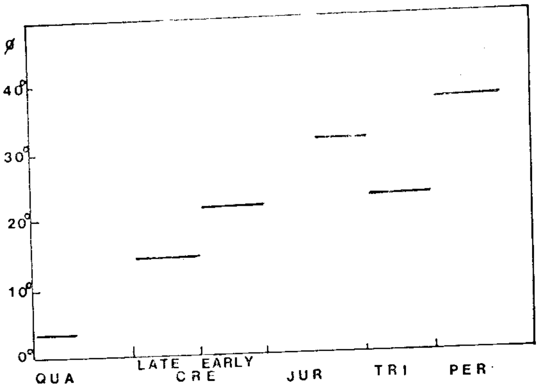


Fig. 8 Variation of the divergence ϕ with age for southern Korea.

the average rate of ϕ becomes to be 1.9cm/year, which compares well with 2.2cm/year for Europe, 2.0cm/year for North America (Irving, 1964).

From the rotation angle Rp for each age (Table 6), it is noticed that southern Korea rotated anticlockwise about 93 degrees relative to the early Cretaceous in late Jurassic, about 18 degrees clockwise in late Early Cretaceous relative to Early Cretaceous, and about 26 degrees clockwise relative to the Quaternary in Tertiary.

It is noticed that declination had been changed gradually to the west since the Permian to the early Jurassic with large gap in the late Jurassic and small gaps in the late Early Cretaceous and in the Tertiary (Table 5, Fig. 7A). It is also noticed that inclination had been increased gradually from the Permian to the early Cretaceous (Table 5, Fig. 7B).

Apparent polar wander path (APWP) since the Permian

Paleopoles for different ages for southern Korea are listed in Table 7, and APWPs for southern and northern Korean land masses are drawn with that for the northern Eurasian continental block in Figs. 9, 10. It is noticed that the APWP for northern Eurasian continental block is continuous, while that for southern

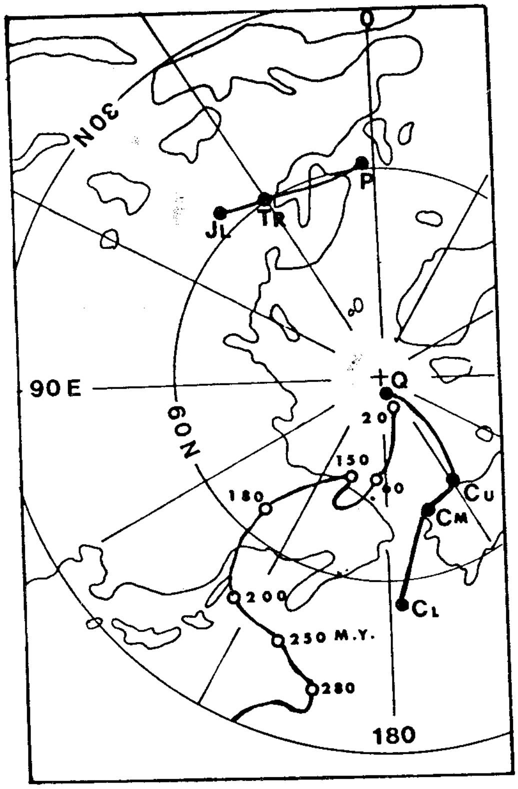


Fig. 9 Apparent polar wander paths for southern Korea and northern Eurasian continent. Solid (open) circles are paleopoles for southern Korea (northern Eurasia). P : Permian, TR : Triassic, JL : lower Jurassic, CL, CM, CU : lower, middle and upper Jurassic, respetively.

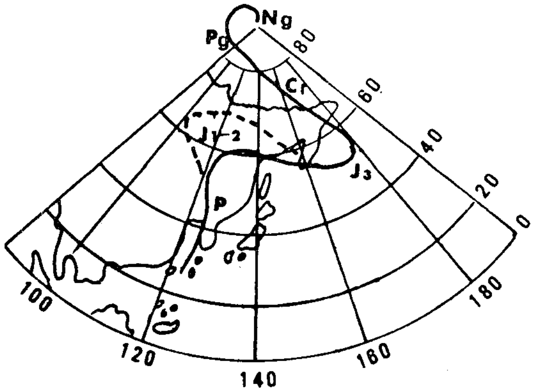


Fig. 10 Apparent polar wander path from northern Korea (Kang, 1972).

Korean land mass is discontinuous, suggesting a large degree of rotation which might be resulted from collision in late Jurassic. Paleopoles of the early and late Cretaceous obtained from northern Korean land mass (Kang, 1972) do not coincide with those obtained from southern Korean land mass (Fig. 10). The APWP since the Permian for northern Korean land mass is continuous, which is quite different from that of southern Korean land mass.

Comparison of the paleopoles of southern Korea with those of the stable northern Eurasian continent

Paleopoles are listed in Table 7 for each geologic age from southern Korea since the Permian. The corresponding paleomagentic field directions are given in terms of paleolatitude and declination with their associated errors. The paleolatitude value for the Trassic seems to be anomalously high relative to that of the early Jurassic.

In ordder to describe the displacement of the southern Korean block, northern Eurasian continental block was used as a reference frame. From the mean poles for northern Eurasia which were calculated by Irving (Irving, 1977) for each 10 m.y. interval, the expected northern Eurasian field directions were obtained using the following formula (Irving, 1964).

$$\sin \lambda p = \sin\lambda' + \cos\lambda r \cos\lambda' \cos(\phi - \phi r)$$

where

λp	; expected paleolatitude
$\lambda r, \phi r$	; latitude and longitude of reference locality
λ', ϕ	; latitude and longitude of paleomagnetic pole for northern Eurasia

For each age since the Permian the expected northern Eurasian field directions in terms of paleoaltitude and declination with their associated

Table 7 Paleopoles of each geologic age for southern Korea and relative translocations of southern Korea to northern Eurasia.

Period	Pole position		a95 (°)	Paleolatitude(λp) $\pm d\lambda p$	$D \pm dD$	Calculated direction for northern Eurasia		Relative motion	
	Lat. (°N)	Long. (°E)				$\lambda p + d\lambda p$	$D + dD$	$\Delta\lambda p$(°) northward	ΔD(°) clockwise
Quaternary	87.4	178.8	6.6	36.5± 3.2	2.0±11.1	37.5± 4.2	5.9± 7.3		
Late Cretaceous	67.1	209.8	2.0	38.3± 2.5	28.3± 6.8	47.3± 3.5	17.5± 8.1	−9.0± 4.3	10.8±10.6
Early Cretaceous	57.5	186.3	4.5	46.5± 6.0	41.3±11.0	51.6± 5.6	15.6±10.0	−5.8± 8.1	27.4±14.9
Early Jurassic	48.5	39.2	10.0	25.1± 7.6	313.4±13.6	68.1±15.0	22.0±13.6	−43.0±16.8	−68.8±19.3
Triassic	59.9	30.1	11.8	27.8	325.9	69.9	47.5	−42	−81.6
Permian	55.1	2.3	12.8	13.2± 7.4	331.5±14.0	66.0± 5.2	56.6±13.3	−52.8± 9.0	−85.1±19.3

dD=a95/cosIm, where Im is the inclination for each age. $d\lambda p$=a95$(1+3\cos^2\lambda p)/2$, where λp is paleolatitude. The errors in $\Delta\lambda p$ and ΔD are given by $[\sum(d\lambda p)]^{1/2}$ and $[\sum(dD)^2]^{1/2}$.
Expected directions (λp and D) are calculated from the northern Eurasian poles of each age for the mean coordinate of the sampling localities (36.5°N, 128.0°F).

errors are calulated (Table 7). The observed paleolatitudes of the Permian (13. 2°N±7. 4°) and early Jurassic (25. 1°N±7. 6°) are quite different from those of the Permian (66. 0°N±5. 2°) and early Jurassic (68. 1°N±15. 5°) which were inferred from the expected for northern Eurasia. The observed declinations of the Permian (331. 5°±14. 0°) and early Jurassic (313. 4°±13. 6°) are also quite different from those of the Permian (56. 6°±13. 3°) and early Jurassic (22. 0°±13. 6°) which were inferred from the expected for northern Eurasia. The observed and the expected paleolatitudes during the Cretaceous are similar to each other within error limits, but the observed declinations for the same period are significantly different form those of the expected declinations. The observed and the expected paleolatitudes and declinations of the Cenozoic are nearly equal each other. Because there are few observed paleomagnetic data of the Tertiary, the observed Quaternary direction was compared with that of the expected Tertiary.

From the evidences mentioned above it is suggested that southern Korean land mass moved to north before the late Jurassic, while northern Eurasian continent experienced only little latitudinal displacement and large rotational motion. During the late Jurassic southern Korean land mass experienced large latitudinal displacement toward north, and northern Eurasian land mass did relatively large latitudinal displacement toward south. It is inferred that the two land masses might be collided each other. Large westward declination data and large anticlockwise rotation relative to northern Eurasian continent since the Permian to early Jurassic also suggest that thare might be collision in late Jurassic. The relative delinations of the early Cretaceous (27. 4°±14. 9°) and late Createceous (10. 8°±10. 6°) reveal that Korean land mass might be rotated colckwise in two different ages, probably in late Early Cretaceous and in Tertiary.

DISCUSSIONS AND CONCLUSIONS

Discussions

The Gobangsan and the Nogam Formations and the Bansong Group distributed in north of Danyang and south of Yeongchun are characterized by normal polatity. If the magnetizations of the Gobangsan and the Nogam Formations are those of the primary, there is a possibility that these formations might be deposited in late Triassic. Sites of the Amisan Formation in the lower Nampo Group are characterized by reversed polarity and those of the younger formations than the Amisan by normal, suggesting the age of the Amisan might be early Jurassic. The results of paleontologic studies on fossil floras from the Amisan Formation by several researchers also have revealed the same age.

The Permian and Triassic directions obtained from this study area are close to the present field direction befroe bedding correction, whereas the early Jurassic direction from the Bansong and Nampo Groups are significantly different from the present direction. The magnetic directional change from the Permian to early Jurassic is systematic after bedding correction and therefore, the similar directions of the Permian and Triassic to the present field direction may be the result of tectonic rotation of the southern Korean Peninsula.

The divergence (ϕ), the angle between the mean direction for any age and that of the geocentric dipole field, was calculated for each age. A systematic increase of ϕ is noted from the Quaternary to Permian except for the Triassic. If the age of the Gobangsan Formation is Permian, average increasing rate of ϕ is about $0.13°/10^6$ years, which means that Korean land mass has moved north at the rate of 1. 4cm/year. When the Gobangsan Formation is considered to be upper Triassic, this becomes 1. 9cm/year, which compares well with 2. 2cm/year for Europe, 2.0cm/year for north America.

When comparing the observed mean directions with those of the expected northern Eurasian continent, it is inferred that Korean land mass experienced large tectonic translocation toward north from about 13°N in the Permian and sutured to Siberian land mass with large anticlockwise rotation in late Jurassic.

Park (1977) suggested, referring to Cowie (1971) and Whittington & Hughes (1974), that Iran, Austrlia, Korea, China and Vietnam might belong to the same trilobite province which had been located at the warm shallow sea of Gondwana margin, and referring to Meyen (1970) and Hart (1974), that Korean Peninsula and the southern part of China had been located at the tropical area of Pangaea between the equator and about 10°N latitude. Won and Lee (1977) suggested, in the consideration of conodont fauna which were discovered from the Mungog Formation in Yeongwol area, Gangwon Province, that most of the species are similar to those which have been known from the sediments ranging from the upper Tremadocian to the lower Arenigian (early Ordovician) in Australia, North America, Iran and Europe.

According to the late Permian to late Jurassic plate tectonic interpretation for south-eastern China (McElhinny et al., 1981), Sino-Korean land mass had moved from about 5°N in latitude to north since the late Permian and sutured to Siberian Craton in late Jurassic. Jones et al. (1982) suggested that the present distribution of Tethyan fusulinids in eastern Siberia, New Zealand and in the western terranes of the Rocky Moutains provides strong evidence for large-scale tectonic dislocations of the crustal blocks formerly in the Tethyan region near the equator. The tectonic study of eastern China, Mongolia and Far East (Klimetz, 1983) indicated the collision of the South China block with a combined North China-Northeast China fold zone block in the late Triassic-early Jurassic, their collective suturing to Eurasia in the late Jurassic-early Cretaceous.

Lee (1984) suggested, from the comparison of the paleomagnetic results of Korea, China and Japan, that these areas had been on similar latitude since lower Cretaceous Period, but that there had been important and different rotations among these areas.

Conclusions

Total 577 oriented hand samples were collected to study the paleomagnetism of southern Korea since the Permian. Stepwise a.f. and thermal demagnetization experiments were undertaken. Sites from each formation showing relatively high level of intrasite and intersite consistency were chosen for this paleomagnetic study.

The paleolatitude obtained from the Gobangsan Formation distributed in the north of Danyang and south of Yeongchun (Permian) is 13.2°N±7.4°, and that obtained from the Bansong and the Lower Nampo Group distributed in and around Danyang and in the Chungnam Coalfield (lower Jurassic), respectively, is 25.1°N±7.6°. The paleolatitudes of the early and late Cretaceous obtained are 46.5°N±6.5° and 38.3°N±2.5°, respectively.

From the divergence values (ϕ), it is inferred that Korean land mass has moved north at the rate of 1.4~1.9cm/year.

The paleomagnetic directions expected on the paleopoles from the stable northern Eurasian continent are also calculated to compare with the observed paleomagnetic directions obtained from each formation studied. When comparing the observed directions with those of the expected, it is inferred that southern Korean land mass had experienced large latitudinal dislocation toward north and rotated about 70 degrees anticlockwise in late Jurassic. The observed declinations of the early Cretaceous (41.3°±11.0°) and late Cretaceous (28.3°±

6.8°) are significantly different from those of the expected early Cretaceous (15.9°±10.0°) and late Cretaceous (17.5°±8.1°). The relative declinations of the early Cretaceous (27.4°±14.9°) and late Cretaceous (10.8°±10.6°) reveal that Korean land mass rotated in two different times, probably in the late Cretaceous and in the Tertiary.

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페름紀 以後 韓國의 古地磁氣에 關한 研究

金光浩*·鄭鳳日**

요약 : 페름기 이후 한국의 고지자기를 연구하기 위하여 영춘면 남쪽 단양 북쪽의 고방산층, 녹암층, 반송층군 및 하부남포층군, 충남탄전 일대의 하부남포층군, 왜관—경산 및 대구—고령사이의 경산누층군, 제주도 및 전곡의 현무암으로부터 577개의 암석시료를 133개의 지점에서 채취하였다.

각 지점으로 부터 2~3개의 pilot specimen을 택하여 교류소자 실험과 열소자실험을 실시한 후 지질시대별 고지자기 방향을 구하였다.

페름기 이후 각 지질시대별 평균 고지자기 방향으로부터 apparent polar wandering path(APWP)를 구하였다. 본 연구로 부터 얻은 APWP는 쥬라기말에 큰 불연속을 보였다. 페름기이후 고지자기자료에 의하면 한반도는 페름기에 북위 13°±7°, 쥬라기초에 북위 25°±9°에 위치하고 있었으며 그후 계속 북쪽으로 이동하여 쥬라기말에 아시아 대륙과 충돌 하였고, 이때 반시계 방향으로 약 70° 회전한 것으로 해석 되었다.

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