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Does the Imjingang Fold Belt cross the mid-Korean Peninsula along the demilitarized zone (DMZ) as an extension of the Sulu Belt, China?

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ABSTRACT

Recent regional geological mapping data, coupled with structural, petrological and geochronological data on the so-called Imjingang Fold Belt (IFB) along the demilitarized zone (DMZ) in the central Korean Peninsula have revealed that: (1) the IFB does not extend eastwards across the NNE-trending Jookgaryeong fault, (2) ultrahigh pressure minerals such as coesite or diamond characterizing the Dabie-Sulu metamorphic rocks in east China have not been found from metamorphic rocks in the IFB, (3) Chemical Th-U-total Pb Isochron Method (CHIME), Sm-Nd and K-Ar age data show that the ca.250 Ma thermal event took place extensively in the Korean Peninsula and the event is not restricted to the IFB but is common in the Gyeonggi massif, Yongnam massif and Ogcheon belt, (4) the distribution of the Upper Devonian to Lower Carboniferous Imjin System is narrower than that has been thought, and much of the Imjin System should be substituted by the Middle Proterozoic Yeoncheon Group, (5) the Haeju-Wonsan fault (HWFT) is an important tectonic line, dividing the structural trend of the basement gneisses in the Korean Peninsula and the HWFT corresponds to the northern boundary of the IFB to the west of the Jookgaryeong fault, and (6) since the ductile shear zone in the Proterozoic Yeoncheon Group is restricted within the IFB, the IFB is better to be called the Imjingang shear zone.

The results of this study do not support the previous tectonic models that the IFB in the central Korean Peninsula is an eastern extension of the Quinling-Dabie-Sulu collisional belt in China. Thus, to better understand the tectonic evolution of East Asia, a re-examination of the IFB itself as well as other tectonic provinces in the Korean Peninsula is necessary.

INTRODUCTION

The Korean Peninsula is located as part of a continental interior between the North and South China blocks and the Japanese Island arc. Tectonic indications in the possible extension of the Chinese Sulu Belt into the Korean Peninsula have increased during last twenty years (Fig. 1). A possible provenance of the Hida terrane of Japan has been suggested to the Yeongnam massif in the southeastern part of the Korean Peninsula (Adachi and Suzuki, 1993; Suzuki and Adachi, 1994). Thus, the geology of Korea is important to understanding any tectonic link between China and Japan, as well as the tectonic evolution of East Asia.

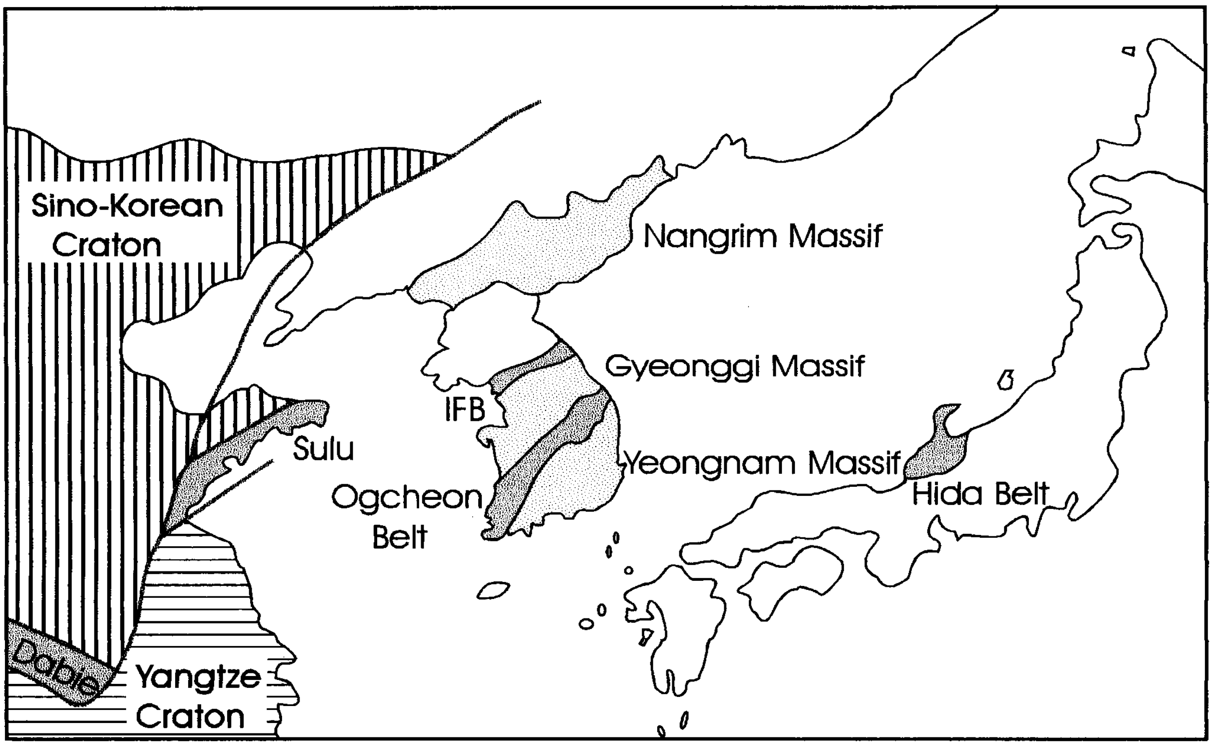

Fig. 1. Simplified geologic map of northeastern Asia. IFB: Imjingang Fold Belt.

The Imjingang Fold Belt (IFB, or Imjingang Belt), crossing the middle Korean Peninsula between the Precambrian Nangrim and Gyeonggi massifs, was first described by Ri et al. (1963) as an intracontinental mobile belt. The IFB consists of the Upper Proterozoic Sangweon Supergroup, the Lower Paleozoic Joseon Supergroup and the Middle Devonian – Lower Carboniferous Rimjin* System, according to the North Korean geologists (Ri, 1964; Ri and Ri, 1990, 1994; Paek and Ju, 1993, 1996).

Recently, the IFB has been suggested to be an eastward extension of the Quinling – Dabie – Sulu collisional belt of China (e.g. Yin and Nie, 1993, Ernst and Liou, 1995, Ree et al., 1996).

For example, Cho et al. (1995) suggested that some amphibolites from the IFB experienced a retrograde metamorphic pressure-temperature-time path from granulite to amphibolite facies at ca. 250 Ma, and that the IFB might be an extension of the Sulu Belt. Also, Ree et al. (1996) proposed that the IFB is an extension of the Chinese collisional belt based on a compilation of structural, metamorphic and geochronologic data from the southwestern part of the IFB. However, not much is known about the geology of the IFB mainly because the most part of the belt is in North Korea and the demilitarized zone (DMZ). Also, without any direct evidence of a collisional belt such as ultrahigh pressure minerals and rocks, it is still not clear whether the IFB is a real eastward extension of the Chinese collisional belt.

* Rimjin, romanization by North Korea; Imjin, romanization by International linguistic phonation standard.

The classical division of tectonic provinces in Korea is based mainly on geologic age of rock units without paying much attention to their structural patterns. With newly accumulating data on the tectonics of the Korean Peninsula, however, a revised tectonic division of the peninsula is needed. The aims of this paper are to define the IFB based on a new scheme of tectonic division and to establish the stratigraphy of the Yeoncheon Group within the IFB. I will also discuss problems with IFB as a collisional belt and suggest a new possible suture belt in the middle Korean Peninsula.

NEW TECTONIC SCHEME FOR THE KOREAN PENINSULA

The Korean Peninsula is composed of three Precambrian massifs; Nangrim, Gyeonggi and Yeongnam massifs (Fig. 1), and four Paleozoic basins; Pyeongnam, Duman, Hyesan-Iweon and Ogcheon basins of previously unknown age.

Considering the structural patterns and ages of regional metamorphism (250Ma), the three Precambrian massifs might constitute one geologic entity until the early Paleozoic (Adachi et al., 1996, 1997a, 1997b).

In the present new scheme of tectonic provinces, the Haeju-Weonsan fault (HWFT) striking ENE is suggested to be an important tectonic line, dividing the structural trend of the Korean Peninsula into two (Fig. 2). The Jookgaryeong (Koto, 1903) fault striking NNE is also suggested to be another important tectonic boundary in the Korean Peninsula, having been activated intermittently since the Proterozoic.

The Ogcheon metasedimentary rocks have long been age-unknown, but are now defined to be around upper Devonian, strictly speaking post-ca. 370 Ma (Adachi et al., 1996). Therefore, these rocks are equivalent to the Imjin sediments developed along the western part of the HWFT. I describe characteristics of the Jookgaryeong and Haeju – Weonsan faults below.

(1) Jookgaryeong fault belt

Nearly all the major faults of the Korean Peninsula have been active intermittently, undergoing movements during several different geological ages since the Paleozoic. Among those faults, three Paleozoic fault belts, the Chugaryeong (Chwae et al., 1996) and Yeseonggang (Chwae et al., 1997) faults, the Ogdong-Haenam peninsula fault (Choi et al., 1992), and the HWFT were recognized as playing leading roles in the tectonic formulation of the Korean Peninsula since Paleozoic times.

The Chugaryeong fault belt (Chwae et al., 1995) originates in the Jookgaryeong trough (Koto 1903), and extends from Weonsan-man through Pyeonggang-Yeoncheon to the Seoul district (Fig. 3). Kobayashi (1953) called the Jookgaryeong the Chugaryeong. Takahashi (1962) named it the Weonsan-Seoul rift. On the other hand, Tateiwa (1976) reported that the Chugaryeong lineament extends from the northeastern coast of the Korean Peninsula, at Gilju-Myeongcheon, to the middle southwestern coastal area of the Korean Peninsula, Chungcheongnam-do. He thought that the lineament might extend

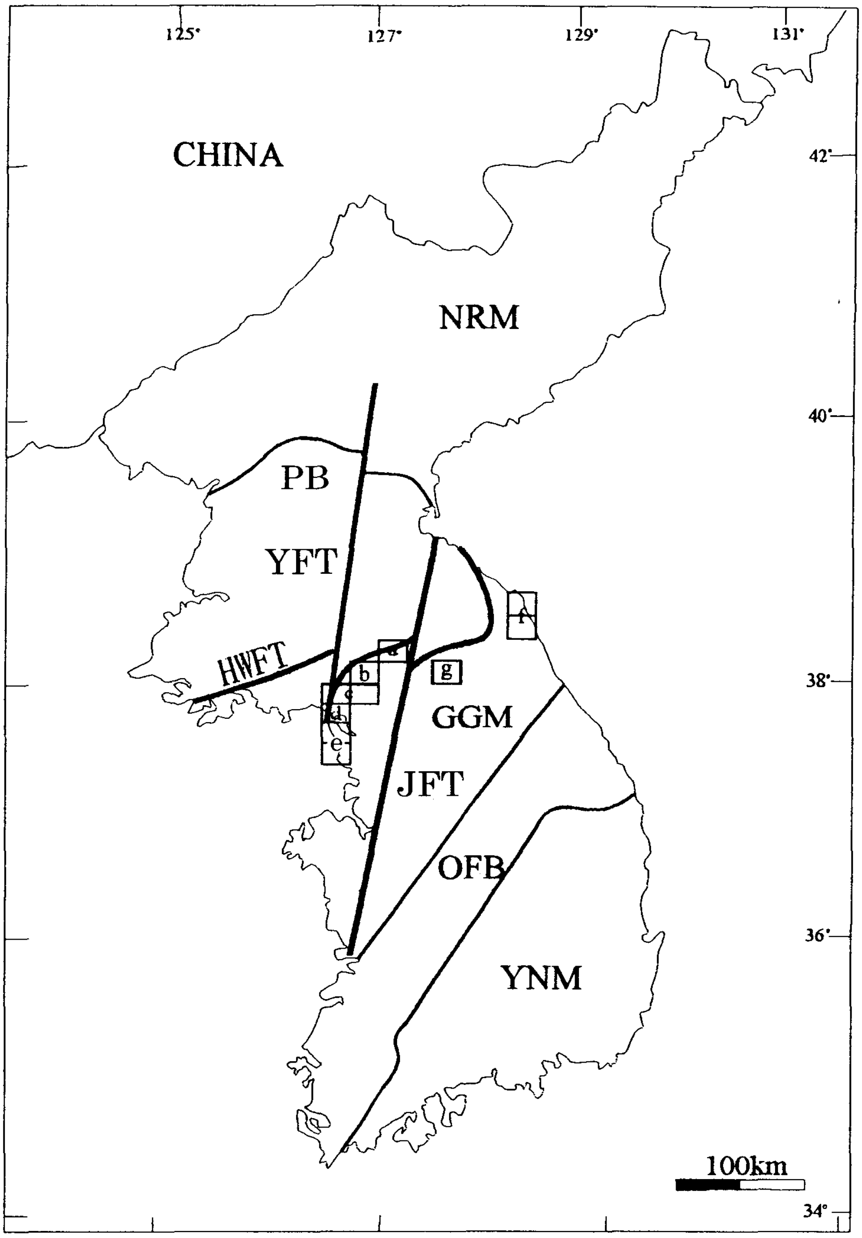

Fig. 2. Tectonic province map of the Korean Peninsula (modified after Ri and Ri, 1994). NRM: Nangrim Massif, PB: Pyeongnam Basin, GGM: Gyeonggi Massif, OFB: Ogcheon Fold Belt, YNM: Yeongnam Massif, HWFT: Haeju-Weonsan Fault, JFT: Jookgaryeong Fault, YFT: Yeseonggang Fault. a: Cheolweon, b: Majeonri, c: Munsan, d: Tongjin, e: Gimpo-Incheon, f: Goseong-Ganseon, g: Hwacheon.

further to the north. Toziro (1956) pointed out that the Weonsan-man is composed of oceanic crust. Lee et al. (1983) suggested the Weonsan-man may be a failed aulacogen, which lost one-third eastern block. Kim et al. (1984) suggested that the Chugaryeong lineament is a locus of strike-slip movement, extending from Sikhote-Alin. Kang (1984) and Kang et al. (1985) called the lineament the Chukgaryeong fault set. Weon (1983) described the lineament as a rift valley rather than as a trough. However, Lee and Lee (1991) refuted the continental rift interpretation using gravity bouger anomaly data. Lee and

Fig. 3. Satellite image of the Jookgaryeong fault striking N15°E. The Jookgaryeong fault is composed of several NNE faults and formed Mesozoic basins. WS: Weonsan, SEL: Seoul.

Lee (1995) divided the lineament into three segments and inferred the lineament to be the active fault. Kim and Song (1995), Song and Kim (1996) and Kim et al. (1997) reported that the lineament was formed around 83Ma and used palaeomagnetic data to infer that the rift valley was transferred by tensile stress to the southwestern coastal area of the Korean Peninsula. Kim et al. (1997) reported that Cretaceous volcanics of the southern part of the rift valley have been rotated 40 degrees anticlockwise.

After Koto Bunjiro's (1903) given-name, Jookgaryeong, it is suggested that the "Jookgaryeong fault" rather than the Chugaryeong fault or rift valley seems more reasonable within geological sense. The Jookgaryeong fault crosses the Korean Peninsula with a trend of N10°–15°E (Chwae et al., 1996). The Yeseonggang fault (Chwae et al., 1997) is parallel to and is west of the Jookgaryeong fault. The EW separation of these two faults is about 70 km. According to aeromagnetic data for southeast Asia, the Jookgaryeong fault belt is inferred to extend to Taiwan (data of CCOP). The HWFT is offset by the Jookgaryeong and Yeseonggang faults with right-lateral movements.

The Jookgaryeong and Yeseonggang faults characteristically displace sediments of nearly all geological ages from Middle Proterozoic to Quaternary. The initiation age of the Jookgaryeong fault is interpreted to have been during the Proterozoic for the reason explained below. The activity of Jookgaryeong fault is believed to have continued intermittently from the Proterozoic through the Triassic to the Quaternary together with the Yeseonggang fault.

If it is considered that the middle Proterozoic Yeoncheon Group (Chwae et al., 1995, 1996) no longer extends eastward across the Jookgaryeong fault, and that the trend of the regional structure in the western side of the Jookgaryeong fault is EW while that in the eastern side of the fault is NNE, the initial movement of the Jookgaryeong fault containing Quaternary basalts probably did not occur in the Cenozoic. The age of regional metamorphism of the Majeonri area is Permo-Triassic (Ree et al., 1996). Similar Permo-Triassic regional metamorphism and the widespread ductile reverse shearing (top-up-to-the-south) are also reported in the Cheolweon area, which is in the western side of the Jookgaryeong fault (Chwae et al., 1996; Cho et al., 1996). To the east of the Jookgaryeong fault, in the Hwacheon area, the metamorphic age of basement gneiss is around the Permo-Triassic (Cho et al., 1996). Here, the trend of regional foliation is NS or NE in the Hwacheon area, compared to E-W trend in the west side of the Jookgaryeong fault. Therefore, the initial movement along the Jookgaryeong fault should have occurred, prior to the Permo-Triassic metamorphism and the S-directed reverse ductile shearing.

The Jeongog sedimentary basin developed during late Triassic to early Jurassic due to the reactivation of the Jookgaryeong fault with a dextral strike-slip movement. The Cretaceous Cheolweon basin formed due to later sinistral strike-slip movement of the Jookgaryeong fault. The Quaternary Pyeonggang basalt flowed along the Jookgaryeong fault.

These episodes of the fault activity reveal that the Jookgaryeong fault is not simply the Cenozoic trough or rift but a crustal-scale fault, of which activity has intermittently continued from the Paleozoic through the Mesozoic to the Quaternary. It is also possible that the Jookgaryeong fault has been active since the last basalt erupted at 0.27 Ma (Choi, 1982).

(2) Haeju-Weonsan Fault (HWFT)

The Upper Proterozoic Sangweon Group-south type based on the Baekryeong-do (Island) is composed of quartzofeldspathic schist, quartzite, calc schist and metapsammitic to metapelitic rocks. The Gyeonggi massif, having southern contact with the Sangweon-south type, is generally composed of gneiss and schist and has the Lower to Middle Proterozoic CHIME ages. The Upper Devonian to Lower Carboniferous Imgin Group is developed along the boundary between the Sangweon Group-south type and the Gyeonggi massif in the west of the Jookgaryeong fault.

The trend of the regional structure of the northern Korean Peninsula to the north of the northern boundary of the IFB is quite different from that of the southern Korean Peninsula. The northern Korean Peninsula has an EW trend of the regional structure while the southern Korean Peninsula tends to have a NE trend (Fig. 4). Thus the northern boundary of the IFB, trending ENE from Haeju (west coast) to Weonsan (east coast), is the most important structural discontinuity in the Korean Peninsula. This major discontinuity is newly named as the Haeju–Weonsan fault (HWFT, Figs. 2 and 4).

DESCRIPTION OF GEOLOGY

The study area is divided into three districts, western, east-central, and north-eastern coastal districts. The western district includes Incheon, Gimpo, Tongjin, Gaesung, Munsan, Majeonri and Cheolweon areas (Fig. 2). The eastern-central district is the Hwacheon area and the eastern coastal district is the Goseong and Ganseong area.

THE WESTERN DISTRICT

Gimpo-Incheon area

The rocks of the area are mainly basement rocks of the Gyeonggi gneiss complex that consist of banded gneiss, biotite schists and intercalated quartzites and/or limestone lenses. These schists are on top of the basement with a possible Proterozoic unconformity. The regional foliation has a superposed folding pattern with a low-angle dip. Cretaceous volcanic rocks such as andesite and rhyolite and their pyroclastic equivalents are observed around the coastal area. The general trend of mineral/elongation lineation is mostly EW although the lineation was locally rotated to NS.

Tongjin area

The area is underlain by banded gneiss, biotite schist, intercalated with several quartzite and limestone layers, quartzofeldspathic schist (Fig. 5a),

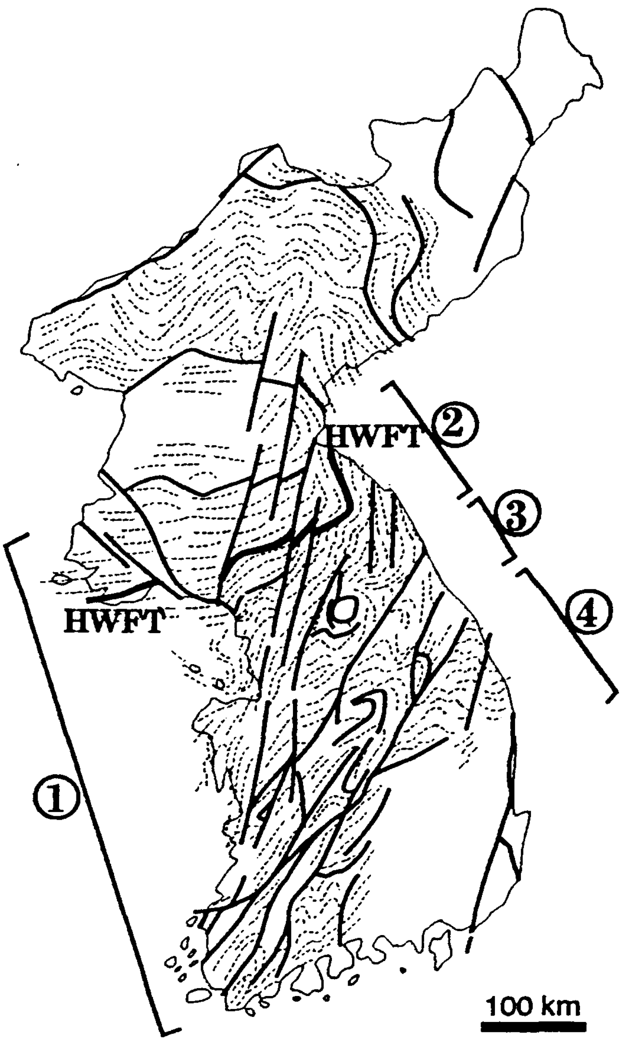

Fig. 4. Form-line pattern of foliation in the Korean Peninsula. HWFT: Haeju-Weonsan fault. ① the area to the west of the Jookgaryeong fault, ② the area between the Jookgaryeong fault and the NW border of the Ogcheon Fold Belt, ③ the Ogcheon Fold Belt, ④ the SW of the Ogcheon Fold Belt.

porphyroblastic granite gneiss, diorite, together with Mesozoic sediments and Jurassic granite.

Regional structures show remarkably striking patterns which can be divided into two parts. The northern half of the Tongjin area has NS-striking foliation (Fig. 5b) and north-plunging mineral/elongation lineation (Fig. 6d). In contrast, the southern half shows EW-striking foliation. The boundary between the two halves is probably the southern limit of the IFB. From the cross sections of NS and EW directions, it can be seen that EW foliation is earlier than NS foliation (Fig. 7).

The middle (?) – late Triassic to early Jurassic sedimentary basin formed along the NNE faults, the Yeseonggang fault. The depo-center of the Mesozoic basin has migrated southward, producing the Cretaceous sedimentary basin; the shape of basin is rectangular with a NS trend.

Munsan-Gaesung area

The boundary between the Yeoncheon Group and the Gyeonggi gneiss complex to the south is a fault in the Munsan-Gaesung area. The complex is composed of banded gneiss, biotite gneiss, porphyroblastic gneiss (Fig. 5c), quartzofeldspathic schist, quartzite (Fig. 5e), marble and syenitic gneiss. Garnet occurs locally in the syentitic gneiss. A ductile shear zone with ENE trend passes through the syenitic gneiss body and the intrusion age of the syenite should be older than the regional deformation age (ca. 250 Ma) in this area. The apparent metamorphic age of the syenitic gneiss by Rb/Sr dating is 750 to 800 Ma.

Within the ductile shear zone, small-scale Upper Triassic to Lower Jurassic sedimentary basins are locally developed. The sedimentary rocks do not show any evidence of ductile shearing. Therefore, the ductile shearing should pre-date the basins, and possibly activated around ca. 250 Ma.

Mylonitic foliation within the shear zone strikes EW and dips north with a north-dipping mineral/elongation lineation. On the other hand, the gneiss complex in the central Munsan area shows a variable orientation of regional foliation due to multiple folding events earlier than the shear zone development although the mineral/elongation lineation tends to plunge north.

Cheolweon-Majeonri area

The area is the type locality of the Proterozoic Yeoncheon Group (Chwae et al., 1996), which is about 30 km wide when measured in an N-S sense. The group consists of the Misan, Daegwangri and Cheondeogsan Formations in ascending order (Chwae et al., 1996).

The rocks of the Yeoncheon Group are generally of two distinct types. The lower part is composed mainly of quartzofeldspathic schist, quartz-mica schist, quartzite, banded dolomite, calc-silicate (Fig. 6a) and amphibole schist of basaltic origin (Kwon et al., 1995). The upper Yeoncheon Group is more pelitic compared to the lower part. It is composed mainly of sillimanite-kyanite-garnet-bearing biotite schist (Fig. 6b), with alternating metapsammites (Fig. 5e) and metapelites, and some marble lenses.

In the Daegwangri Formation, the upper middle part of the Yeoncheon Group, metamorphic minerals such as sillimanite, kyanite and garnet have been described (Yamaguchi, 1951; Cho et al., 1995; Chwae et al., 1996). The garnets are observed throughout the Yeoncheon Group (Fig. 6c). At the northern border of the Yeoncheon Group, the biotite schist of the upper Proterozoic Sangweon Group-south type has an EW fault contact with the Yeoncheon Group. The fault shows an oblique shear sense (reverse and dextral).

The regional foliation of the rocks strikes E-ENE and dips to north with a moderate angle. The mineral/elongation lineation on the foliation surface consistently plunges NNW. Earlier asymmetric fabrics with a reverse shear sense (Figs. 6b and 6c) are overprinted by later fabrics with a normal shear sense. Shear zones striking E-W occur along the Daegwangri and Cheondeogsan Formations.

In the NS cross-section through the Yeoncheon Group (Fig. 8), there are two

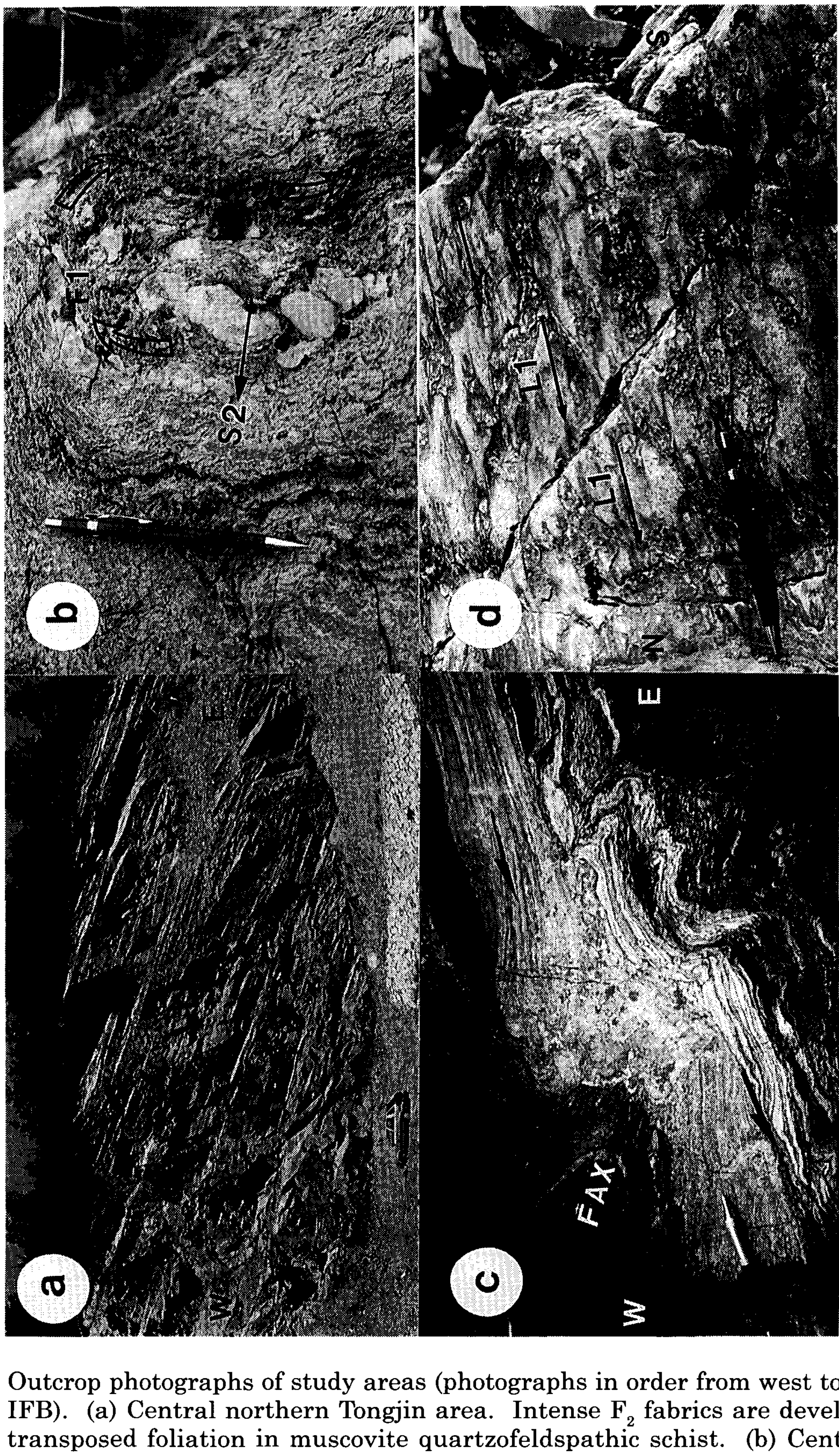

Fig. 5-1. Outcrop photographs of study areas (photographs in order from west to east along IFB). (a) Central northern Tongjin area. Intense F_2 fabrics are developed along transposed foliation in muscovite quartzofeldspathic schist. (b) Central part of Tongjin area. Strongly sheared biotite gneiss shows F_1 fold and late crenulation cleavage. Pegmatite boudins have sigmoidal shape. (c) Central western Munsan area. Amphibole-biotite gneiss shows F_2 plunging west. The fold vergence indicates a top-down-to-the west sense of shear. FAX: fold axis. (d) Northern central Munsan area. North dipping quartzite with mineral/elongation lineation (L_1).

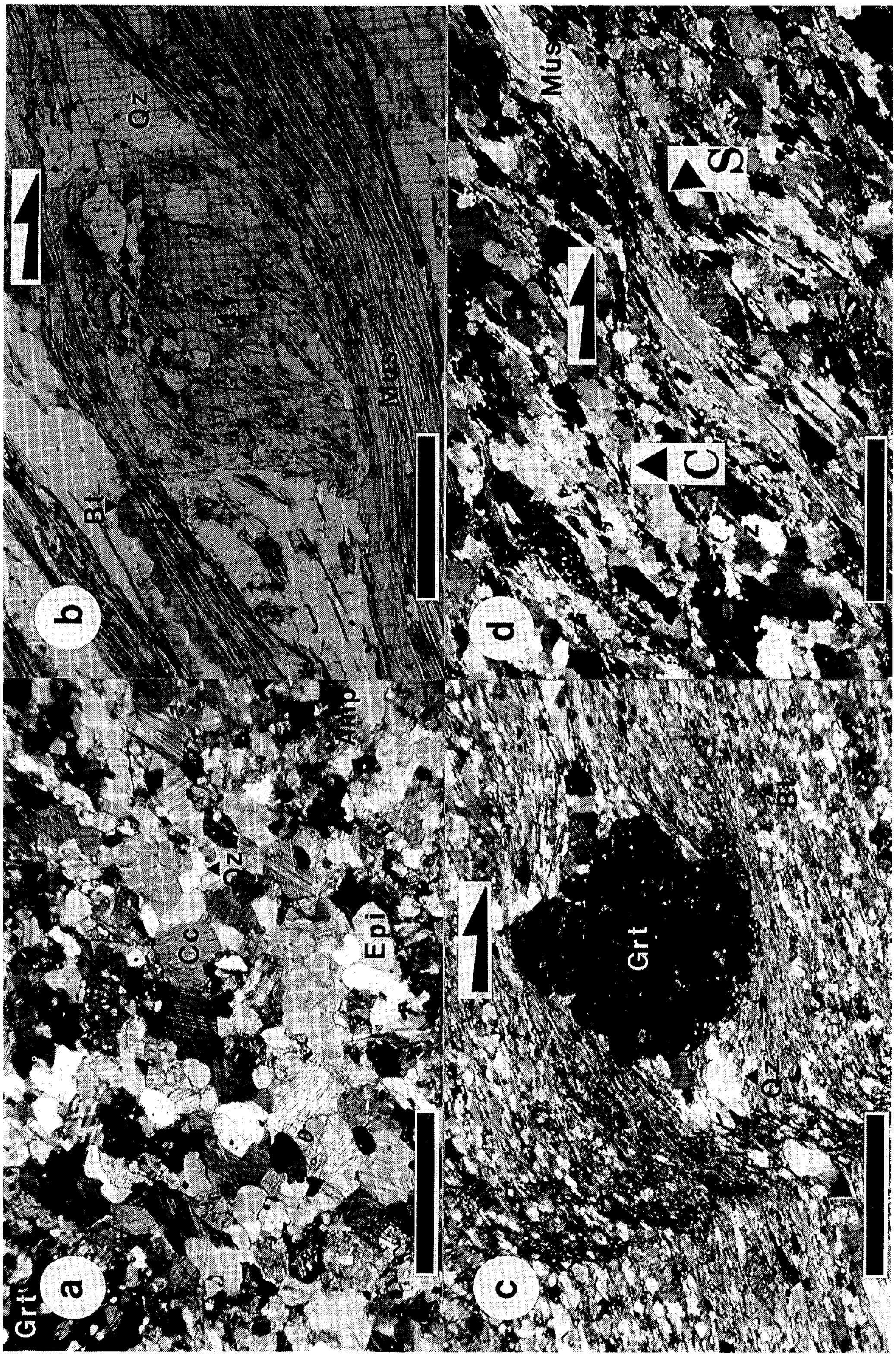

Fig. 6-1. Photomicrographs of metamorphic rocks from the Gyeonggi massif. (a) Metamorphosed limestone (Misan Formation). (b) Sillimanite-kyanite-garnet-biotite schist (Daegwangri Formation). (c) Garnet-bearing phyllite (Cheondeogsan Formation) from in the Yeoncheon Group. (d) Quartzofeldspathic schist (Tongjin area). Scale bar = 1 mm.

Fig. 6-2. (e) Banded gneiss (Hwacheon area). (f) Sillimanite-biotite schist (Hwacheon area). (g) Banded sillimanite-biotite gneiss (Ganseong area). (h) Porphyroclastic granite gneiss (Ganseong area) from the basement Gyeonggi gneiss complex. Note that top-up-to-the south reverse shear sense is observed in b, c, d and h. Scale bar = 1 mm. Cross-polarized light except b and g. Bt: biotite, Cc: calcite, Crd: cordierite, Epi: epidote, Grt: garnet, Ky: kyanite, Mus: muscovite, Pl: plagioclase, Qz: quartz, Sil: sillimanite.

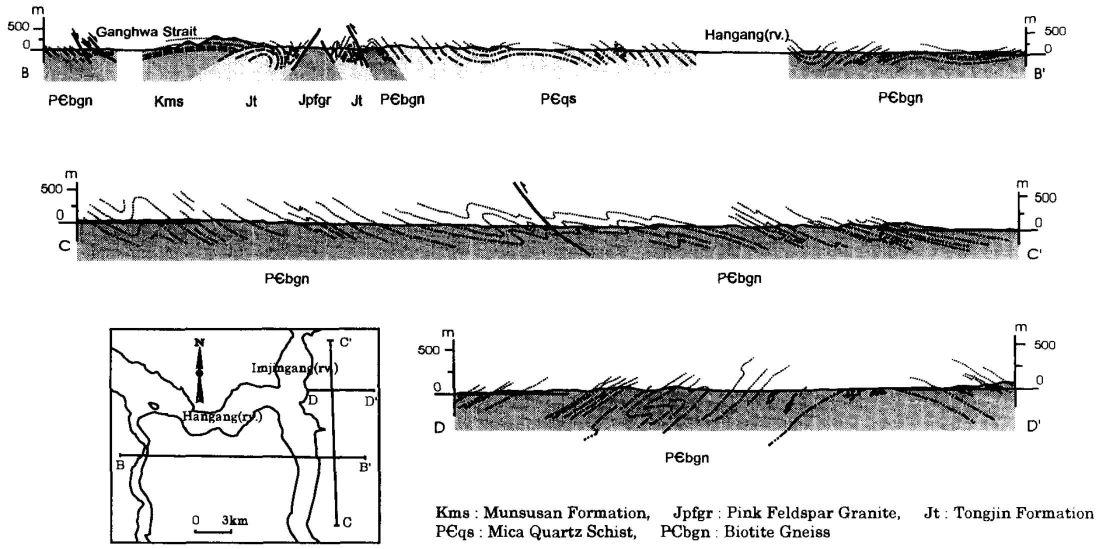

Fig. 7. Schematic cross-section through the Tongjin area. South-vergent structures (section C-C') are older than east-vergent structures (sections B-B' and D-D').

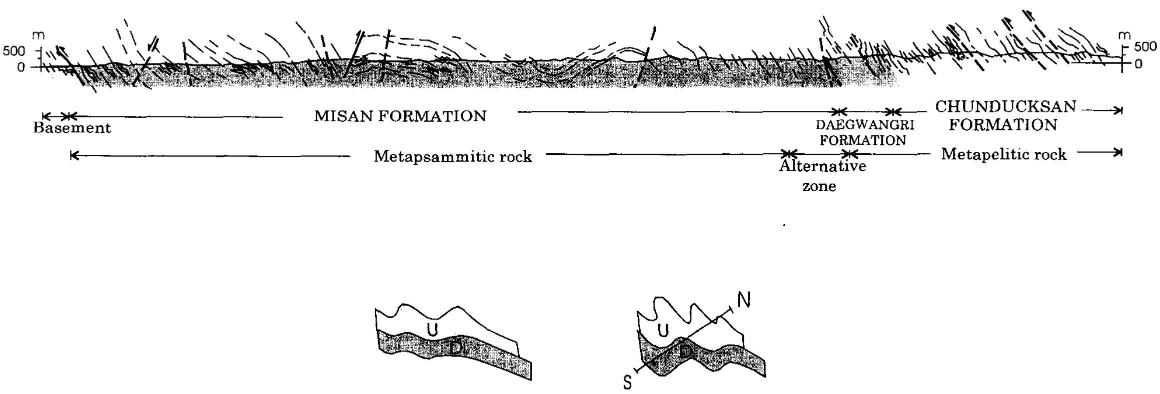

Fig. 8. Schematic cross-section across the Yeoncheon Group. (right side: north, left side: south). Lower psammitic part (Misan Formation) shows regional open fold patterns while upper pelitic part (Daegwangri and Cheondeogsan Formations) shows steep isoclinal folds. Cartoon below illustrates that the upper pelitic part (U) was more highly deformed than the lower psammitic part (L).

distinguishable geometrical patterns. The northern part of the Yeoncheon Group shows a steep isoclinal fold pattern. In contrast, the southern part shows an open fold pattern with a gentle dip of foliation. This difference is due to a ductility contrast between dominantly pelitic rocks to the north (more ductile) and dominantly psammitic rocks to the south (less ductile), and faults between pelitic and psammitic rocks.

The amphibole schist of a basaltic origin intruding the Yeoncheon Group has yielded a Sm/Nd age of about 824 ± 143 Ma (Ree et al., 1996). Therefore, the sedimentation of the Yeoncheon Group must have been earlier than the Upper Proterozoic, possibly as early as the Middle Proterozoic.

EASTERN CENTRAL DISTRICT (HWACHEON AREA)

The Hwacheon area is underlain mainly by Proterozoic (?) gneiss and schist with Jurassic and Cretaceous intrusives. The Proterozoic gneiss complex is divided into migmatitic biotite gneiss, banded gneiss (Fig. 6e) and sillimanite-biotite schist (Fig. 5f) with gradational and/or fault-contact with each other. While gneiss has gradational boundaries with each other, the boundary between gneiss and schist is a NS-striking thrust with a north-dip. The schist on the east of NS thrust is intercalated with quartzofeldspathic schist, quartzite, phyllite and amphibole schist. The regional foliation of schist strikes NS or NE and dips east with a low angle, compared to steep dip of gneiss (Fig. 5f). Accessory minerals of the schist include sillimanite, garnet, monazite and zircon.

The ortho-amphibolite intruded the gneiss complex. Amplibolites occur as small dikes, and are accompanied by garnet-bearing parts. The ortho-amphibolite shows simplectite of plagioclase + hornblende + ilmenite (Lee et al., 1996). The garnet-bearing granite gneiss is regarded as a latest Proterozoic intrusive. Characteristic garnets occur with a size of up to 5 cm. Lee et al. (1996) and Lee et al. (1996) reported that the granite gneiss with orthopyroxene underwent a granulite-facies metamorphism. These rock types mentioned above are widely distributed in the eastern central Gyeonggi massif.

Jurassic intrusive rocks include alkali gabbro, calc-alkaline porphyritic granite, two-mica granite and garnet-bearing two-mica granite. The Jurassic intrusive rocks are part of a series of batholiths, trending NNE-SSW in the middle Korean Peninsula. Cretaceous aplite has a sigmoidal pattern.

EASTERN COASTAL DISTRICT (GOSEONG-GANSEONG AREA)

The north-eastern coastal area is underlain by Proterozoic (?) gneisses, in which regional foliation and several shear zones trend NS. Jurassic granites also occur in the area. The gneisses include banded cordierite-sillimanite-biotite gneiss (Fig. 6g), biotite quartzofeldspathic gneiss, porphyroclastic granite gneiss (Figs. 5h, 6h) and garnet-bearing granite gneiss (Fig. 5g). The garnet-bearing granite gneiss of the area is widespread in the eastern-central Gyeonggi massif, through Yanggu to eastern Hwacheon, with a NNE to NE trend of regional foliation.

Although the garnet-bearing granite gneiss has many xenoliths of paragneiss along the eastern boundary, the relationship between the paragneiss and orthogneisses is still unclear. Jurassic granites of the area extend to south-western tip of the Korean Peninsula, mostly along the boundary between the Gyeonggi massif and the Ogcheon belt, so that the nature of the boundary between the two tectonic provinces is unclear.

Table 1. Stratigraphic sequences of the study area.

	Gimpo-Incheon	Tongjin	Munsan-Gaesung	Cheolweon-Majeonri	Hwacheon	Gosung-Ganseong
Q			Basalt			Basalt
T				Quartz-porphyry		
K	Tuff Rhyolite	Tuff Andesite Munsusan-Formation		Tuff Rhyolite Mudstone Shale Megabreccia Andesite	Aplite	
Jr	Andesite Granite	Granite	Granite	Granite	Granite	Granite
Tr		Syenite Diorite Tongjin-Formation (coal seam)	Syenite			
Pal						
LPr			Syenite	Amphibole-schist (basalt origin)	Amphibolite	
MPr			Yeoncheon-Group	Yeoncheon-Group		
EPr	Quartzite Limestone Schist Paragneiss	Quartzite Limestone Schist Paragneiss	Schist Quartzite Limestone Paragneiss		Schist Quartzite Limestone Paragneiss	Paragneiss Orthogneiss

Abbreviation: **Q**, Quaternary; **T**, Tertiary; **K**, Cretaceous; **Jr**, Jurassic; **Tr**, Triassic; **Pal**, Paleozoic; **LPr**, Late Proterozoic; **MPr**, Middle Proterozoic; **EPr**, Early Proterozoic.

The stratigraphic sequences are correlated among the three districts above, the western, eastern-central, and eastern coastal areas in Table 1.

STRATIGRAPHY OF THE RIMJIN SYSTEM AND THE YEONCHEON GROUP

As a type locality of the Rimjin System, north Korean geologists described rock units from two districts; the Rimjin System in the eastern district and the Kangryong Group in the western district. The eastern district includes the Gaesung, Geumchun and Cheolweon areas along the Haeju-Weonsan fault (HWFT) with small-scale basins of EW trend (Fig. 9). The Proterozoic Yeoncheon Group (Chwae et al., 1996) has been regarded as the Rimjin System by north Korean geologists (Table 2). The Yeoncheon Group has already been named the

Table 2. Stratigraphic correlation of the Yeoncheon Group.

	D	S	O	C	LPr	MPr	EPr	Ar
Kawasaki, 1918								Yeoncheon S: crystalline-schist
Yamaguchi, 1951	Yeoncheon S ? Yeoncheon z Jingog z Heugseog z Samgot z							
North-Korean, 1996, 1996	Rimjin S Sannyong Sr Puap Sr Anhyop Sr							
Na, 1973, 1978					Yeoncheon Gr Yeoncheon S Chuncheon S			
Na and Kim, 1987					Yeoncheon Gr			
Cho et al., 1995						Samgot F		
Chwae et al., 1996						Yeoncheon Gr Chundeoksan F Daegwangri F Misan F		

Abbreviation: **D**, Devonian; **S**, Silurian; **O**, Ordovician; **C**, Cambrian; **Tr**, Triassic; **LPr**, Late Proterozonic; **MPr**, Middle Proterozoic; **EPr**, Early Proterozoic; **Ar**, Archean S, System; z, zone; Sr, Series; Gr, Group; F, Formation.

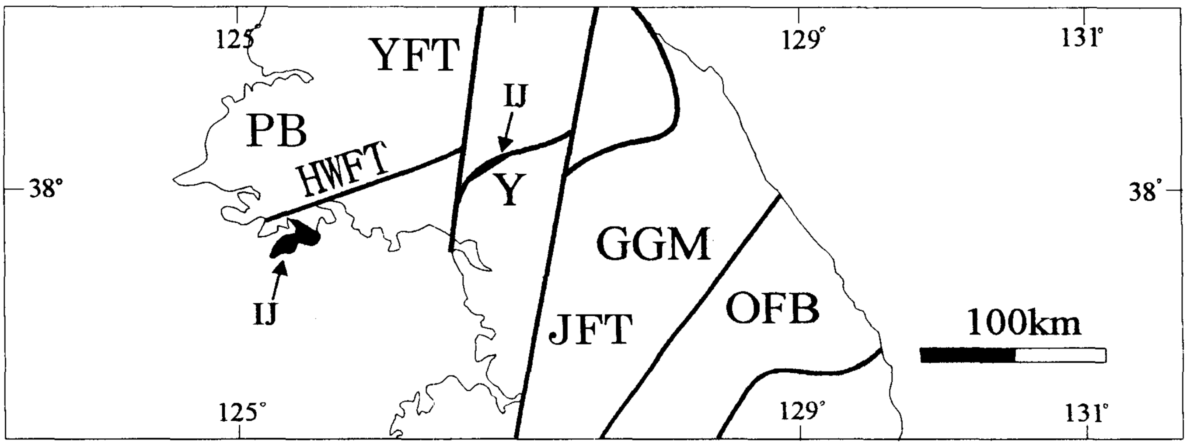

Fig. 9. Distribution map of the Yeoncheon Group and the Rimjin System. IJ: Imjin Group, Y: Yeoncheon Group, HWFT: Haeju-Weonsan Fault, JFT: Jookgaryeong Fault, YFT: Yeseonggang Fault, PB: Pyeongnam Basin, GGM: Gyeonggi Massif, OFB: Ogcheon Fold Belt.

Archean Yeoncheon System by Kawasaki (1918) and the Silurian to Devonian Yeoncheon System by Yamaguchi (1951).

Yamaguchi (1951) divided the Yeoncheon System into five metamorphic zones, from north to south, the Yeocheog, Jingog, Gyeho, Heugseog and Samgot zones without a stratigraphic meaning. From the misinterpreted uppermost part of the Sangwon System, Yamaguchi reported some Silurian fossils, *Monograptus* (Silurian graptolite) and *Cypridea* (Mesozoic ostracods), and wrongly thought that the Yeoncheon System might be the Silurian or Devonian because the Yeoncheon System lies on the Sangweon System.

North Korean geologists have divided the Rimjin System into three series; the Anhyeop, Puab and Sangnyeong series in ascending order. The Devonian fossils have been reported mostly from the Gaesung, Geumchun and Cheolwon areas. The fossil horizon indicates that the Rimjin System is developed along the HWFT with a narrow NS horizontal width of a few kilometers, much narrower than NS horizontal width of 30 km of the Yamaguchi's Yeoncheon System.

To define the stratigraphic sequence from the Yamaguchi's metamorphic units established in 1951, Chwae et al. (1996) have established the stratigraphic order and have divided the Yeoncheon Group into three formations; the Misan, Daegwangri and Cheondeogsan Formations in ascending order (Table 2).

To the east of the Jookgaryeong fault, neither the Rimjin System nor the Yeoncheon Group is distributed. The north Korean geologists have lost even the meaning of the Rimjin System in the area of the Yeoncheon Group (Chwae et al., 1996).

STRUCTURES OF THE YEONCHEON GROUP AND THE IMJINGANG SHEAR ZONE

There is a remarkable difference in lithology and regional structures between the Cheolweon and Majeonri areas. Two big faults have made the difference remarkable between the northern metapelitic belt of the Cheolweon area and the southern metapsammitic belt of the Majeonri area (Fig. 8). Isoclinal folds with high-angle dipping foliation and a pervasive ductile shearing with reverse shear sense are typical in the Cheolweon area for most metapelitic rocks. In outcrops, the relationship of the regional foliation and new shearing surfaces looks apparently as classical S1/S2 relationship (Fig. 10f).

Under the microscope for oriented thin sections, it is clear that s/c fabric shows a top-up-to-the-south (reverse) shear sense, and that the outcrop foliation surface is a shearing surface. The stretched mineral alignment has been rearranged to the dip direction of the foliation with an oblique shearing (dextral and reverse). The kink bands overprinted the reverse slip s/c fabric with a normal slip sense.

On the other hand, in the Majeonri area, the foliation of metapsammitic rocks has a lower angle of dip with a regional open fold pattern (Fig. 8). All the intrafolial minor fold axes consistently plunge north. The ductile shear sense is a top-down-to-the-north (normal slip), compared to the Cheolweon area. The sigmoidal, complex pattern of the intrafolial fold axial traces of crystalline limestone bed, having two decoupling bands inside, is a clear indicator of the top-down-to-the-north (normal) shear sense that overprinted the earlier reverse shear sense (Fig. 10c). During the late stage (possibly post-Cenomanian), all the NS faults including those in the Cheolweon basin had a series of sinistral displacements. The structural sequence is summarized in Table 3.

The Imjingang ductile shear zone with a NS horizontal width of 30–50 km occurs between the NNE Jookgaryeong fault and the Yeseonggang fault, which is parallel to the Jookgaryeong fault at about 70 km to the west of the Jookgaryeong fault (Fig. 9). The shear zone does not cross the mid-Korean Peninsula but occurs only locally with a rectangular shape. The Proterozoic Yeoncheon basin is about half of the Imjingang shear zone in size. The northern limit of the shear zone is equivalent to the paleo-ENE fault, HWFT. The southern limit is inferred to be along the Gokreungcheon stream in the Tongjin sheet through the Geumchun district to the Hwaecheon district immediately south of the Dongducheon district. The Imjingang shear zone experienced a Jurassic normal-shear movement after an intense Permo-Triassic reverse-shear activity.

Since the IFB does not cross the middle Korean Peninsula, the IFB has to be substituted by the Imjingang ductile shear zone, of which distribution is restricted to the west of the Jookgaryeong fault.

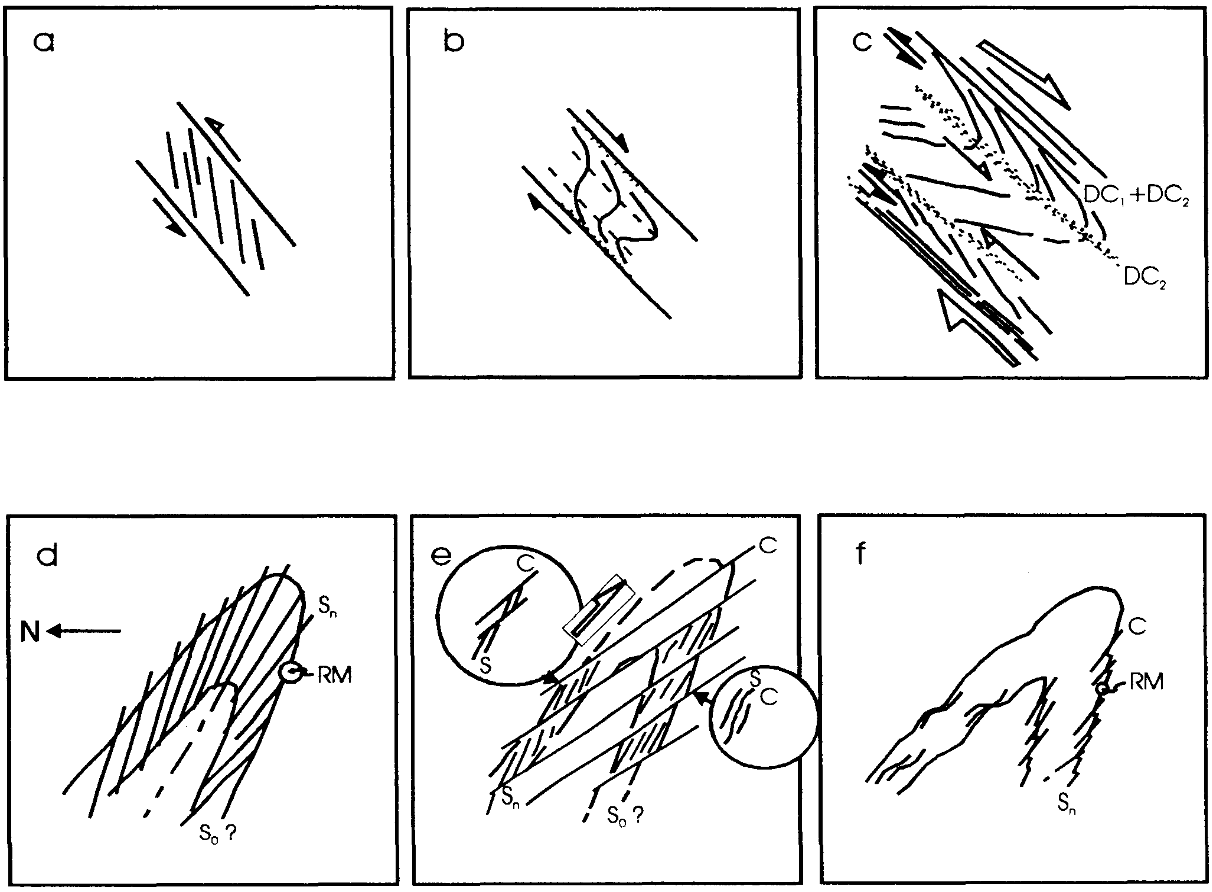

Fig. 10. Outcrop sketches of limestone bed (a, b, d and e), Misan Formation (c), and metapsammitic rock of the Cheondeogsan Formation (f). a-c: normal slip after reverse shear with two sets of decoupling bands (DC). d-f: reverse shear (C) cross-cutting cleavage (S1), RM: ripple mark.

Table 3. Structural sequences of the Yeoncheon Group.

Deformation Stage	Geologic Age	Events
D4	Quaternary	Basaltic flow along the Jookgaryeong fault (ca. 0.28 Ma)
	Tertiary ?	Jookgaryeong fault: right-lateral movement
	Cretaceous	Jookgaryeong fault: NS left lateral movement
		Formation of Cheolweon basin
		Volcanic activity
D3	Jurassic	Imjingang shear zone: normal sinistral (?) movement
		Jookgaryeong fault: NS right-lateral movement
D2	Triassic	Imjingang shear zone: deformation of Jeongok basin
		- EW reverse dextral movement
		- stretching mineral alignment
		Formation of Jeongok basin
		Regional metamorphism
D1	Paleozoic	Non-penetrative cleavage in psammitic rocks
		F1 fold, ML1
	Proterozoic	amphibole schist (basalt origin)
		Formation of Yeoncheon basin
		Formation of Jookgaryeong fault
		Haeju-Weonsan fault

THE FORM-LINE PATTERN

The form-line pattern of regional foliation could be one of the possible tools to divide an area concerned into several sub-areas. The form-line pattern of the Korean Peninsula has been gathered and reinterpreted from the published 225 geological maps (1:50,000) and surveillance mapping (Fig. 4).

The characteristics of the form-line pattern of the Korean Peninsula are as follows; (1) There are two fold axes of EW and NE trends in the northern Korean Peninsula (Fig. 4). (2) In the southern Korean Peninsula, it can be seen that NE trend is much stronger than EW trend. (3) EW trend is earlier than NE trend in the Korean Peninsula. The NE trend involves the Middle Triassic to Early Jurassic sedimentary rocks, so that the age of the NE form-line has to be the syn- to post-Early Jurassic. (4) The Korean Peninsula can be divided into two parts across the HWFT by the form-line pattern (Fig. 4). (5) In the southern part of the HWFT, the form-line pattern could be divided into four blocks; the west of the Jookgaryeong fault, the area between the Jookgaryeong fault and the NW border of the Ogcheon fold belt, the Ogcheon fold belt and the SW of the Ogcheon fold belt (Fig. 4). The upper limit of the age of faults between individual blocks has to be Permo-Triassic, before the age of the sedimentation in the Mesozoic basins. The HWFT and the Jookgaryeong fault are newly recognized as important division lines of tectonic provinces in the Korean Peninsula.

THE TRANSPORT DIRECTIONS OF THE EAST AND WEST OF JOOKGARYEONG FAULT

The Cheolweon area for the Proterozoic Yeoncheon Group, the Tongjin and Munsan areas for the Precambrian cover rocks and basement, and the Seosan area for the Early Proterozoic Seosan Group are chosen as typical areas within the Jookgaryeong fault belt (which means a wide belt between the Jookgaryeong and Yeseonggang faults).

The orientation of foliation and mineral/elongation lineation from the Jookgaryeong fault belt and the Ogcheon fold belt were compared to see each transport direction (Fig. 11). For the Ogcheon fold belt, the Goesan area of the Ogcheon Group and the Imgye area of the Choseon Supergroup were selected because they show a transport direction different from each other.

In the Cheolweon area, the foliation in metapelites and metapsammites of the middle Proterozoic Yeoncheon Group generally strikes ENE-WSW to WNW-ESE (mean strike E-W) and dips consistently N at moderate to steep angles (Figs. 11a, 12a, b). The mineral/elongation lineation, mainly defined by quartz and mica flakes, lies obliquely to the dip direction of the foliation, and plunges N to NW (Figs. 11a, 13a). Most of the kinematic criteria, including meso- and micro s/c fabric, and asymmetric pressure shadows around garnet and kyanite, indicate a SE-directed reverse-slip along the penetrative mineral lineation. The strike of the foliation progressively changes from N-S in the Munsan area (Figs. 11b, 12c, 13c) and the north area of Tongjin (Figs. 12d, 13d) to E-W in the south, and the foliation dips gently to morderately W or N (Figs. 11c, 12d, e). The mineral lineation is generally sub-horizontal and its N-S trend in the north area rotates toward E-W in the south (Figs. 11b, c, 13a, c, d). The change in orientation of foliation and lineation is due to a later NNW-SSE trending folding in the area.

The ductile shear zone occurs within the granite of early Proterozoic age in the Seosan area. The granite intruded the metasediments of the early Proterozoic Seosan Group. The shear zone generally strikes N-S and dips gently to moderately W, with a W-plunging stretching lineation (Fig. 11d). The structure is gently folded by later NNE-SSW trending folding. S/c fabric and porphyroclast systems of σ- and δ-type around feldspars in the mylonitic granite indicate consistently a top-up-to-the-east sense of shear.

In the Goesan area, the central part of the Ogcheon belt, a well developed NW-dipping regional foliation and a penetrative NW-plunging mineral stretching lineation are the dominant structures observed in the Ogcheon Group (Fig. 11e). The down-dip lineation and kinematic criteria indicate a top-up-to-the

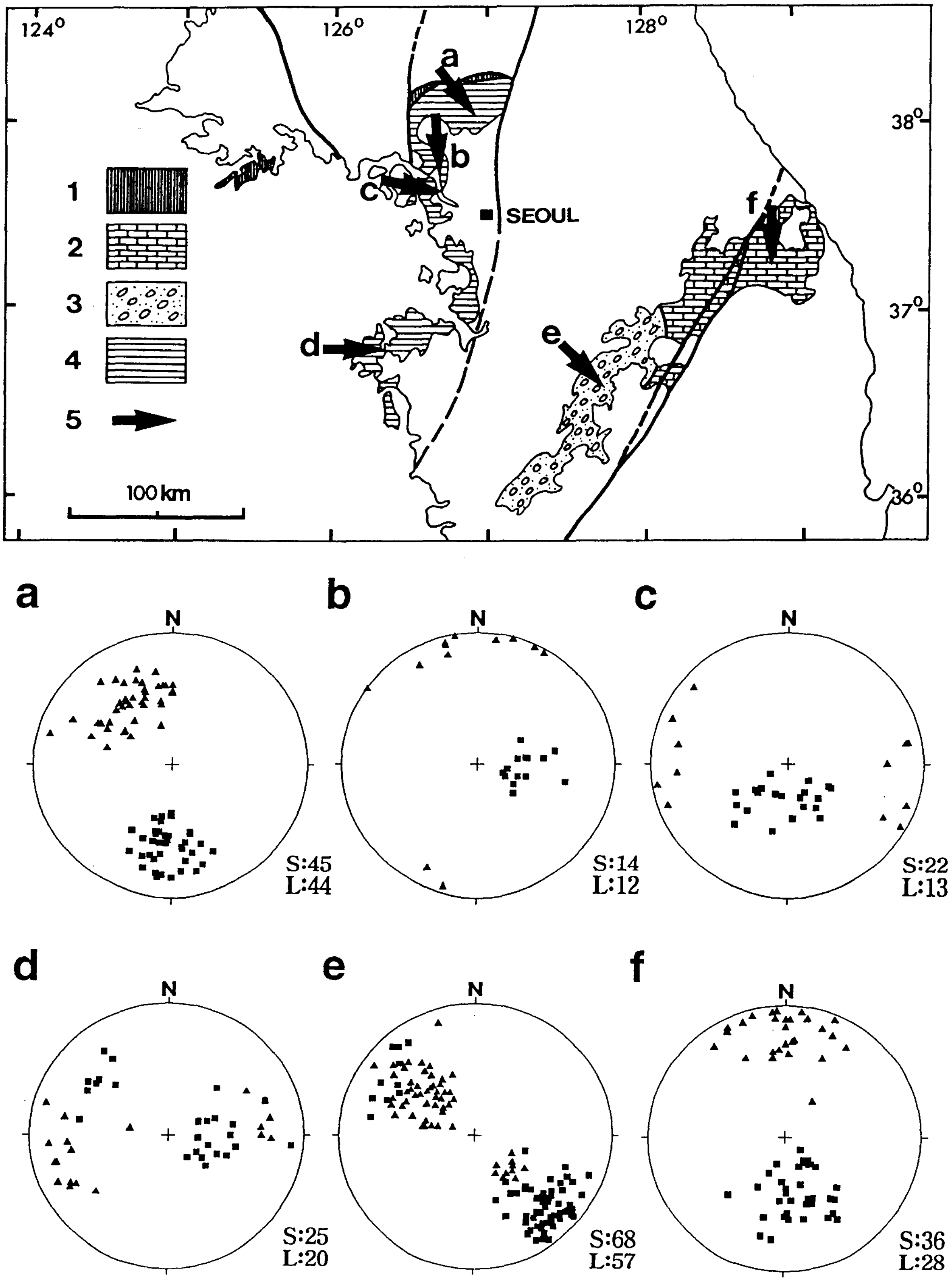

Fig. 11. Lower hemisphere equal-area projections of poles to foliation (S: squares) and mineral lineation (L: triangles) orientation in the Cheolweon (a), Tongjin (b & c), Seosan (d), Goesan (e) and Imgye (f) areas. Map shows the tectonic transport directions. 1. Imjin Group, 2. Joseon Supergroup, 3. Ogcheon Group, 4. Yeoncheon and Seosan Groups, and 5. Mean orientation of mineral lineation and sense of shear.

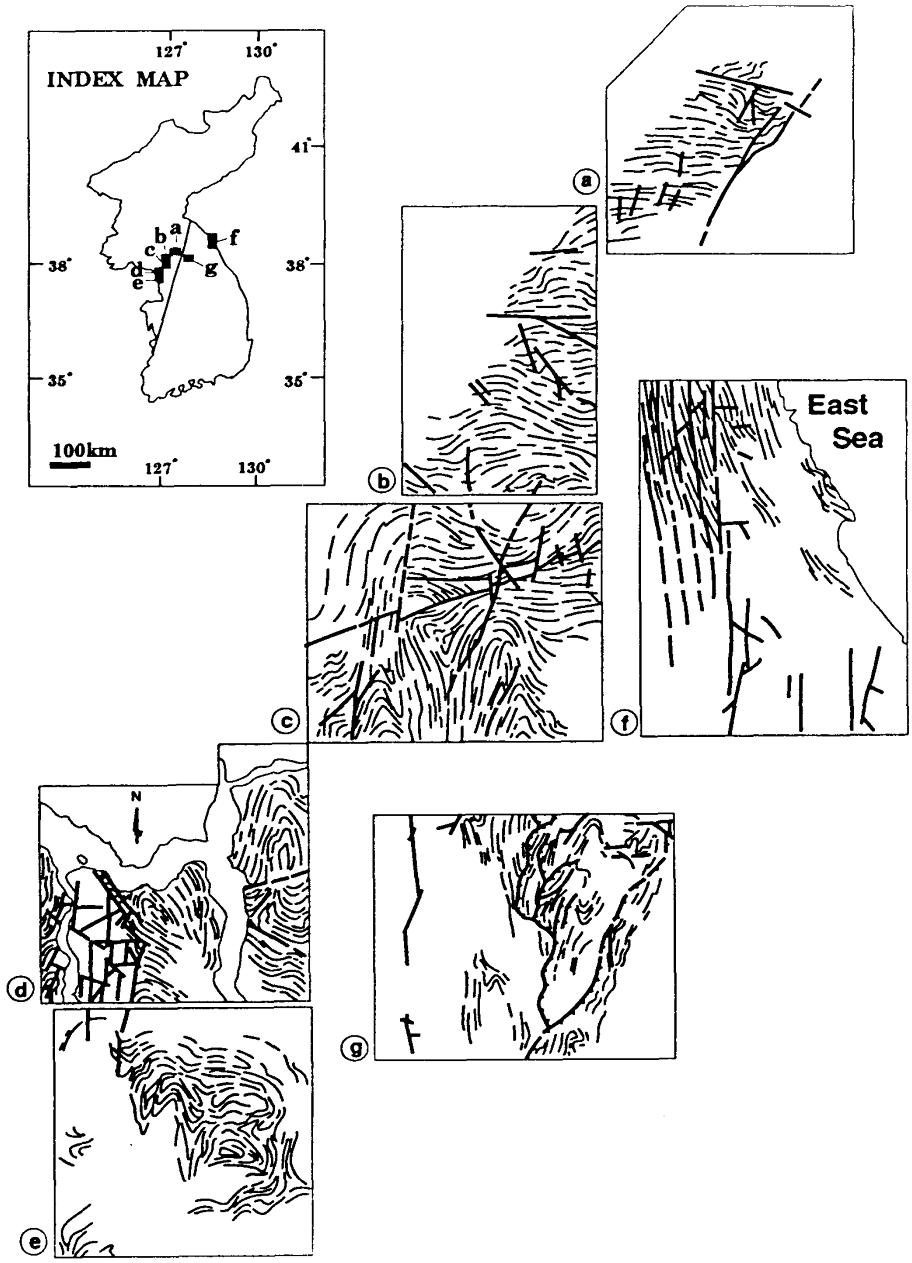

Fig. 12. Form-line pattern of foliation in the study areas. The foliation orientation progressively changes from E-W in Cheolweon-Majeonri through N-S in Munsan and northern Tongjin to E-W in southern Tongjin and Gimpo-Incheon. The N-S trend also occurs in Goseong-Ganseong. a-g: the same as in Fig. 2.

southeast transport.

A ductile shear zone found in the Imgye area, the northernmost part of the Ogcheon belt, occurs along the contact of the Precambrian Jungbongsan granite with the basal quartzite of the Cambro-Ordovician Joseon Supergroup. The zone itself acted as a detachment zone, in which the deformation is heterogeneous, involving mylonitic foliation striking E-W and dipping gently to moderately N with a nearly down-dip lineation trending NNE-SSW to NNW-SSE (Fig. 11f). Kinematic criteria such as s/c fabrics and feldspar porphyroclasts with

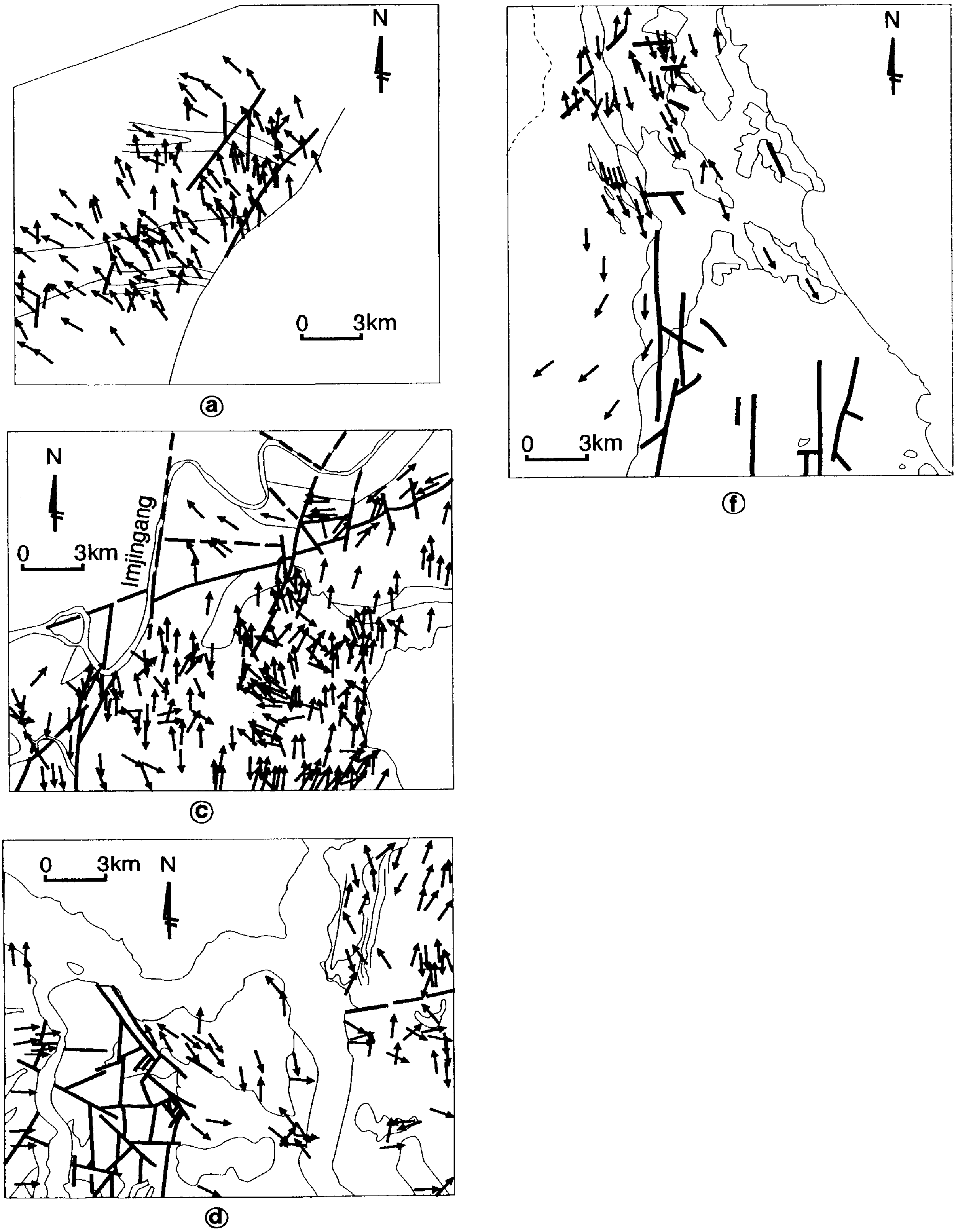

Fig. 13. Trend of mineral/elongation lineation of the study areas (a, c, d and f; see Fig. 2 for the location). Mineral lineation to the west of the Jookgaryeong fault plunges N to NW in the northern district but is orientated towards E-W in the southern district. In the east of the Jookgaryeong fault the lineation shows a northward trend.

asymmetric tails consistently indicate a top-up-to-the-south shear sense.

The transport directions have been rotated from NS to EW. This suggests that EW form-lines are earlier than NNE-NE trend in the Korean Peninsula. The Korean Peninsula can be divided into two provinces, the Nangrim and Gyeonggi massifs, prior to the upper Devonian.

REGIONAL METAMORPHISM

In the past, it has been believed that the Precambrian basement of Korean Peninsula is composed of Archean rocks. Due to a lack of age data on the basement of the Korean Peninsula, however, it has been uncertain how many geologic episodes were in the Archean.

Recently, from the southern middle part of eastern coastal area of the Korean Peninsula, the Proterozoic gneiss, the upper Paleozoic to early Mesozoic regional metamorphism and igneous activities have been reported (Suzuki and Adachi, 1994). Although Turek and Kim (1995) reported the Middle Proterozoic granite gneiss (2.1 Ga and 1.8 Ga) from the Jirisan gneiss complex of the Yeongnam massif with zircon data, the age of the regional metamorphisms was not certain.

A series of CHIME data using monazite, zircon and allanite from the Gyeonggi massif, the IFB, Ogcheon fold belt, and Yeongnam massif have been obtained for the age of regional metamorphisms in South Korea. The results are listed in Table 4.

The CHIME ages of gneiss protoliths from the Gyeonggi and Yeongnam massifs are between 1.4 Ga – 1.7 Ga and 1.9 Ga – 2.0 Ga (Adachi et al., 1997a, 1997b, Suzuki et al., 1997). The zircon ages by CHIME from the Jirisan gneiss complex are 1.96 Ga – 2.04 Ga, 1.65 Ga – 1.69 Ga and younger than 1.0 Ga (Suzuki et al., 1997). These reveal that the basement age of the Korean Peninsula has to be the post Middle Proterozoic rather than the Archean.

Considering that the age of the regional metamorphism of the Gyeonggi and Yeongnam massifs and Ogcheon fold belt is ca. 250 Ma, it is clear that the upper Permian to lower Triassic regional metamorphism gave an intense and widespread effect on the Korean Peninsula (Tables 4 and 5). This means that the regional metamorphism of ca. 250 Ma was not restricted to the IFB. In other words, this specific age of the regional metamorphism in the IFB cannot simply be used as evidence that the IFB is a collisional belt.

DISCUSSION AND CONCLUSIONS

The structural patterns and regional metamorphism of the Gyeonggi massif imply that it is unnecessary to separate the IFB from the Gyeonggi massif as a collisional suture belt. As a suture belt, the Sangweon Supergroup-south type located in the southern North Korea seems more likely to be a candidate rather than the IFB. The Sangweon Supergroup-south type retains a penetrative EW trend. The HWFT, the northern border of IFB, is the boundary between the

Table 4. CHIME ages of monazite, zircon and allanite of the Precambrian basement and Ogcheon metasediments, South Korea (① Suzuki and Adachi, 1994, ② Cho et al., 1996, ③ Adachi et al., 1996, ④ Adachi et al., 1997a, ⑤ Adachi et al., 1997b, ⑥ Suzuki et al., 1997, ⑦ Suzuki, personal communication, ⑧ Kim et al., 1997).

	Area	Rock types	Dating-mineral	Age (Ma)	Authors
Gyeonggi massif	Cheolweon	Garnet-staurolite-kyanite schist	monazite	255±8	②
	Hwacheon	Garnet-sillimanite gneiss	monazite	245±3	②
	Ganghwado	Banded biotite gneiss	zircon	ca. 2200-2000 (core) ca. 1600 (rim)	④
	Guri	Banded biotite gneiss	monazite	ca. 240	④
	Ganseong	Porphyroclastic granite gneiss	zircon monazite	ca. 1652 1676±66	⑦
		Garnet-bearing granite gneiss	monazite	ca. 1455	
		Quartzofeldspathic gneiss	monazite	ca. 1528	
Ogcheon fold beld	Chungju	Granite gneiss pebble in phyllite	monazite	373±37	③
		Muscovite-chlorite-quartz schist	allanite	250±10	
Yeongnam massif	Imweon	Leucocratic granite gneiss	monazite	1726±20	①
	Yulri	Sillimanite-biotite gneiss	monazite	1733±44 1729±84	⑤
	Namdae (Sobaegsan)	Biotite gneiss	monazite	1654±29	⑤
	Gongseong (Sangju)	Medium-grained biotite granite	monazite	251±3	⑧
	Jangsu	Amphibole-bearing biotite gneiss	zircon	1990±90 1940±100 1910±50 1690±120 1670±40 1650±210	⑥
			monazite	1540±30 253±4	
			allanite	250±5	
	Jirisan gneiss complex	Porphyroblastic granite gneiss	monazite	1660±10	⑥
		Porphyroblastic granite gneiss	zircon	1960±30	⑥
			monazite	1660±50	
		Leucocratic granite gneiss	zircon	1990±50	⑥
			monazite	1610±40	
		Garnet-cordierite-biotite gneiss	zircon	2020±40 2030±50 2040±110	⑥
			monazite	1670±50	

Table 5. K/Ar, Sm/Nd and Rb/Sr data for the Proterozoic rocks of Cheolweon (C), Tongjin (T), Gimpo-Incheon (I), Hwacheon (H) and Goseong-Gangseong (G) distiricts (① Chwae et al., 1995, 1996, 1997, ② Kwon et al., 1995, ③ Cho et al., 1995, ④ Tureck and Kim, 1995).

	Area	Rock type	Dating-method	Age (Ma)	Authors
Basement	C	Banded biotite gneiss	K/Ar bt	254±4	①
		Porphyroblastic biotite gneiss	K/Ar bt	252±2	
	T	Biotite gneiss	K/Ar bt	218±4	①
		Biotite gneiss	K/Ar bt	208±4	
		Migmatitic biotite gneiss	K/Ar bt	180±4	
		Quartzite	K/Ar mus	216±5	
		Granite gneiss	K/Ar bt	216±5	
	H	Garnet-bearing granite gneiss	U/Pb zr	1840	④
		Banded gneiss	U/Pb zr	2103	
	G	Biotite quartzofeldspathic gneiss	K/Ar bt	169	①
		Biotite granite gneiss	K/Ar bt	169	
Yeoncheon Group	C	Amphibolite	Sm/Nd pl-grt-hb	249±31	③
			Rb/Sr pl-grt-wr	221±31	②
Igneous rocks	C	Granodiorite	Rb/Sr wr	165	②
			Rb/Sr wr	202	
			K/Ar bt	228	①
			K/Ar Kfd	157	
	T	Syenite	K/Ar bt	193±4	①
		Pink feldspar granite	K/Ar bt	140±4	
	I	Biotite granite	K/Ar bt	162	①
	G	Hornblende biotite granite	K/Ar bt	167	①
		Rhyolite dike	K/Ar wr	68	
		Felsite dike	K/Ar wr	48	

Abbreviation: C, Cheolweon; T, Tongjin; H, Hwacheon; G, Ganseung; I, Incheon; bt, biotite; mus, muscovite; zr; zircon; pl, plagioclase; grt, garnet; hb, hornblende; wr, whole-rock; Kfd, Alkali-feldspar.

southern Upper Proterozoic Sangweon Supergroup and the Gyeonggi massif.

The Baegryeongdo Island, a western part of the southern Sangweon Supergroup, is critical to geological interpretations, particularly to interpretations of the extension of the Sulu suture belt of China. The island is underlain by mica schist, quartzofeldspathic schist, quartzite, phyllitic rocks, black shale to slate, dark gray metapsammite, Jurassic (?) granodiorite and Pliocene (?) basalt with peridotite nodules. The general attitude of the regional foliation shows an EW strike and north dip of low to moderate angle. The trend of mineral/elongation lineation is mostly NW to WNW. The foliation of low-grade schists dips north at a low angle. The black slate and metapsammite show a south dip of S_0 and north dip of S_1 and/or S_2. Any characteristic structure indicating a collisional belt is not observed over the entire island.

From a structural point of view, the IFB and Ogcheon fold belt cannot constitute the northeastern tip of the South China block (Fig. 14a) because two belts have different form-line patterns (Fig. 14b). Thus, the previous tectonic model (e.g. Yin and Nie, 1993) seems not appropriate.

Several geologically consistent suggestions for the orientation of the trace of the collisional suture from the Sulu Belt to the Korean Peninsula are as follows; (1) The fossil faunas of the northeastern block of the Ogcheon fold belt have been correlated with those of the North China block (Kobayashi, 1966a, b; Lee and Lee, 1986; Seo, 1989; Lee and Lee, 1990; Choi, 1992). (2) The Hida belt experienced the regional metamorphism of ca. 250 Ma and originated from the southeastern part of the Korean Peninsula (Suzuki and Adachi, 1991, 1994). The Hida belt rotated 47° clockwise, so that the reconstructed geographic location is around the northeastern sea of the Korean Peninsula (Hayashida and Torii, 1988). (3) The paleomagnetic data of the Carboniferous to Triassic Pyeongan Group of the Ogcheon fold belt indicate that the Pyeongan Group has been rotated 70°–90° clockwise (Lee et al., 1995, 1996, 1997). (4) The sedimentation age of the Ogcheon Group is post-370 Ma (Adachi et al., 1996). The regional metamorphism occurred at ca. 250 Ma (Adachi et al., 1996). (5) According to deep seismic data of the Yellow Sea for the oil drilling during last 20 years by KIGAM, it is convincing that the curved northern boundary of Kunsan basin might be the southern border of a possible extension of the Sulu Belt toward the Korean Peninsula (Fig. 15). (6) The IFB has lost its meaning as an extended collisional suture belt, as discussed in this paper.

Therefore, any extension of the Sulu Belt into the Korean Peninsula would not be connected to the IFB or the Sangweon Supergroup, but with structures around the southwestern part of the Korean Peninsula (Fig. 15).

The conclusions are as follows; (1) The most part of the Rimjin System, excluding the Kangryong Group, should be reduced to the Early to Middle Proterozoic Yeoncheon Group. The Yeoncheon Group was deposited within the Proterozoic Yeoncheon basin. (2) Neither the Rimjin System (Ri and Ri, 1963; Paek et al., 1993; Paek and Ju, 1993, 1996; Ri and Ri, 1994) nor the IFB (Ri, 1964, Ri and Ri, 1994; Cho et al., 1995; Ree et al., 1996) extends to the east of the Jookgaryeong fault in South Korea (Chwae et al., 1996). (3) The re-

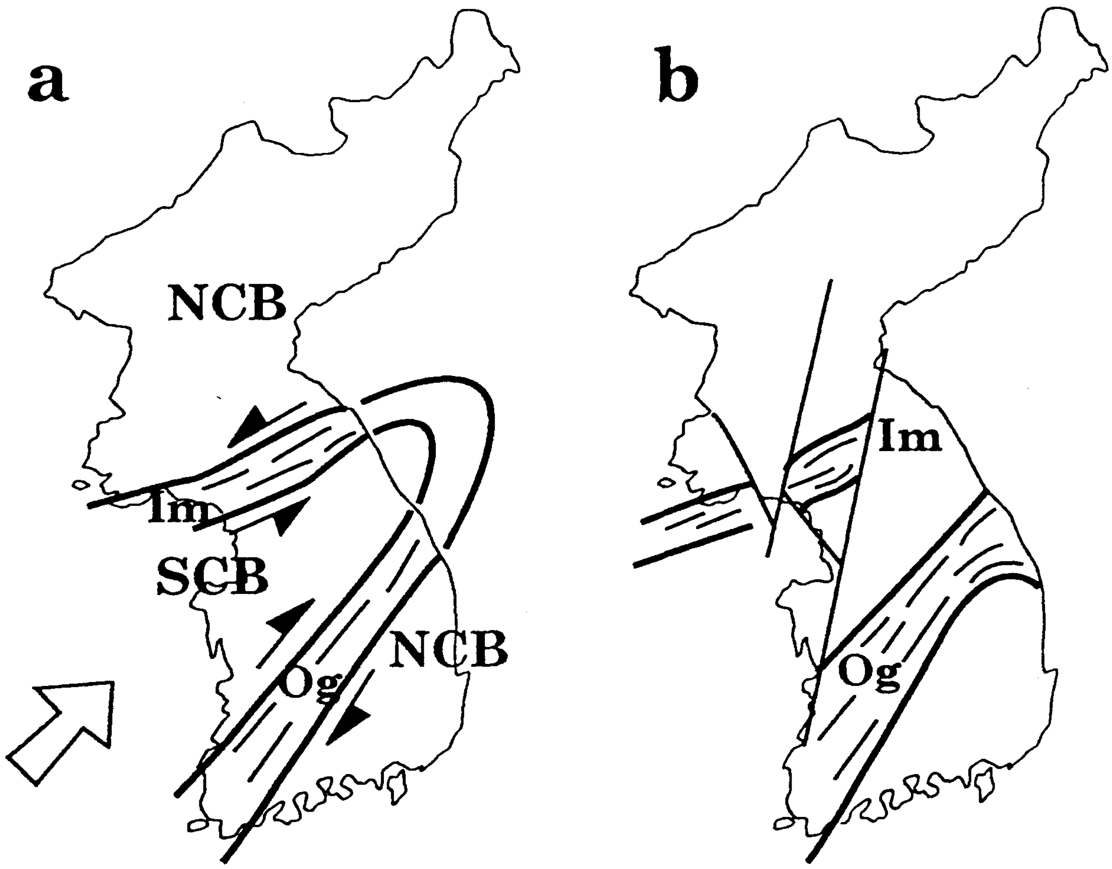

Fig. 14. Simplified cartoon showing relationships between (a) an inferred previous tectonic model by others and (b) a field-based tectonic model from this study on the Korean Peninsula. Im: Imjingang fold belt, Og: Ogcheon fold belt, NCB: North China block, SCB: South China block.

gional metamorphism of ca. 250 Ma was not restricted only within the IFB, but gave an intense effect throughout the Korean Peninsula. (4) Ultrahigh pressure phase-assemblages, such as diamond- or coesite-bearing eclogite found in the Sulu Belt in China, have not been found in the IFB and elsewhere in Korea. (5) The HWFT, which formed prior to the Jookgaryeong fault, is tectonically dividing the structural fabrics between south and north Korean Peninsula. The regional structure of the Sangweon Supergroup-south type shows EW trend and the west of the Jookgaryeong fault preserves this EW trend near the HWFT. In contrast, the district far from the HWFT retains NNE trend. To the east of the Jookgaryeong fault, the regional structure shows NNE-NE trend. (6) The shear zone in the Yeoncheon Group is restricted within the basin, so that the IFB is better to be called the Imjingang shear zone.

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Geological mappers and a jeep for fieldwork have been escorted by armed

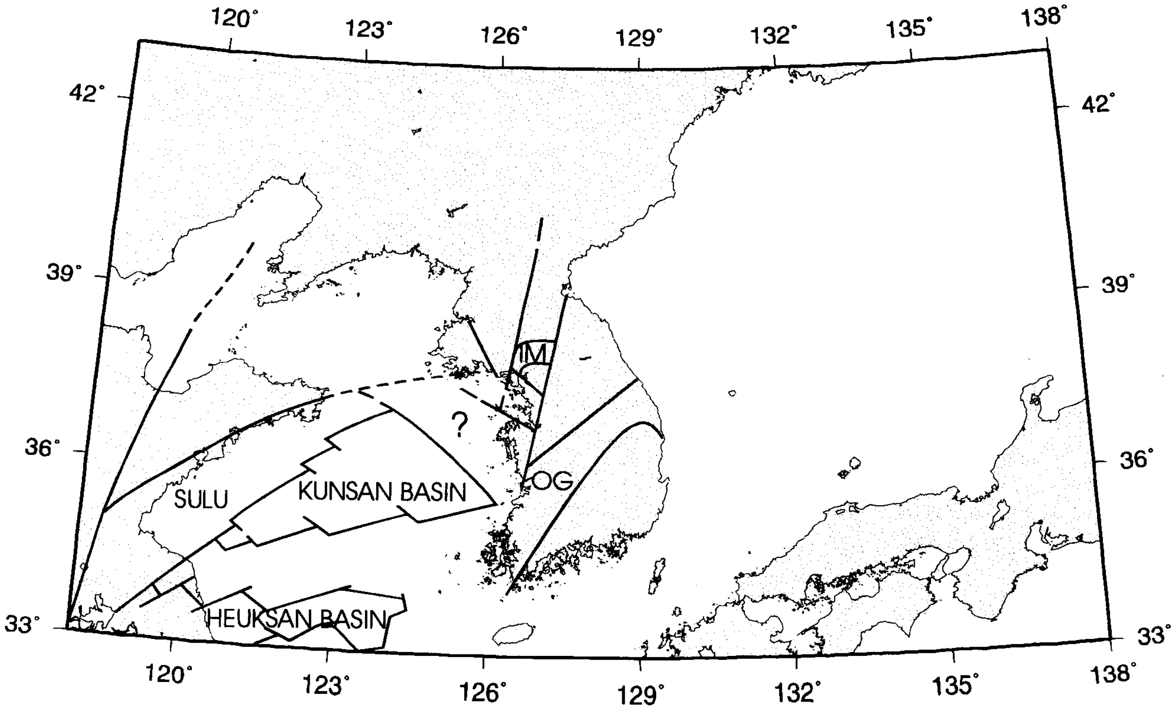

Fig. 15. Simplified tectonic faults and basins under the Yellow Sea. The eastern extension of the Sulu Belt seems to be curved toward southwest and truncated by the Jookgaryeong fault belt. The Sulu Belt becomes narrower toward east due to the development of the Kunsan basin. IM: Imjin and Yeoncheon Groups. OG: Ogcheon Fold Belt.

soldiers during the whole period of surveying. Therefore, thanks should be given to special escorts, who had a dangerous duty to prevent any mapper from treading land mines. This study is based largely on the seven years geological mapping along the DMZ and civilian-restricted areas of the Korean Peninsula, and Chemical Th-U-total Pb Isochron Method (CHIME) data of Nagoya University, Japan.

Deepest thanks should go to Professors M. Adachi and K. Suzuki for their kind help. I would like to express profound thanks to Dr. J.H. Ree for his severe and fruitful criticism. My special thanks are given to Dr. S.J. Choi, my wife, for her brave fieldwork along the DMZ during the seven years and endless high pressure.

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