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Geological structures in the Tongri–Dogye and Sangdeog areas in the eastern part of the Samcheog Coalfield, Korea

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ABSTRACTS: The study area, the Tongri–Dogye and Sangdeog areas, is located in the eastern part of the Samcheog Coalfield and consists of Precambrian granitic rocks, Paleozoic sedimentary rocks, and Cretaceous sedimentary and volcanic rocks. The study area is characterized by the E–W trending folds and thrusts, and N–S trending faults. The E–W trending folds and thrusts are well developed and are cut by the N–S trending faults in the study area. The N–S trending faults records two components of fault movements; earlier stage of the west dipping normal fault and later stage of strike-slip fault. A series of these normal faults have a character of step faults and stratigraphic positions are younger toward the west across these faults. Cretaceous volcanic rocks have two phases, extrusive and intrusive phases. Extrusive volcanic rocks are affected by the southwards thrust movement, while others intruded into the thrust sheets. Age of volcanic rocks ranges from 66.9 Ma to 49.2 Ma. These lines of evidences indicate that thrust movement occurs between 66.9 Ma and 49.2 Ma. The Osipcheon Fault, one of the major N–S trending faults in the eastern part of the Samcheog Coalfield, is characterized by strike-slip with dextral movement. Along the Osipcheon fault, the horse tail structures are developed near the tip area in the western part and subparallel faults are dominant in the eastern part of the fault. The Osipcheon Fault is terminated in the Triassic Donggo Formation near the Tongri town. Thrust faults and related structures are also developed along the lateral tip line of the minor thrust such as ramp structures, crescent type anticline, and antiformal stack structures. Along the Osipcheon Fault, minor reverse faults and domino-type extensional faults are developed on the coaly shale beds during the strike-slip faulting.

Key words: Samcheog Coalfield, thrust, Hambaegsan Fault, Osipcheon Fault

1. INTRODUCTION

The Samcheog Coalfield includes the area where the sedimentary rocks of Carboniferous–Triassic Pyeongan Supergroup is mainly exposed in the central zone of the Baegunsan Syncline and small portions in the northen limb and Dogye areas in the Mt. Taebaeg region, northeastern part of the Ogcheon Belt (Yamanari, 1926; Fig. 1a, b). The Duwibong-type sequence of the Cambro–Ordovician Choseon Supergroup is mainly exposed in the E–W trending Baegunsan Syncline from Hambaeg to the W to Dogye to the E (Kobayashi, 1953; GICTR, 1962; Fig. 1b). The asymmetrical Baegunsan Syncline shows a E–W trending axial trace: southern limb dips at 30°–50° toward the N and northern limb dips at 60–80° toward the S, respectively. In some places, northern limb dips at 30° toward the N indicating overturned fold shape toward the eastern part of the syncline. Thrust faults are commonly developed in the overturned northern limb area (Fig. 1b).

The Samcheog Coalfield can be divided into two parts by the Hambaegsan Fault; eastern and western parts of the coalfield (Fig. 1b). The eastern part of the coalfield consists of Precambrian rocks, Paleozoic sedimentary rocks, and Cretaceous sedimentary and volcanic rocks (Fig. 1b).

The Samcheog Coalfield is one of the major coalfields in the Korean Peninsula and has been studied since Yamanari (1926). Paleontology and stratigraphy of the coalfield were studied by Cheong (1973, 1974, 1976), and studies of structural geology were carried out by Wright (1979), Kim and Kim (1985), Kim et al. (1985), Choi (1986), Kim et al. (1986), and Kim and Won (1987). Thrust and imbricate structures are firstly reported by Yamanari (1926) and Shiraki (1930, 1940) and Kobayashi (1953) also reported these structures in the eastern part of the Samcheog Coalfield. Cheong (1976) noted the thrust faults in the eastern part of the Samcheog Coalfield. Wright (1979) reported that sedimentary rocks of the Pyeongan Supergroup in the area between Hwangji and Jangseong were controlled by the imbricate fault system.

In this paper, we describe the characters of the thrusts and faults and constrain the age of the thrust and strike-slip faults in the Tongri–Dogye and Snagdeog areas, in the eastern part of the Samcheog Coalfield (Fig. 1b).

2. GEOLOGIC SETTING

The study area consists of Precambrian granite, Cambro–Ordovician Choseon Supergroup and Carboniferous–Triassic Pyeongan Supergroup, and Cretaceous sedimentary and

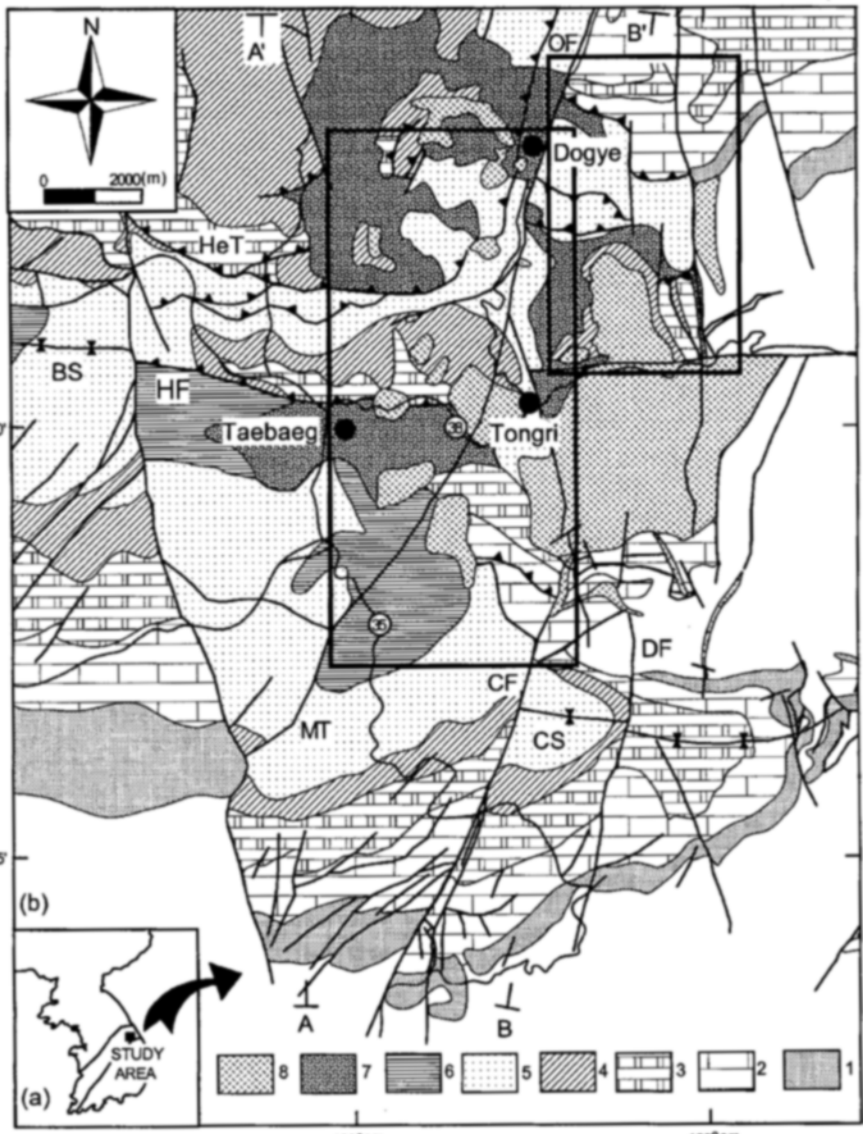

Fig. 1. **(a)** Index map of location of the study area. **(b)** Geological map in the eastern part of the Samcheog Coalfield (modified from GMIK, 1973). **(c)** Geological cross section. 1: Cambrian clastic rocks, 2: Cambrian limestone formations, 3: Ordovician limestone formations, 4: Carboniferous rocks, 5: Permian rocks, 6: Triassic rocks, 7: Cretaceous sedimentary rocks, 8: Cretaceous volcanic rocks. A–A': Line of Geological cross section. BS=Baegunsan Syncline, CF=Cheolam Fault, CS=Cheolam Syncline, DF=Dongjeom Fault, HF=Hambaegsan Fault, HeT=Hyeolam Thrust, MT=Mungog Thrust, OF=Osipcheon Fault.

volcanic rocks (Fig. 1b).

Precambrian granites occur as basement of this region, of which age ranges from $1,825 \pm 20$ Ma to $1,440 \pm 140$ Ma by Rb–Sr method (Ueda, 1969; Kim et al., 1979). Cambro–Ordovician Choseon Supergroup was deposited on the Precambrian basement rocks, which consists of Cambrian basal quartzite, slate, and a series of intercalation of limestone and mudstone beds in ascending order. Mid-Carboniferous to Early Triassic Pyeongan Supergroup is distributed in the study area (Figs. 1b and 2a, b). The lower part of the Pyeongan Supergroup represents a shallow-water marine environment gradually changing to non-marine shallow water to swamp environment in which the coal-bearing measures were deposited. The non-marine shallow water environment persisted for the deposition of the entire uppermost strata of the Pyeongan Supergroup (Cheong, 1973, 1974). Cretaceous sedimentary and volcanic rocks are mainly exposed in Tongri and Dogye areas (Fig. 2c, d). Cretaceous rocks consist of conglomerate of the Jeoggagri Formation at the base, volcano-clastic shales and sandstones of the Heungjeon Formation in the middle part, and mainly volcanic rocks of the Baegbyeongsan Tuff at the upper part.

Cretaceous sedimentary rocks unconformably rest on the Paleozoic sedimentary rocks, and the margin of the Cretaceous basin is fault contact with the Paleozoic rocks (Fig. 2d). Volcanic rocks have a character of extrusive and intrusive phases. Age of these igneous rocks ranges from 66.91 Ma to 49.42 Ma (Park et al., 1988; Jin et al., 1989; Won et al., 1994).

3. REGIONAL STRUCTURAL SETTING

Geological structures in the study area are characterized by the E–W trending folds and thrust faults, and NNE–SSW

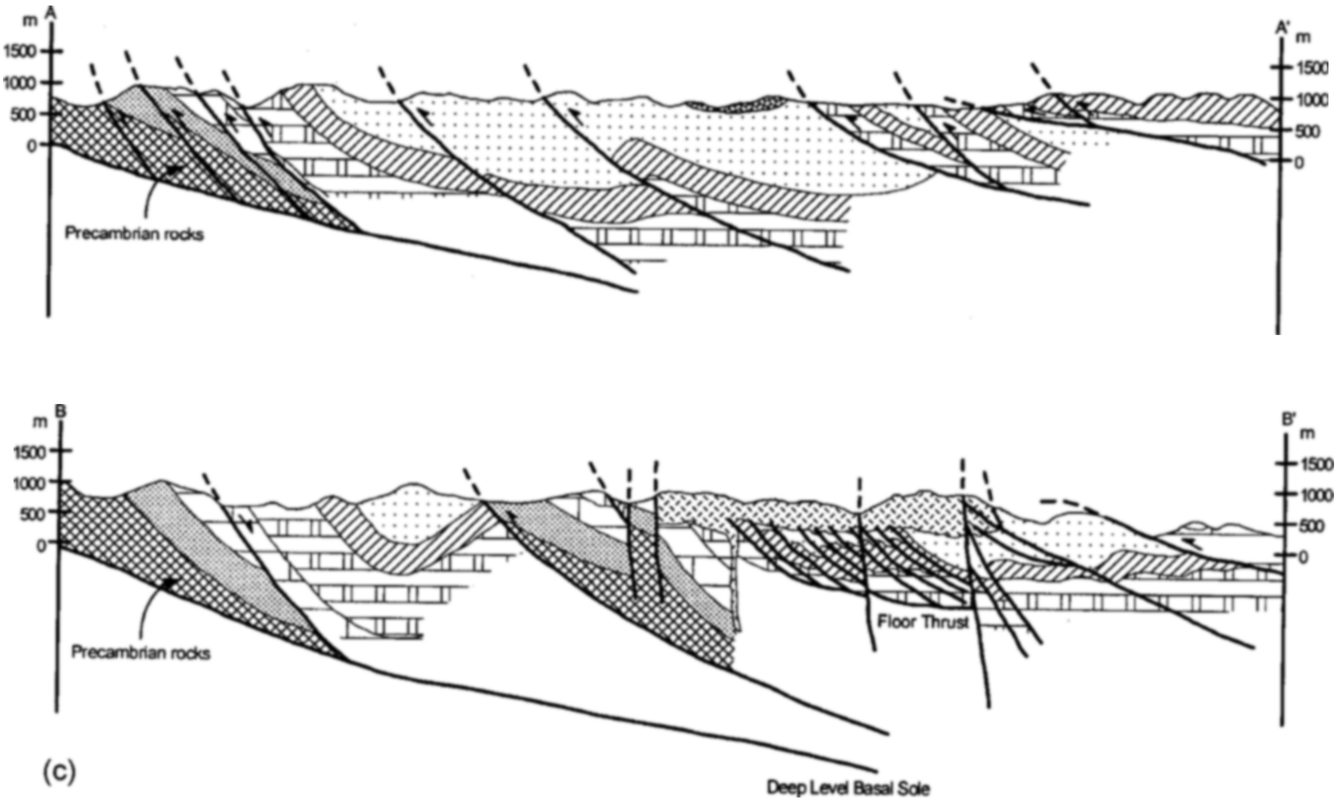

Fig. 1. (continued).

or NNW–SSE trending faults (Fig. 1b). Age of the formation of the E–W trending folds including the Baegunsan and Cheolam synclines has not been known yet. However, whole succession of the Pyeongan Supergroup was deposited continuously in the central portion of the early Paleozoic basin and only the small portions in the Dogye area. The Baegunsan Syncline has been cut by a series of the N–S trending faults, especially toward to the eastern margin of the syncline (Fig. 1b). These normal faults have a character of step faults and stratigraphy is younger toward the west across these faults (Fig. 1b). It indicates that the Pyeongan Supergroup deposited, and then it was folded and faulted.

The rocks in the study area have been undergone by thrust movement which occurred after sedimentation and extrusive phase of volcanic rocks during late Cretaceous time. The E–W trending thrust faults have different geometries depending upon the topographic levels, as duplex structures at the topographic lower level (Lim et al., 1992) and imbricate fan structures in the topographic higher level (Fig. 1c: B–B'). Most of thrusts propagate as a leading imbrication, but duplex zones were formed at the trailing edge (Fig. 1c). Thrust transport direction may be determined from the section lines of evidences by Dahlstrom (1970) and Coward (1984). According to them, thrust faults in the study area transport from the N to the S.

The N–S trending faults reactivated on the pre-existing normal fault during the thrust movement and had a character of the tear faults. Some volcanic rocks in the area lied beneath the Cambrian and Ordovician limestones by the thrust faults (Fig. 3a), but others intruded into the thrust sheets (Fig. 3b). In order to compare the structural characters, the study area can be divided into the Sangdeog and Tongri–Dogye areas, respectively.

3.1. Sangdeog Area

The Sangdeog area is located in the eastern part of the Osipcheon Fault (OF) and bounded by the Jeoggagri fault (JF) to the east (Fig. 4). The OF is one of the major N–S trending faults in this area, which was originally named as the Bakyori Fault by Kobayashi (1953) and GICTR (1962) renamed as the Osipcheon Fault, later. The area comprises of Precambrian granites, sedimentary rocks of Choseon and Pyeongan supergroups, and Cretaceous sedimentary and volcanic rocks. The Sangdeog area can be divided into five structural domains based on their structures and geological characteristics, which are the Sangdeog Nappe (SN), Sangdeog Window (SW), Obangsan Nappe (ON), Kusari imbricate zone (KIZ), and Precambrian basement rocks (Fig. 4). Precambrian rocks are mainly exposed in the eastern part of the area and bounded by the Sangdeog Thrust (ST), and JF (Fig. 4). The SN is bounded by the OF to the west and the ST to the south, as well as the JF to the east, respectively. The ST, which is one of major thrusts in this region, has a E–W trend

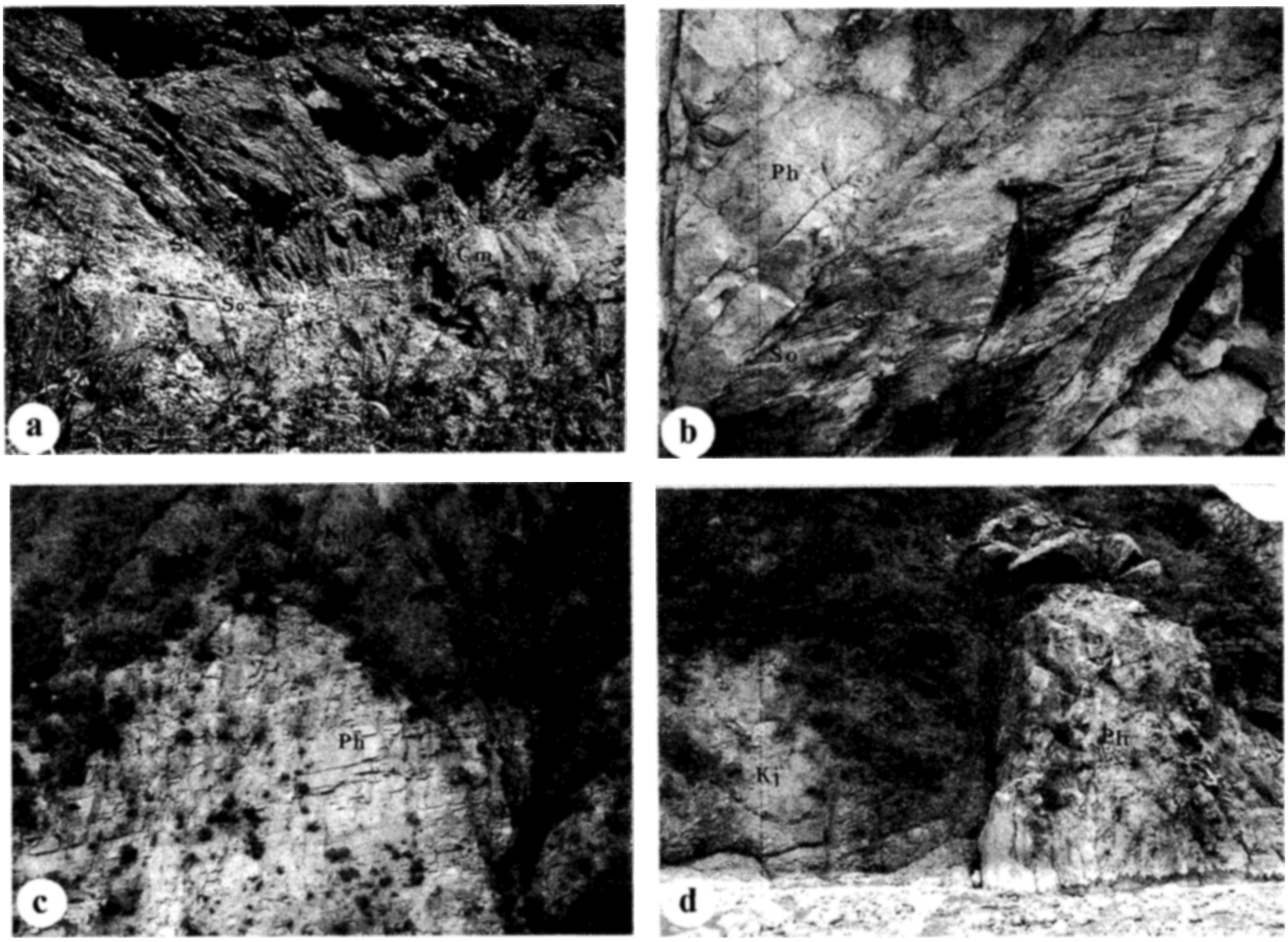

Fig. 2. Photographs of outcrops. **(a)** and **(b)** Outcrops showing bedding-cleavage relationships in the Manhang (Cm) and Hambaegsan formations (Ph). **(c)** Cretaceous Jeoggagri Formation (Kj) rests on the Hambaegsan Formation (Ph). **(d)** Fault contact between Cretaceous Jeoggagri Formation (Kj) and Hambaegsan Formation (Ph).

with dips at 30° toward the N. The ST carried mainly the Pungchon and Hwajeol formations onto the sedimentary rocks of the Pyeongan Supergroup. The ST is displaced by the NE-trending minor tear faults (Fig. 4). Fault breccia zones with 2 m in thickness commonly occur along the thrust. These breccias were derived from limestone of the Pungchon Formation, and sandstone and shale of the Pyeongan Supergroup.

Difference of the topographic level between the Tongri town to the south and the Dogye town to the north is about 400m (Figs. 1b and 4). The Sangdeog area is situated in the topographic lower area. The SW is located in the central part in the Sangdeog area and bounded by the ST to the N and Obangsan Thrust (OT), Cretaceous Jeoggagri Formation and the KIZ to the S. The SW area consists mainly of the Pyeongan Supergroup. The E–W trending anticline and syncline were developed in the footwall area of the ST. The ST developed on the back limb area of the asymmetrical anticline, which indicates the out of sequence thrust fault (Butler, 1982).

The ON is located in the topographically higher level and the hanging wall area of the OT (Fig. 4). This area consists of the Permian Jangseong and Hambaegsan formations, Cretaceous Jeoggagri and Heungjeon formations, and Baegbyeongsan volcanic rocks. The OT was branched off from the ST and dip toward the S (Fig. 4). The OT is cut by the OF to the west and the JF to the east, and covered with the Jeoggagri Formation.

The KIZ is located at the topographically higher area and situated in the southeastern part in this area (Fig. 4). Thrust faults in this area are branched off from the ST and taken a role of the higher level sole thrust. Minor imbricate thrusts are branched off from the ST. Cretaceous Baegbyeongsan volcanic rocks lied on the foot wall area of minor thrust. Fault breccia has 2 m in thickness along the thrust, which were derived from mainly limestone of the Pungchon Formation and Cretaceous rhyolitic rocks (Fig. 3a).

Structural elements in this area were plotted on the ste-

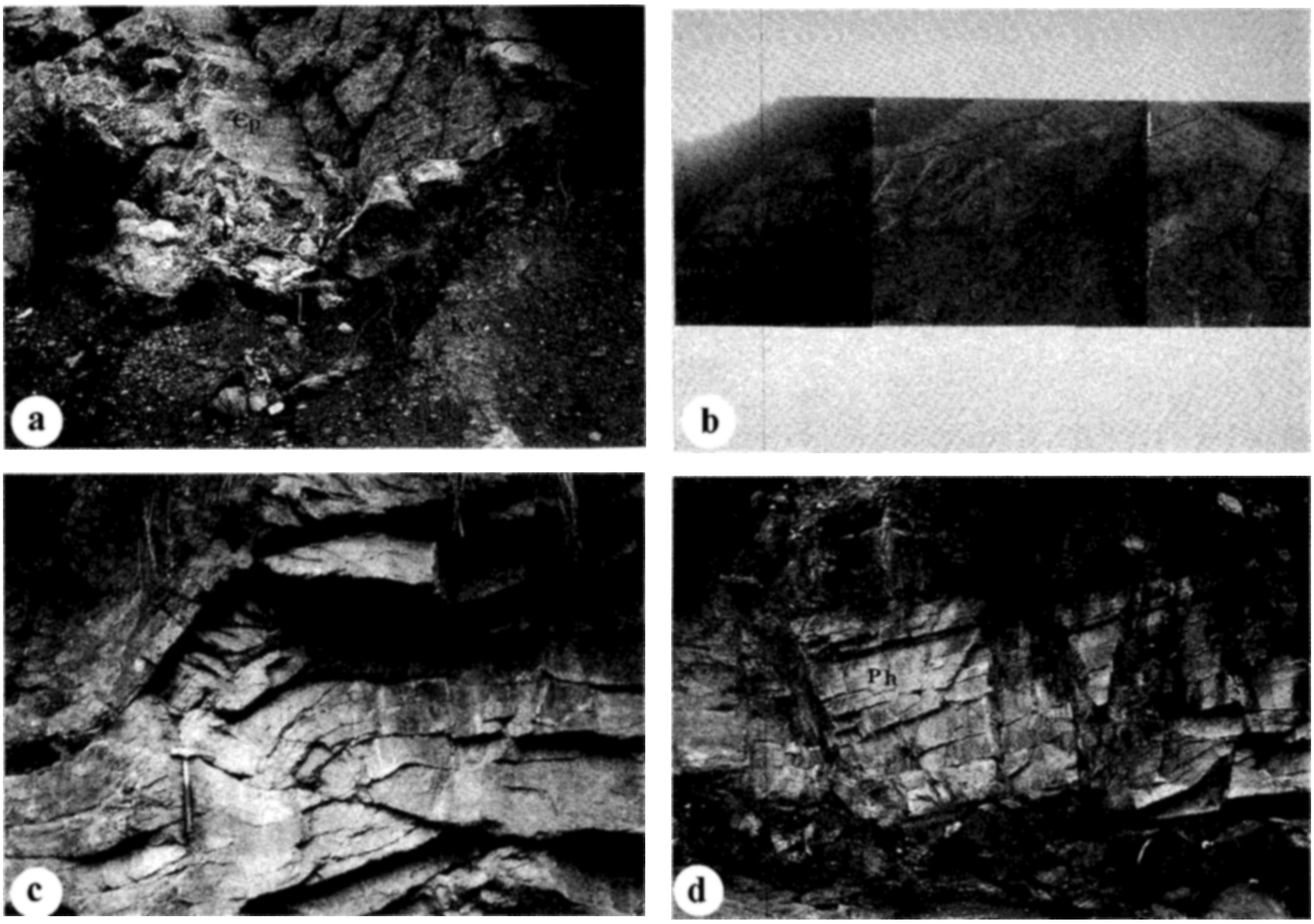

Fig. 3. Photographs of outcrops. (a) Limestones of the Pungchon Formation (Cp) rest on the Cretaceous volcanic rocks (Kv) by thrust. **(b)** Cretaceous quartz porphyry (Kv) intruded into the Hambaegsan Formation (Ph). **(c)** Minor hanging wall anticline developed on the minor thrust. **(d)** Domino-shape normal faults developed on the coaly shale beds (Ph: Hambaegsan Formation, Pj: Jangseong Formation).

reogram and rose diagram (Fig. 5). Poles to bedding surfaces of the Choseon and Pyeongan supergroups are scattered on the stereonet due to effects of folding and faulting (Figs. 5: 1a, 2a). Cleavages are well developed in the alternation zone of sandstone and shale in the Manhang and Hambaegsan formations, which have high angle to the bedding surface (Figs. 5: 2a, 2b). In spite of small numbers of measurements, poles to cleavages have different patterns between rocks of the Choseon and Pyeongan supergroups (Figs. 5: 1b, 2b). Bedding–cleavage intersection lineations are rather consistent and gently plunging toward the NE and WNW (Figs. 5: 1c, 2c). Dominant trends of normal and strike-slip faults are the NE and NW (Fig. 5: 3a, 3b), but dominant orientation of thrusts is the WNW (Fig. 5: 3c). Faults in the Cretaceous rocks displays different pattern (Fig. 5: 3d).

3.2. Tongri–Dogye Area

The Tongri–Dogye area includes the OF and its adjacent area (Figs. 1a and 6). This area is characterized by the E–W trending strike-slip faults, and NNE and NNW trending thrusts and normal faults (Fig. 6). The OF can be seen along the Osipcheon river and its southern extension is not traceable (KIGAM, 1979; Lim et al., 1992). The OF is terminated in the Triassic Donggo Formation near the Tongri town.

This area consists of sedimentary rocks of the Choseon and Pyeongan supergroups, and Cretaceous sedimentary and volcanic rocks. General trends of stratigraphic positions are younger toward the north (Fig. 6). Major thrust faults carried the Cambro–Ordovician rocks with the Pyeongan Supergroup. Cretaceous quartz porphyry intruded into the thrust sheets (Fig. 3b) and also cut by the strike-slip faults (Fig. 6).

This area can be divided into five structural domains based on the fault and thrust distributions to compare with the structural trends of each domains (Fig. 7). Poles to the bedding surfaces are more concentrated and fold axes have the NE and E–W trends. Structural domains of the eastern part of the OF have two orientations of fold axes, while domains of the western part has only the E–W trend (Fig. 7: 1a–1e). The NE-trends of fold axes are parallel to the OF and might be related with the strike-slip movement of the OF. The E–W trending folds are parallel to the axis of the Cheolam syn-

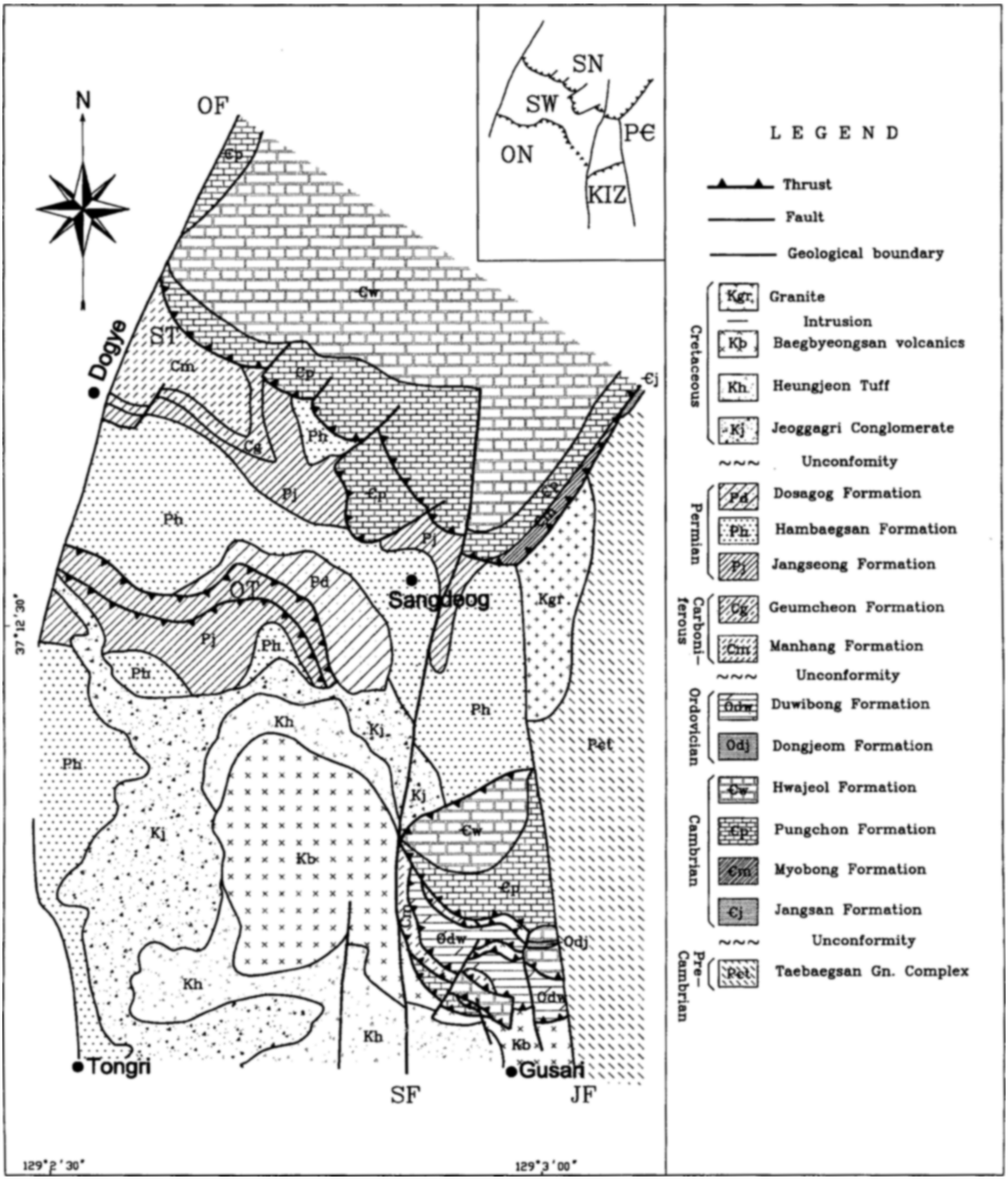

Fig. 4. Geological map of the Sangdeog area (modified from Choi, 1986). JF=Jeoggagri Fault, OF=Osipcheon Fault, OT=Obangsan Thrust, ST=Sangdeog Thrust, KIZ=Kusari imbricate zone; ON=Obangsan Nappe, SN=Sangdeog Nappe, SW=Sangdeog Window, PE =Precambrian rocks.

cline in the study area (Figs. 1b and 7: 1b–1e).

Trends of faults in this area are shown in Figure 7 (2a-2e). The NNE trending faults are dominant in domain a, d, and e in Figure 7, which might be reflected the NE-trending

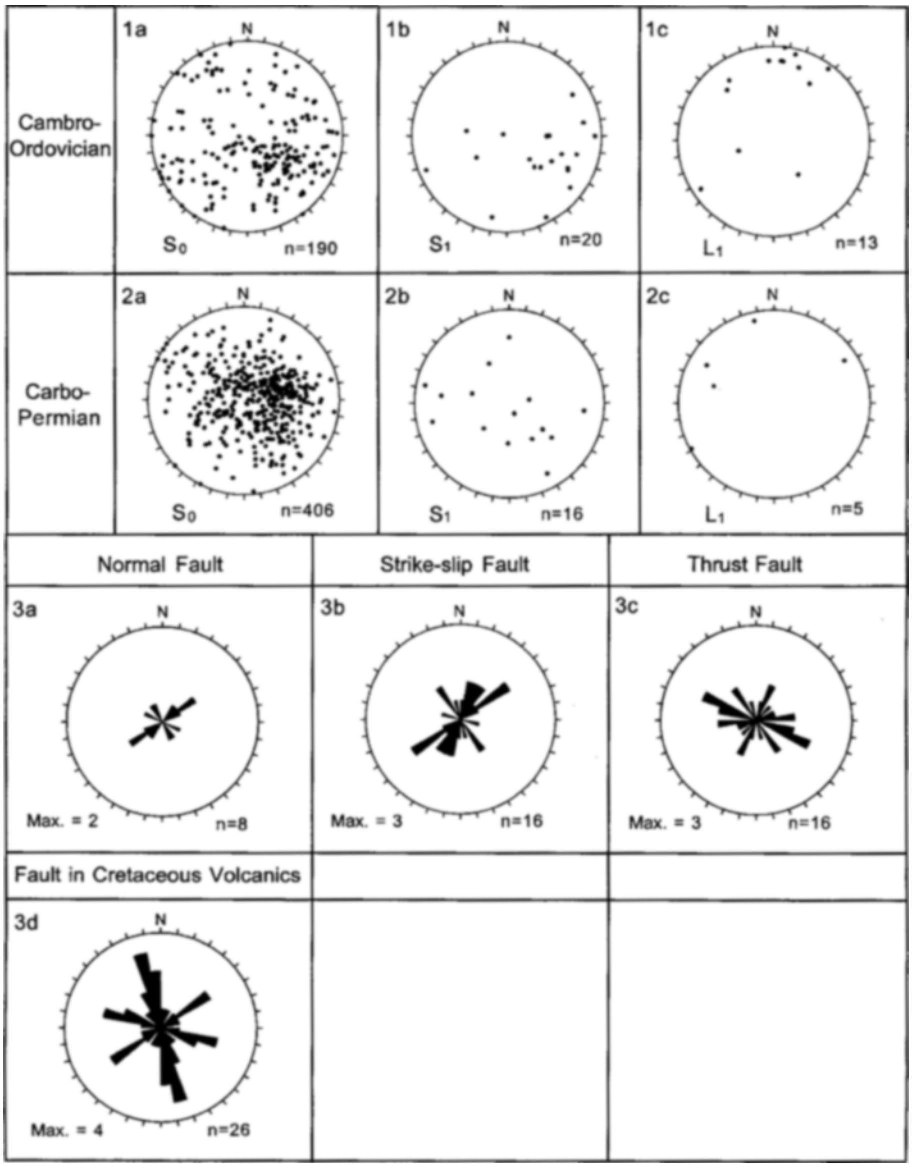

Fig. 5. Stereoplots of poles to bedding (S_0) and cleavage (S_1), and intersection lineation (L_1). Rose diagram showing the orientations of faults in the Sangdeog area.

strike-slip faults. However, orientation of faults in domain b in Figure 7 is the WNW trend, which represents the trend of thrust faults. Domain c in Figure 7 shows variable orientations, reflecting both thrust and strike-slip fault.

Structures related with thrust faults are clearly shown along the Osipcheon river (Figs. 8 and 9), which is developed on the lateral tip line of the minor thrust in the Hambaegsan Formation. It shows the various structures related with thrust fault from the N to S along 2 km distance. Minor thrust faults have a ramp structures (Figs. 8a and 9), rootless crescent type anticline with axial trace of 270°/37° on the thrust fault (Figs. 8b and 9), flat-lying hangingwall and footwall (Figs. 8c and 9) and antiformal stack structures (Figs. 8d and 9).

There are numbers of strike-slip faults parallel or subparallel to the OF (Fig. 6). Faults in the western part of the OF cut the lower level thrusts and covered by higher level thrusts. Some faults are merged into the OF (Fig. 6). These features display the horse-tail structures at the tip area of the OF. However, faults in the eastern part of the OF are almost parallel to each others (Fig. 6). Minor reverse fault and domino-type normal faults are also found in the eastern part of the OF (Fig. 3c, d). Minor hangingwall anticline and syncline developed on the minor reverse fault, but this fault could not migrate on the upper syncline (Fig 3c). Domino-type minor faults occurred along the contact of sandstone and coaly shale beds (Fig. 3d).

4. DISCUSSION

In this section, relative timing and relationships of major structural features of thrusts and faults in the study area are described in order to understand the structural evolution of the study area.

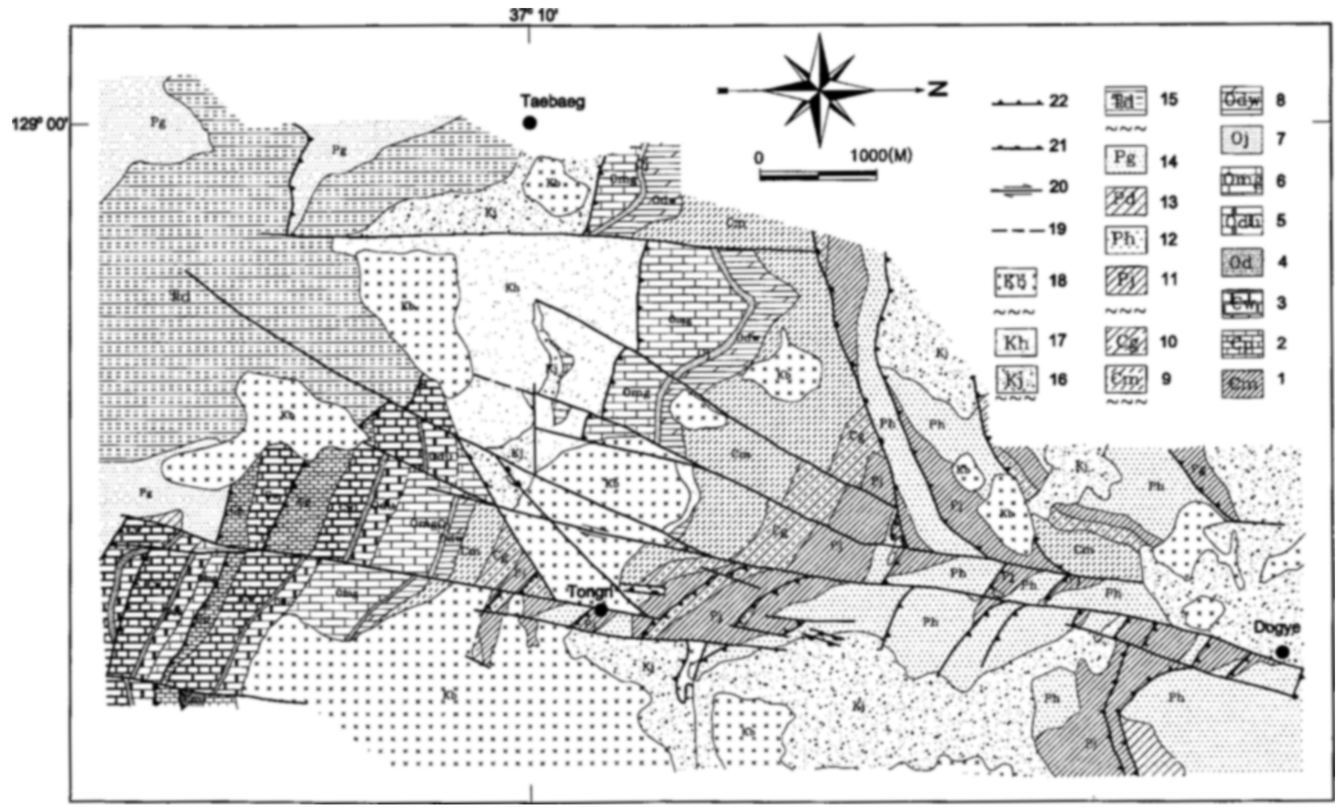

Fig. 6. Geological map of the Tongri–Dogye area. OF=Osipcheon Fault. Cambrian Myobong Formation(1), Pungchon Formation(2), and Hwajeol Formation(3), Ordovician Dongjeom Formation(4), Dumudong Formation(5), Maggol Formation(6), Jigunsan Formation(7), and Duwibong Formation(8), Carboniferous Manhang Formation(9) and Geumcheon Formation(10), Permian Jangseong Formation(11), Hambaegsan Formation(12), Dosagog Formation(13), and Gohan Formation(14), Triassic Donggo Formation(15), Cretaceous Jeoggagri Formation(16), Heungjeon Formation(17) and Baegbyeongsan volcanics(18). 19=inferred geological boundary; 20=strike-slip fault; 21=normal fault; 22=thrust.

Thrust faults and related imbricate structures in the eastern part of the Samcheog Coalfield were reported by Yamanari (1926), Shiraki (1930, 1940), and Kobayashi (1953). Kobayashi (1953) considered the age of the thrust movement to be late Jurassic to middle Cretaceous period, because he thought that most intense deformational event in the Korean Peninsula might be the Jurassic Daebo orogeny. GICTR (1962) recognized these thrust structures, but they interpreted these due to the overturned folding. But, coal measures had been mined beneath the Ordovician limestone formations in the Hwangji area since early 1960s. Cheong (1976) noted that the nappe structures in the eastern part of the Samcheog Coalfield are related with the overturned folds and age of the nappe structures to be late Jurassic to early Cretaceous period. He also noted age of the Hambaegsan Fault to be late Cretaceous to early Tertiary time, because it cut the nappe structures. KIGAM (1979) published the Geologic Atlas of the Samcheog Coalfield with some of thrust faults. A drilling project by KMPC (1980) had been carried out in the Tongri area in order to find out coal measures beneath the Cretaceous volcanic rocks. Cretaceous volcanic rocks in this area were interpreted as igneous rocks by Kobayashi (1953) and intrusive quartz porphyry by GICTR (1962). During this project, several repeated coal measures were found beneath the Cretaceous volcanic rocks and several thrust faults were identified by the mapping in the underground coal mines. Later studies clarified these relations of the thrust and related structures in the eastern part of the Samcheog Coalfield (Kim et al. 1985; Choi, 1986; Kim et al., 1986). According to them, the E–W trending thrust faults cut the Cretaceous sedimentary rocks and are cut by the N–S trending faults. They thought that the N–S trending faults occurred as tear faults during the thrust movement. Some extrusive volcanic rocks are affected by thrust movement (Fig. 3b), while others intruded into the thrust sheets (Lim et al., 1992). The isotope ages of these volcanic rocks yield between 66.9 and 49.4 Ma (Park et al., 1988; Jin et al., 1989; Won et al., 1994). Thus, age of thrust movement confined between 66.9 and 49.4 Ma.

Some of the N–S trending faults reactivated during later deformational event and taken a role of the formation of the Cretaceous sedimentary basin in the Tongri and Dogye areas. Mechanism of Cretaceous basin formation in the Tongri–Dogye area has not been fully understood yet. Lim et al.

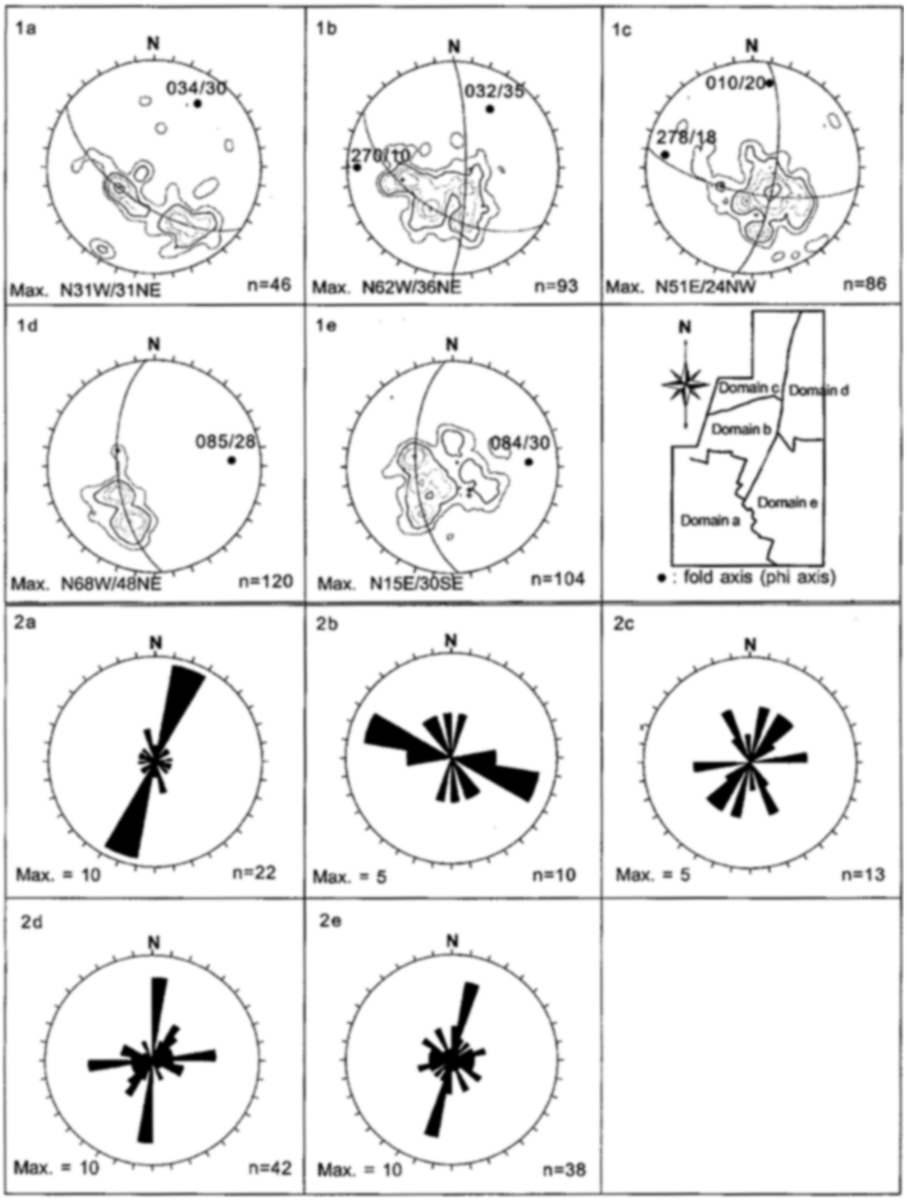

Fig. 7. Stereoplots of poles to bedding (1a–1e) and rose diagram for faults (2a–2e) in each domain.

(1992) interpreted it as a pull-apart basin during the strike-slip movement of the OF, but the boundary fault of the basin margin can not be found by authors. Instead, the Cretaceous basin might have been formed as a graben or half graben type due to the extensional environment for the OF (Fig. 2d).

After sedimentation and volcanism, this area was affected by the E–W trending thrusting and N–S trending strike-slip faulting. Thrust faults have different geometry of either duplex structures or imbricate fan structures depending upon the topographic level (Fig. 1b).

Most thrusts in the study area migrate as a leading imbrication, but duplex zones were formed at the trailing edge of the thrust (Fig. 1c). Thrust faults in the study area transport from the N to the S, evidenced by section lines (Dahlstrome, 1970; Coward, 1984). Some of the N–S trending faults reactivated on the pre-existed normal fault and have a character of the tear faults.

The OF is one of the major strike-slip faults in the Mt. Taebaeg Region (GICTR, 1962). Recently, Lim et al. (1992) reported its southern extension of the OF further the south to the Cheolam area and connected to the Cheolam Fault (Fig. 1b), but we could not find any evidences of the southern extension in the study area (Fig. 6). According to this study, the OF was developed through three stages. During the first stage, the fault occurred as a normal fault due to the directions of E–W trending maximum extension and N–S trending maximum compression. Thus, graben or half-graben type of Cretaceous basins might be formed in this stage (Fig. 2d). At the second stage during the thrust movement, the OF acted as lateral tip line or tear fault within thrust faults. At the last stage, the OF reactivated as strike-slip fault, and horse tail structure and subparallel patterns were developed.

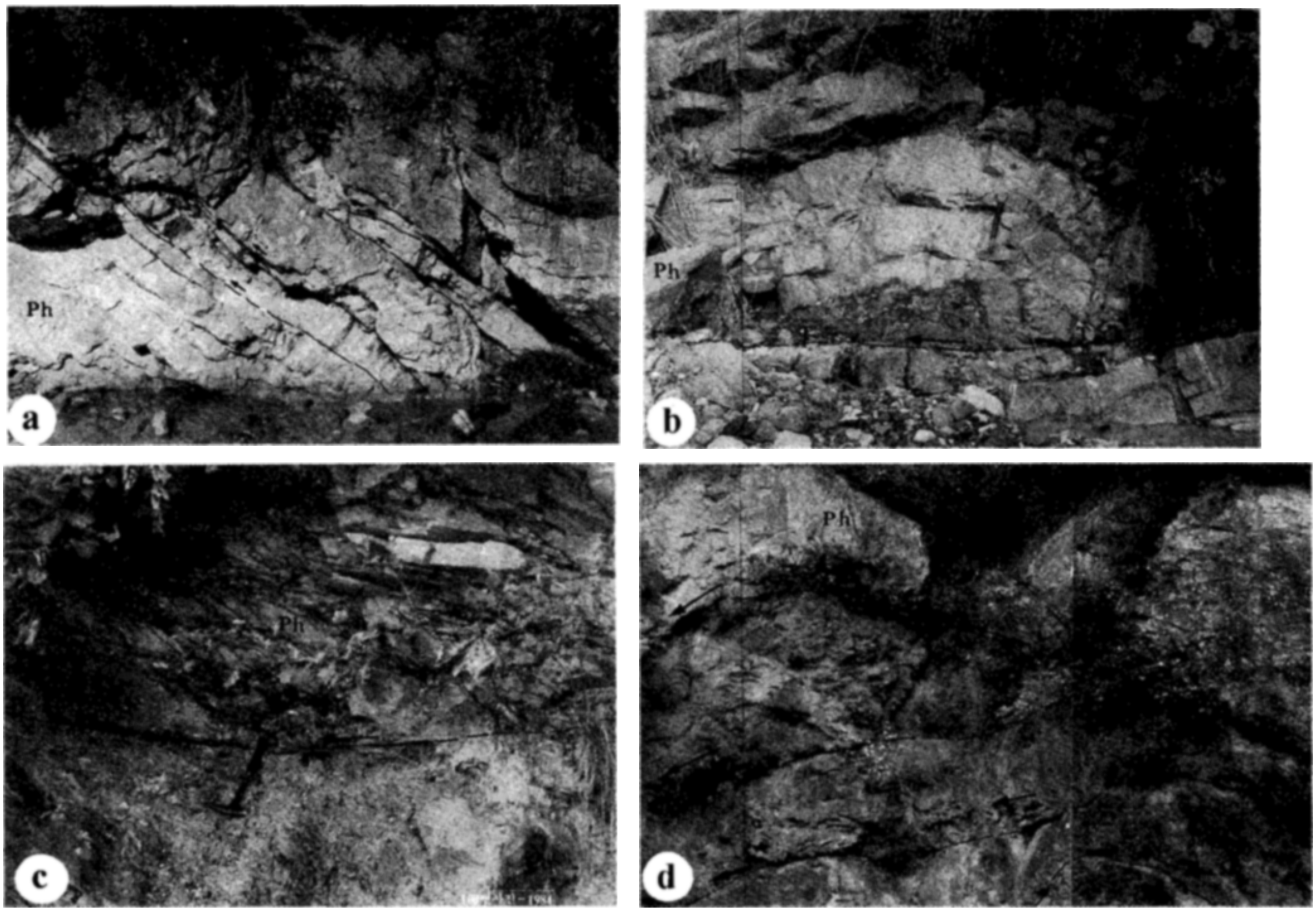

Fig. 8. Outcrop photographs. **(a)** Minor reverse faults occur as ramp structures. **(b)** Rootless crescent type anticline on the thrust surface. **(c)** Flat lying hanging wall and foot wall. **(d)** Antiformal stack structures along the minor thrust.

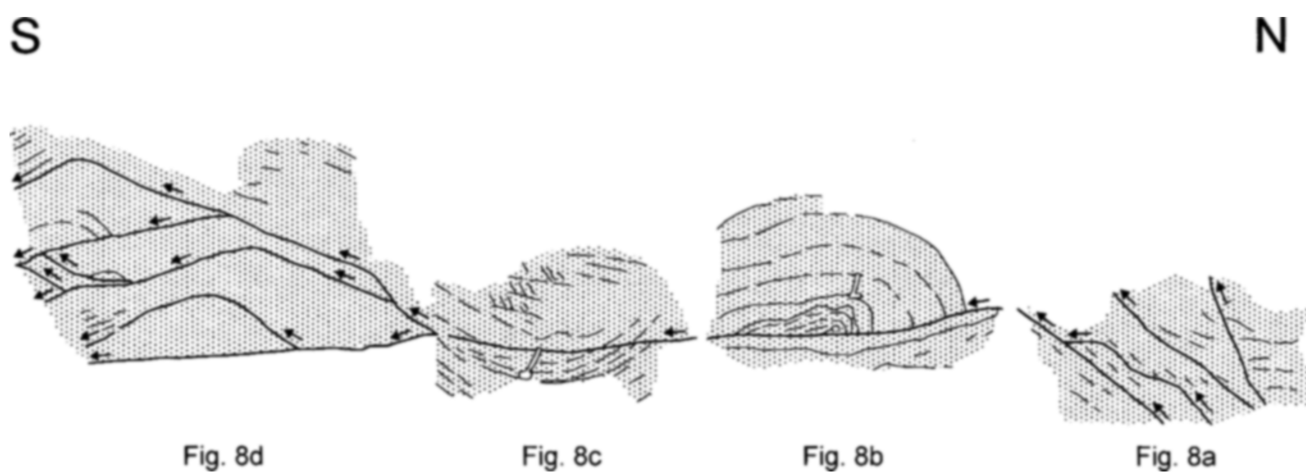

Fig. 9. Sketches of outcrops in Fig. 8.

The OF formed as fault zone with subparallel faults and terminated at the Triassic Donggo Formation.

5. CONCLUSION

The study area, Tongri–Dogye and Sangdeog areas, in the eastern part of the Samcheog Coalfield consists of Precambrian granites, Paleozoic sedimentary rocks, and Cretaceous sedimentary and volcanic rocks. The study area is characterized by the E–W trending folds and thrust, and N–S trending faults. A series of N–S trending normal faults have a character of west dipping step faults and stratigraphic position in compartment area by faults younger toward the west. Cretaceous sedimentary rocks might be deposited in graben or half graben type basins. Thrust movement in the study area occurred after the sedimentation and volcanism of Cretaceous rocks and terminates before 49 Ma.

Geometries of thrust faults are variable from duplex structures to imbricate fan structures depending on the topographic levels.

During the thrust movement, the pre-existied NE-trending faults were reactivated as tear faults, and then strike slip faults. The N–S trending of the OF formed as fault zone with parallel or subparallel faults and terminated in the Triassic Donggo Formation near the Tongri town.

Structural elements such as planar and linear structures, and faults are plotted on the stereograms and rose diagrams. Poles to bedding surfaces show variable orientations in the Sangdeog area, but more concentrated in the Tongri–Dogye area. Bedding–cleavage intersection lineations and fold axes are concentrated to the NE and NW with low plunging angles. The WNW-trending structures are related with the E–W trending folds. Faults have variable orientations depends on their characters. Strike-slip faults have a N–S or NNW–SSE trend and thrusts have approximately an E–W trend in both the Sangdeog and Tongri–Dogye areas.

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