Geology of the Tertiary Yangnam and Pohang Basins, Korea

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(Abstract)

The Yangnam and Pohang basins are the largest Tertiary ones in the southern Korean Peninsula, and their geologic events are enumerated as follows in chronological order:

(1) Early-Middle Eocene dacitic volcanism on land: The Wangsan Formation was deposited.

(2) Oligo-Miocene rifting of the Pohang-Ulsan Graben between the Proto-Korean Peninsula and Paleo-Ulleung Land. The Paleo-Ulleung Land had existed until the Late Pliocene.

(3) Early Miocene dacitic and andesitic-basaltic volcanisms on land and under water: The Beomgogni and Janggi groups were deposited.

(4) Upheaval of the Yangnam Basin: Beomgogni and Janggi groups were eroded and the terrestrial Danguri Conglomerate and Gangdong Formation of the Yeonil Group were deposited.

(5) Yeonil Marine Transgression: Marine Transgression started to advance into the Pohang -Ulsan Graben in the late Early Miocene, and subsequently, in the Middle Miocene, the graben became an open sea, and the Paleo-Pohang and Paleo-Ulsan troughs and Paleo-Yangnam Ridge were formed. The Cheongogsa, Hagjeon and Heunghae formations of the Yeonil Group in the Pohang Basin are the uplifted parts of the marine sediments which were deposited in the Paleo -Pohang Trough, while the Sinhyeon Formation in Eoil and Ulsan areas of the Yangnam Basin is the uplifted parts of the marine sediments on the Paleo-Yangnam Ridge.

(6) Uplifting of the Gampo and Janggi domes: Radial fault systems were formed, and the Paleo -Pohang and Paleo-Ulsan troughs and Paleo-Janggi Ridge were destroyed. The age of this upflifting is unknown yet, but is presumed to be Mio-Pliocene.

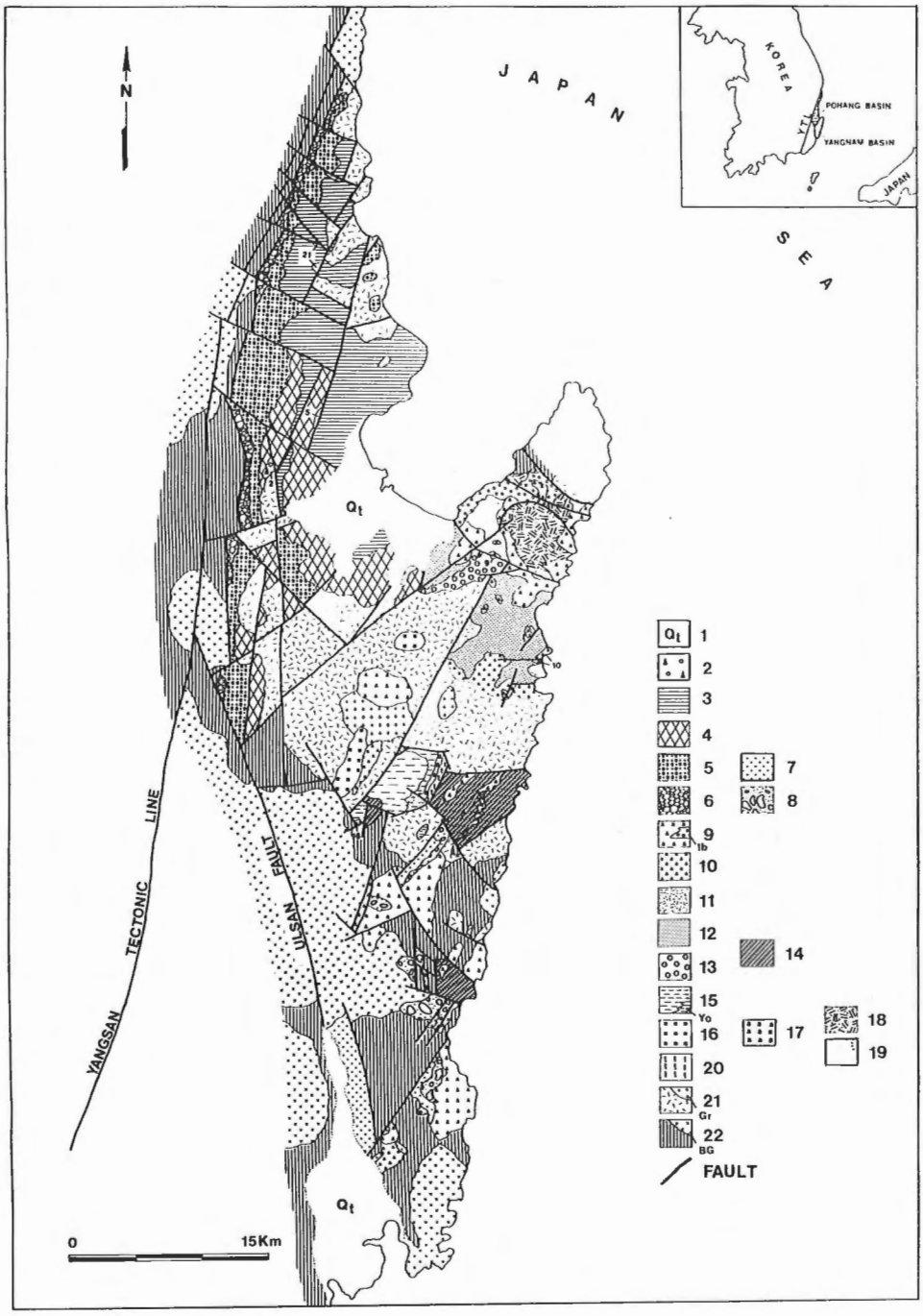
The tectogenesis of the Pohang-Ulsan Graben is diapiric, and named the Eoil Orogeny. The Eoil Orogeny is correlated to the Green Tuff Orogeny in Japan. The Yangsan Tectonic Line is the western wall of the Sado-Pohang Belt in which the Neogene diapiric tectogenesis occurred.

Kyewords : Tertiary geology Yangnam and Pohang basins, Yangsan Tectonic Line, Eoil Orogeny, Pohang-Ulsan Graben, Korea.

Introduction

In the Korean Penisula, Tertiary rocks occur as small patches along its eastern coast, and were named the Gilju-Myeongcheon, Bugpyenong, Yeonghae, Pohang and Yangnam

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basins. Of these five basins, the Gilju-Myeongcheon Basin is in the northern peninsula, and the others are in the southern peninsula.

The Yangnam and Pohang basins are the largest Tertiary ones in the southern Korean Peninsula, and the Tertiary stratigraphy of them represents the Teriary sequences of the Korean Peninsula. The geology of these two basins was first reported by Tateiwa in 1924. Tateiwa's investigation (1924) was achieved in the northern half of the Yangnam Basin and southernmost part of the Pohang Basin. After Tateiwa (1924), the geology of the two basins has been studied by several geologists, but the investigations were mainly carried out in the Pohang Basin, and the geology of the Yangnam Basin has not been studied in detail yet. The reason of the one-sided study on the Pohang Basin is that the Pohang Basin is underlain by thick marine strata and yields various marine fossils such as nannoplankton, dinoflagellates, foraminifera, molluscs, etc.

The present article is to present the stratigraphy, paleoenvironments and tectonic history of the Yangnam and Pohang basins chiefly based on the writer's studies that have been achieved in the past two decades. At this oppotunity, the writer would like express his sincere thanks to Dr. Bong Kyun Kim, former professor of Seoul Nationl University, Dr. Tamio Kotaka, former professor of Tohoku University, Dr. Mizuo Shimazu, former professor of Niigata University, Dr. Junji Itoigawa, professor of Nagoya University, Dr. Hiroshi Noda, porfessor of University of Tsukuba, for their valuable suggestions and discussions on the Korean Tertiary rocks in field and laboratory. Thanks are due to Professor Hiroshi Shibata of Nagoya University for his suggestion to the writer for contributing the present article to Professor Junji Itoigawa Memorial Volume.

Provincial and Geologic Setting of the Yangnam and Pohang Basins

The Yangnam and Pohang basins are distributed along the coastal zone in the southeastern corner of the Korean Peninsula. The designation of the Yangnam and Pohang basins was done by Yoon (1986). Prio to Yoon (1986), three basins, that is, Pohang, Eoil and Ulsan basins were suggested by Kim (1970) for the Tertiary sequences distributed in the present region. Kim's division (1970) of the Tertiary basins is based on the distributions of the marine strata and did not regard the diastrophism caused the formation of Tertiary basins. Yoon (1986) presented the Yangnam and Pohang basins in view of tectonic history of the Tertiary basins. The Yangnam Basin comprises the Eoil and Ulsan basins of Kim

Fig. 1. Index and geologic map of Tertiary Yangnam and Pohang basins.
1 : Alluvium, 2: Dolerite, 3: Heunghae Formation, 4: Hagjeon Formation, 5 : Cheongogsa Formation, 6 : Danguri Conglomerate, 7 : Sinhyeon Formation, 8 : Gangdong Formation, 9 : Eoil Basalts, 10 : Girimsa Dacite, 11 : Manghaesan Formation, 12 : Ocheon Formation, 13 : Jeongcheolli Conglomerate, 14 : Jeondong Formation, 15 : Janghang Formation, 16 : Churyeong Breccia, 17 : Andongni Conglomerate, 18 : Hudongni Formation, 19 : Sangjeongdong Formation, 20 : Waeupni Tuff, 21 : Wangsan Formation, 22 : Gyeonsang Supergroup, BG : Bulgugsa Granite, Gr : Granite, Ib : Ibamdong Formation, Yo : Yongdongni Member, YTL : Yangsan Tectonic Line.

(1970) as local areas where marine strata are left over, and the Pohang Basin is identical with that of Kim (1970).

The Yangnam and Pohang basins are distributed in the east of the Yangsan Tectonic Line (Yangsan Fault, auct. et al.) that bounds the west of the Pohang-Ulsan Graben (Fig. 1). The Pohang-Ulsan Graben (Yoon, 1986) is bounded by ECF-1 in the north, the Yangsan Tectonic Line and Ulsan Fault in the west and ECF-3 and ECF-4 in the east, and is situated between the Proto-Korean Peninsula and Paleo-Ulleung Land. The graben is subdivided into the northern Paleo-Pohang and southern Paleo-Ulsan troughs, and the Paleo-Yangnam Ridge lies betweaen the two troughs (Fig. 4).

The Yangnam and Pohang basins are similar in size and underlain uniformly by Cretaceous sedimentary and igneous rocks of the Gyeongsang Supergroup as basement, but the two basins are quite different from each other in the Tertiary sequences. The Yangnam Basin comprises Early Miocene dacitic and andesitic-basaltic volcanic rocks and terrestrial sediments with thin late Early Miocene marine sediments, whereas the Neogene rocks of the Pohang Basin lack Early Miocene volcanic rocks and consist mainly of late Early-Middle Miocene marine strata. Strastigraphically, the Tertiary rocks of the Yangnam Basin consist of the Early-Middle Eocene volcanic, Early Miocene non-marine and late Early Miocene marine series, while the Pohang Basin comprises the Early-Middle Eocene and late Early-Middle Miocene marine series (Table.1).

The Early-Middle Eocene rocks named Wangsan Formation (Shimazu et al., 1990; Wangsan Dacitic Volcanics, Yoon, 1989) underlie the Yangnam and Pohang basins, and

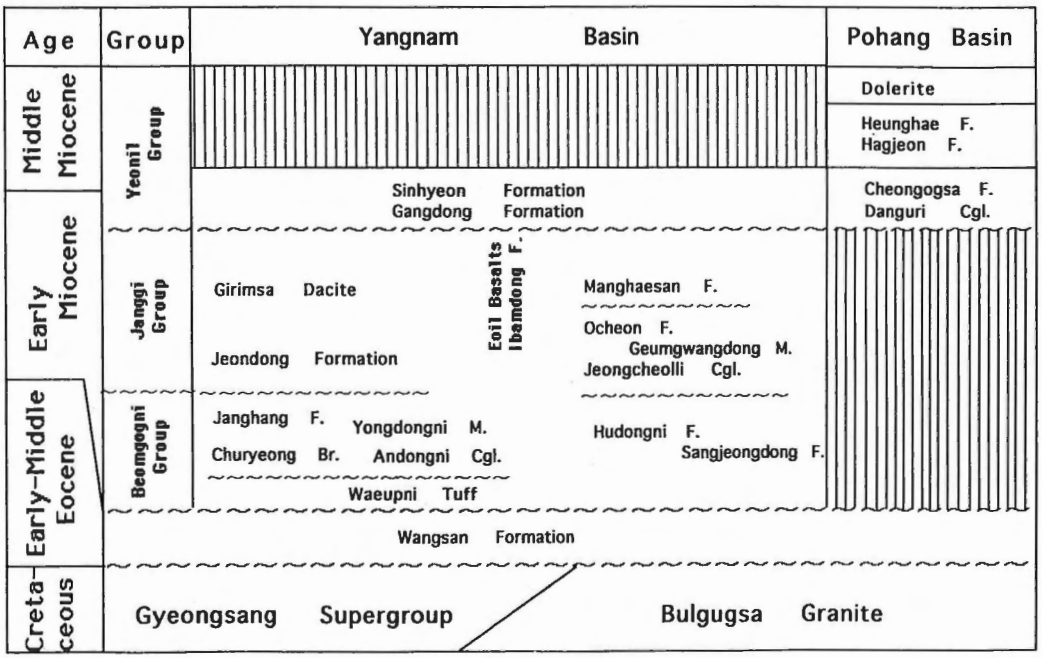


Table 1. Tertiary stratigraphy of the Yangnam and Pohang basins.
Br : Breccia, Cgl : Conglomerate, F : Formation, M : Member.

consist of dacites and dacitic welded tuffs. These rocks were mapped as Cretaceous rocks by Tateiwa (1924) but the radiometric ages of these rocks were dated as Early-Middle Eocene (Shibata et al., 1979; Jin et al., 1988). The Wangsan Formation as well as the Cretaceous Gyeongsang Supergroup is the basement of the Yangnam and Pohang basins.

The Neogene Stratigraphy of the Yangnam Basin

The Neogene rocks of the Yangnam Basin is divided into the Beomgogni, Janggi and Yeonil groups in ascending order. The Beomgogni Group (Poumgogni Group, Tateiwa, 1924) is distributed in the northern part (Guryongpo area) and central part (Gampo area; Eoilli area, Yoon, 1989) of the Yangnam Basin, and consists of dacitic volcanic breccias, lapilli tuffs, conglomerates, tuffaceous sandstones and mudstones. The Janggi Group (Choki Group, Tateiwa, 1924) is mainly distributed in the northern (Geumgwangdong and Mahyeolli area) and in the central part (Gampo area) of the basin, and consists of conglomerates, sandstones, mudstones, dacitic lapilli tuffs, dacitic intrusives, andesitic-basaltic hyaloclastites, hyalotuffs, lavas and intrusives. The Yeonil Group (Ennichi Group, Tateiwa, 1924) is distributed in the Eoil and Ulsan areas, and subdivided into two units: the lower terrestrial Gangdong and the upper marine Sinhyeon formations.

Beomgogni Group

1. Guryongpo area

The Beomgogni group in Guryongpo area is subdivided into the lower Sangjeongdong and the upper Hudongni formations.

Sangjeongdong Formation: The Sangjeongdong Formation (Yoon, 1989) is distributed in the marginal areas of the Hudongni Formation. The formation comprises Tateiwa's Choki Conglomerate near Seog-dong, Donghae-myeon and Nultairi Trachyte Tuff (1924). The Sangjeongdong Formation is conformably overlain by the Hudongni Formation, and consists of alternation of tuffaceous sandstones and mudstones.

Hudongni Formation: The Hudongni Formation (Yoon, 1989) consists of the products of a serial dacitic volcanic activities, and comprises most of Tateiwa's Nultairi Trachyte (1924) in the west of Guryongpo. Kim et al. (1986) subdivided these dacitic volcanic rocks into two units: perlitic dacite and brecciated dacites, and Lee (1987) subdivided them into the Hudongni Tuff, dacite and rhyolite 1. The volcanostratigraphic and petrologic study of these volcanic rocks, however, has not been fully carried out yet. The radiometric age of a dacite is 22.7 ± 1.3 Ma (Kim et al., 1986).

2. Gampo area

The Beomgogni Group in Gampo area is subdivided into the Waeupni Tuff, Andongni Conglomerate, Churyeong Breccia and Janghang Formation in ascending order. The Janghang Formation interbeds the Yongdongni Member in its lowermost part.

Waeupni Tuff: The Waeupni Tuff (Oaeumni Tuff, Tateiwa, 1924) is distributed in the central part of Gampo area, and consists mainly of dacitic welded tuffs and lithic tuffs. The radiometric ages of the dacitic welded tuffs are 21.8 ± 0.5 Ma (Sawada, 1988, letter communication) and 21.20 ± 0.68 Ma-22.27 ± 0.76 Ma (Shimazu, 1988, letter communica-

tion), and is assigned to be Early Miocene in age. The Waeupni Tuff is about 250m in thickness and unconformably overlain by the Andongni Conglomerate.

Andongni Conlomerate: The Andongni Conglomerate (Tateiwa, 1924), which unconformably overlies the Waeupni Tuff, consists of boulder conglomerates and is about 150m in thickness.

Churyeong Breccia: The Churyeong Breccia (Yoon, 1982) is distributed in the western margin of Gampo area. The breccia unconformably overlies the Cretaceous sedimentary rocks of the Gyeongsang Supergroup and the Wangsan Formation, and is conformably overlain by the Janghang Formation. The Churyeong Breccia consists mainly of dacitic volcanic breccias, and lapilli tuffs and tuffaceous sandstones are interbedded in its lower part. The thickness of the Churyeong Breccia is about 300m.

Janghang Formation: The Janghang Formation (Yoon, 1982) conformably overlies the Andongni Conglomerate in the eastern side and the Churyeong Breccia in the western side. The formation consists of dacitic volcanic breccias, lapilli tuffs, welded tuffs add lithic tuffs, and interbeds the Yongdongni Member in its lowermost part. The Yongdongni Member consists of alternation of coarse and fine tuffs, and it comprises the upper part of Tateiwa's Andongni Conglomerate (1924) and the lower part of Tateiwa's Yongdongni Tuff (1924). The Janghang Formation is about 750m in thickness.

Janggi Group

The Janggi Group comprises Early Miocene sedimentary and volcanic rocks. The sedimentary strata of the Janggi Group have some defferences in lithology according to its distributional areas, but commonly have thick conglomerate beds and dacitic volcaniclastic beds in its lower part and andesitic-basaltic hyaloclastitic beds in its upper part. The subdivision of the strata of the Janggi Group in Geumgwangdong area was adopted as the standard of the Yangnam Basin (Yoon, 1989).

Sedimentary rock sequences

1. Geumgwangdong area

The Janggi Group in Geumgwangdong area is subdivided into the lower Jeongcheolli Conglomerate and the upper Ocheon Formation.

Jeongcheolli Conglomerate: The Jeongcheolli Conglomerate (Yoon, 1989) is the basal conglomerate of the Janggi Group, and unconformably overlies the Wangsan Formation. The Jeongcheolli Conglomerate is the emendation of Tateiwa's Choki Conglomerate (1924) in the present area. The Choki Conglomerate (Janggi Conglomerate, herein) was named to the lowermost unit of the Janggi Group in Mahyeolli area, but in Mahyeolli area the basal conglomerate of the Janggi group is not distributed and the name Janggi Conglomerate was abandoned (Yoon, 1989). The Danguri Conglomerate (Yoon, 1980) of the present area is the synonym of the Jeongcheolli Conglomerate. The Jeongcheolli Conglomerate consists chiefly of poorly bedded boulder conglomerates intercalated with thin lenticular sandstone beds, and its thickness reaches about 870m.

Ocheon Formation: The Ocheon Formation (Yoon, 1980) conformably overlies the Jeongcheolli Conglomerate, and consists mainly of sandstones and mudstones interbedding thin lignite beds. Four dacitic volcaniclastic beds are interbedded and were numbered from

1 to 4 in ascending order (Yoon, 1980). The volcaniclastic bed 1 is the equivalent to Tateiwa's Nultairi Trachyte Tuff (1924), and the volcaniclastic bed 2 is the equivalent to Tateiwa's Lower Basaltic Tuff (1924). Tateiwa (1924) adopted the volcaniclastic beds 1 and 2 as key beds, but they are lenticular in shape and not appropriate to be adopted as key beds.

The volcaniclastic beds are similar in lithology one another, and consist of lapilli tuffs and coarse to fine tuffs. The volcaniclastic bed 1 conformably covers the Jeongcheolli Conglomerate, and is conformably overlain by the Geumgwangdong Shale Member (Keumgoangdong Shale, Tateiwa, 1924). The Geumgwangdong Shale Member consists of laminated shales, and yields abundant plant fossils (Changgi Flora, Huzioka, 1972) with rare insect and fish fossils.

The andesitic-basaltic hyaloclastitic beds are not thick in the upper part of the Ocheon Formation in the present area, and it is assumed that much of the upper part of the Ocheon Formation was cut off by the Gwangmyeongdong Fault, by which the Ocheon Formation contacts the Yeonil Group of the Pohang Basin.

2. Mahyeolli area

The Janggi Group in Mahyeolli area is subdivided into the Ocheon and Manghaesan Formation. The lowermost part of the Janggi Group in the present area was named the Janggi Conglomerate (Choki Conglomerate, Tateiwa. 1924) by Tateiwa (1924), but the lowermost part of the Janggi Group in the present area does not comprise conglomerates, especially the boulder conglomerates similar to those of the Jeongcheolli Conglomerate, but conists mainly of alternation of sandstones and mudstones interbedding thin lignite beds. Several conglometrate beds are intercalated in the alternation of sandstones and mudstones, which are about 0.3m to 1m in thickness, lenticular in shape and quite different in lithology from those of the Jeongcheolli Conglomerate. In the present area, the Jeongcheolli Conglomerate, the basal conglomerate of the Janggi Group, is not distributed and the Ocheon Formation only underlies the area. The reason of non-distribution of the Jeoncheolli Conglomerate is that the Girimsa Dacite in the southern part of the present area are not the basement of the Janggi Group but intruded into the Janggi Group, and the intrusion of the dacite made the Jeoncheolli Conglomerate disappear.

Ocheon Formation: The Ocheon Formation in Mahyeolli area comprises Tateiwa's sequence (1924) from the Janggi Conglomerate through the Upper Basaltic Tuff, and is unconformably overlain by the Manghaesan Formation. The Ocheon Formation consists mainly of conglomerates, sandstones and mudstones, and more than six dacitic volcaniclastic beds are intercalated. Of these volcaniclastic beds, the lower two beds are thickest and the lowemost bed was named Nultairi Trachyte Tuff by Tateiwa (1924). The conglomerates are channel-deposits and mainly occur in the middle part of the formation. The upper part of the formation is interbeded with andesitic-basaltic hyaloclastites and hyalotuffs. Peperites were formed at many places, especially around Suyang San (Mountain), by andesitic-basaltic intrusives. The maximum thickness of the Ocheon Formation is about 1,400m.

Manghaesan Formation: The Manghaesan Formation (Park, 1988) unconformably overlies the Ocheon Formation, and consists of dacitic volcanic breccias, lapilli tuffs and

welded tuffs. The Manghaesan Formation comprises Tateiwa's Pansalni Perlite, Manghaisan Andesite and Its Tuff, Changam Perlite and Changam Andesite and Its Tuff (1924). The thickness of the formation is about 700m.

3. Gampo area

The Janggi Group in Gampo area is called the Jeondong Formation.

Jeondong Formation: The Jeondong Formation (Yoon, 1982) interbeds more than three dacitic volcaniclastic beds in its lower part and andesitic-basaltic hyaloclastites and hyalotuffs in its upper part. In view of this fact, the Jeondong Formation is similar in lithologic characteristics to the Ocheon Formation, but the former has some differences in lithology from the latter. In the Joendong Formation, conglomerates are predominant all over the formation, while sandstones and mudstones are in a small amount and minor components. The dacitic volcaniclastic beds of the formation are several meters to more or less 10m in thickness, whereas some volcaniclastic beds of the Ocheon Formation range from about 150m to 300m in thickness. The strata belonging to the Janggi Group in the present area can not be subdivided into the two units: Jeongcheolli Conglomerate and Ocheon Formation, and the name Jeondong Formation was given to the strata as a whole. The Jeondong Formation is about 950m in thickness, and peperites were formed at many places by andesitic-basaltic intrusives.

Volcanic rocks

Girimsa Dacite: The dacitic bodies intruded into the Beomgogni and Janggi groups were named Girimsa Dacite (Shimazu, et al., 1990; Girimsa Dacitic Body, Yoon, 1989). The Girimsa Dacite is distributed in the western part of Gampo area and the southern part of Mahyeolli area. In the western part of Gampo area the Girimsa Dacite intruded into the Beomgogni Group, and in the southern part of Mahyeolli area the Girimsa Dacite intruded into the Janggi Group. The Girimsa Dacite occurs mainly in the terrains of the Wangsan Formation, and it as well as the Wangsan Formation was mapped as the Cretaceous basement of the Yangnam Basin by Tateiwa (1924). At some places, the Girimsa Dacite and Wangsan Formation are not distinguished from each other yet, and detailed mapping to subdivide them remains for future study.

Eoil Basalts: The products of andesitic-basaltic volcanic activity occurred in the late time of the Janggi Group were collectively named Eoil Basalts (Shimazuet al., 1990; Eoil Basaltic-Andesitic Volcanics, Yoon, 1989). The Eoil Basalts comprises Tateiwa's Kuryongpo Andesite in Guryongpo area, Ennichi Basalt and Two Pyroxene Andesite in Geumgwangdong area and Auil Basalt, Hasouri Andesite and Hyotongni Volcanic Rocks in Gampo area (1924), and also Park and Yoon's Dangsari Andesite and Dangsari Andesitic Tuff (1968). The Eoil Basalts occurs as intrusives and flows, and they formed peperites at many palces. The hyaloclastites and hyalotuffs of the upper part of the Janggi group are related to the Eoil Basalts, and the Eoil Basalt Volcanic Acitivity commenced in the late time of the deposition of the Janggi Group, and mainly under water. The radiometric ages of the Eoil Basalts are 17.9±0.6 Ma−18.8±0.5 Ma (Sawada, 1988, letter communication) and 20.5±0.8 Ma−22.7 Ma (Kim et al., 1986) in Guryongpo area, 19.3±1.0 Ma (Tamanyu, 1988) in Geumgwangdong area and 17.16±5.96 Ma−19.57±0.34 Ma (Jin et al., 1988) in

Gampo area.

The andesitic-basaltic volcanic conglomerates and breccias in the northwestern part of Guryongpo area was named Ibamdong Formation (Shimazu et al., 1990; Gonggaesan Formation, Yoon, 1989). Kim et al. (1986) recorded these strata as the Janggi Conglomerate, but the strata do not belong to the Janggi Conglomerate. These volcanic conglomerates are the products of the Eoil Basalt Volcanic Activity.

Yeonil Group

In the Yangnam Basin, the Yeonil Group is separately distributed in Eoil and Ulsan areas, and subdivided into two units: the lower terrestrial Gangdong and the upper marine Sinhyeon formations. The sequence of Gangdong and Sinhyeon formations was established in Ulsan area, and the Songjeon Formation (Yoon, 1976a) of the Eoil area is the correlative to the Sinhyeon Formation. The Hwabongri Formation (Kim, 1970) in the western part of the Ulsan area is the equivalent to the Sinhyeon Formation.

Gangdong Formation: The Gangdong Formation (Yoon, 1976b) unconformably covers the Eoil Basalts, and consists of poorly bedded boulder conglomerates. The thickness of the formation is about 250m in Eoil area and about 80m in Ulsan area. The Gangdong Formation is a piedmont-fluvial deposit, and unconformably overlain by the Sinhyeon Formation. The uncoformity between the Gangdong and Sinhyeon formations is a hiatus existing in the transition from non-marine to marine environments.

Sinhyeon Formation: The Sinhyeon Formation (Yoon, 1976b) consists of alternation of sandstones and mudstones intercalated with thin lenticular conglomerate beds. The thickness of the formation is about 100m to 200m in Eoil area and about 150m in Ulsan area. The Sinhyeon Formation yields marine molluscan fossils belonging to *Vicarya -Anadara* Assemblage (Yoon, 1979) and is an embayment deposit of the late Early to early Middle Miocene time.

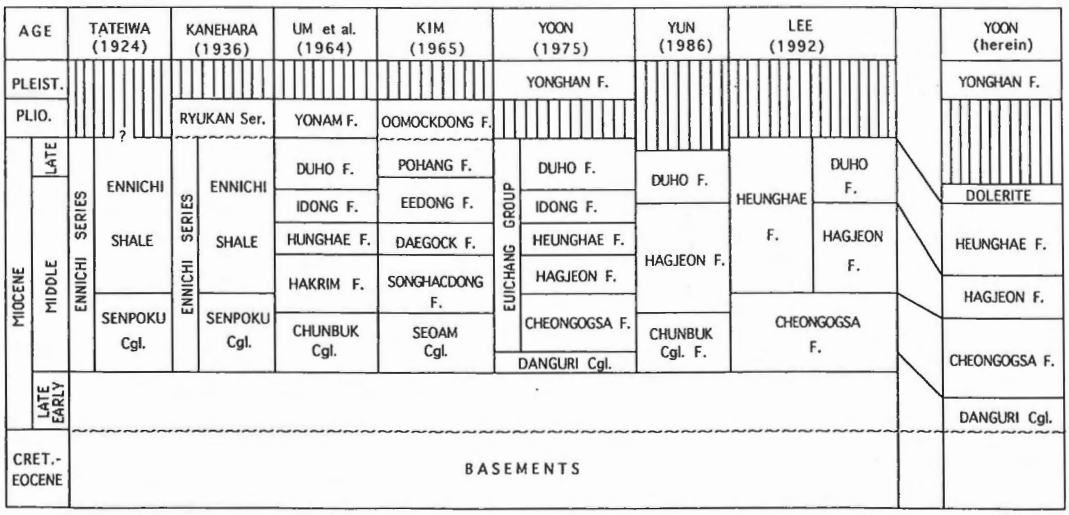


Table 2. Stratigraphic classification of the Yeonil Group in the Pohang Basin.
Cgl : Conglomerate, F : Formation, Ser : Series.

The Neogene Stratigraphy of the Pohang Basin

The Neogene strata of the Pohang Basin are called Yeonil Group, and subdivided into the lower terrestrial Danguri Conglomerate, and the upper marine Cheongogsa, Hagjeon and Heunghae formations. The Idong and Duho formations (Um et al., 1964) is the equivalents of the Hagjeon and Heunghae formations, respectively.

Yeonil Group

Danguri Conglomerate: The Danguri Conglomerate (Yoon, 1975) is distributed along the western margin of the Pohang Basin, and consists mainly of poorly bedded boulder conglomerates intercalated with thin lenticular sandstone beds. At Dangu-ri, the type locality of the Danguri Conglomerate, the boulder conglomerates contain large angular to subangular boulders ranging 30cm to 50cm in major diameter. The largest boulders exceed about 90cm in major diameter. The Danguri Conglomerate is a fault scarp piedmont deposit formed along the Yangsan Tectonic Line, unconformably overlain by the Cheongogsa Formation, and attains up to 200m to 250m in thickness. The uncoformity between the Danguri Conglomerate and Cheongogsa Formation is a hiatus existing in the transition from non-marine to marine environments.

Cheongogsa Formation: The Cheongogsa Formation (Yoon, 1975) consists of conglomerates, sandstones and mudstones, and subdivided into the Bomunji, Doeumsan and Daljeon Alternation members (Yoon, 1975) according to lithological characteristics. The Bomunji and Doeumsan Alternation members consist of alternation of conglomerates and sandstones, whereas the Daljeon Alternation Member consists of alternation of conglomerates and mudstones. The Cheongogsa Formation reaches about 850m in thickness. The Cheongogsa Formation yields marine molluscan remains belonging *Vicarya-Anadara* assemblage (Yoon and Rhee, 1982), *Dosinia-Felaniella* and *Acesta-Conchocele* assemblages (Yoon, 1979), and is an embayment to shallow open sea deposit and late Early-early Middle Miocene in age.

Hagjeon Formation: The Hagjeon Formation (Yoon, 1975) conformably overlies the Cheongogsa Formation, and consists of alternation of sandstones and mudstones. The sandstones are commonly whitish grey in color, arkosic and fine-to medium-grained. The mudstones are very well-bedded and dark reddish grey in color. The Hagjeon Formation yields *Propeamussium* (s.s.) *tateiwai* Kanehara, *Lucinoma acutilineatum* (Conrad), *Conchocele bisecta* (Conrad) etc. (Yoon, 1979) and an open sea deposit. The thickness of the formation is about 50m to 250m.

Heunghae Formation: The Heunghae Formation (Hunghae Formation, Um et al., 1964) conformably overlies the Hagjeon Formation, and consists of siltstones. The siltstones are dark grey in color, fairly well-bedded, yield *Yoldia sagittaria* Yokoyama, *Solemya (Acharax) tokunagai* Yokoyama, *Propeamussium* (s.s.) *tateiwai* Kanehara, *Mizuhopecten Kimurai ugoensis* (Hatai and Nisiyama), *Calyptogena* cf. *elongata* Dall etc. (Yoon, 1979), and are somewhat deep water deposits. The Heunghae Formation reaches about 250m to 300m in thickness, and is Middle Miocene in age.

Geologic Age of the Miocene Marine transgression

The *Vicarya-Anadara* fauna from the Cheongogsa and Sinhyeon formations of the Yeonil Group is analogous to the Arcid-Potamid fauna in Japan, and the marine transgression is coeval with the early Middle Miocene (ca. 16 Ma) transgression into the Japan Sea side area of Japan. In Japan, the Arcid-Potamid fauna (Tsuda, 1965) including many warm water species marks the horizons of the commencement of this marine transgression. This event represents the prominent warm climatic episode called the Mid-Neogene climatic optimum by Tsuchi (1988).

Kim (1990) examined the planktonic foraminiferal fauna of E-core of the Yeonil Group in the Pohang Basin, and stated that the foraminiferal fauna correlates with tropical planktonic foraminiferal zones, N6, N7-N8, N9-N11, N12 and N13 indicating that the basin was an open marine environment between 17.6 Ma and 11.5 Ma.

Yi (1992) studied calcareous nannoplankton from eight cores of the Yeonil Group in the Pohang Basin, and dated the group to be from late Early Miocene 〈upper NN4 (CN3/CN4); 16.5Ma〉 up to Middle Miocene 〈NN6 (CN5a); 12Ma〉 in age.

Yamanoi (1992) discussed the palyno-flora of the Yangnam and Pohang basins with regard to the Korean warm molluscan fauna. Yamanoi (1992) called the contemporaneousness of the Korean *Vicarya-Anadara* fauna with the Japanese Arcid-Potamid fauna in question, and stated that the Japanese Arcid-Potamid fauna comes from the upper B subzone of NP-2, but the Korean *Vicarya-Anadara* fauna comes from the horizon assignable to the lower A subzone of NP-2. NP-2 in Japan is correlative with the Daijima-type flora, and its lower A subzone bears cool floral elements, whereas its upper B subzone contains tropical floral elements. Yamanoi (1992) concluded that the horizon of the *Vicarya -Anadara* fauna in Korea indicates that the paleoclimate was not warm enough to allow habitation of tropical of subtropical plants and animals, and that the marine transgression occurred earlier in Korea than in Central Japan within the Proto-Japan Sea area.

Huzioka (1972) described the Yeonil Flora from the Heunghae Formation, the uppermost unit of the Yeonil Group in the Pohang Basin, and correlated it with the Daijima-type flora in Japan. Huzioka (1972) stated that the majority of the Yeonil species are assignable to the Arcto-Tertiary Geoflora, but 12 (34%) species are regarded as elements of the Paleotropical Tertiary Geoflora. The Heunghae Formation is above the horizon of *Vicarya -Anadara* fauna, and Middle Miocene in age (Kim and Yoon, 1978).

It is likely that the marine transgression, Yeonil Marine Transgression (emendation of Euichangian Marine Transgression, Yoon, 1975), into the Pohang-Ulsan Graben occurred more or less earlier than in Central Japan, and that it commenced already in the period from 17 Ma to 16 Ma (late Early Miocene).

Paleoenvironments of the Yangnam and Pohang Basins

Yoon (1992a) summarized the paleoenvironmental change of the Yangnam and Pohang

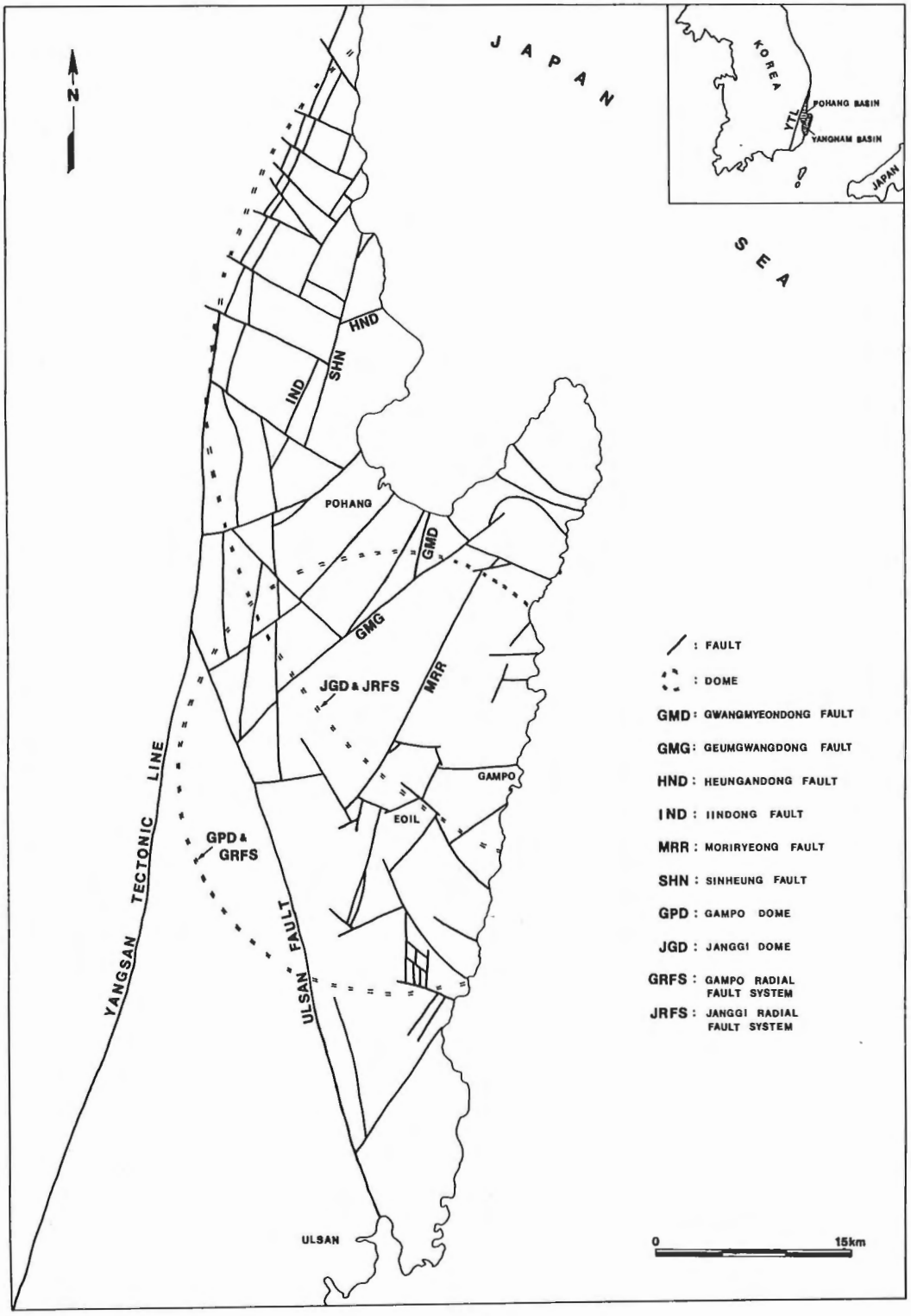


Fig. 2. Radial fault systems of the Yangnam and Pohang basins.

basins, and it is revised as follows:

(1) The Early-Middle Eocene time: Dacitic volcanic activity occurred heavily all over the two basins. The dacitic volcanic activity occurred on land, and a large amount of welded tuffs and volcanic breccias were erupted. The rocks of the Late Eocene through the Oligocene are not found yet, and the area of the Yangnam and Pohang basins seems to have been in a state of quiet and weathering condition in the Oligocene time. In the Oligo -Miocene time, a rift called the Pohang-Ulsan Graben (Yoon, 1986) was formed along the

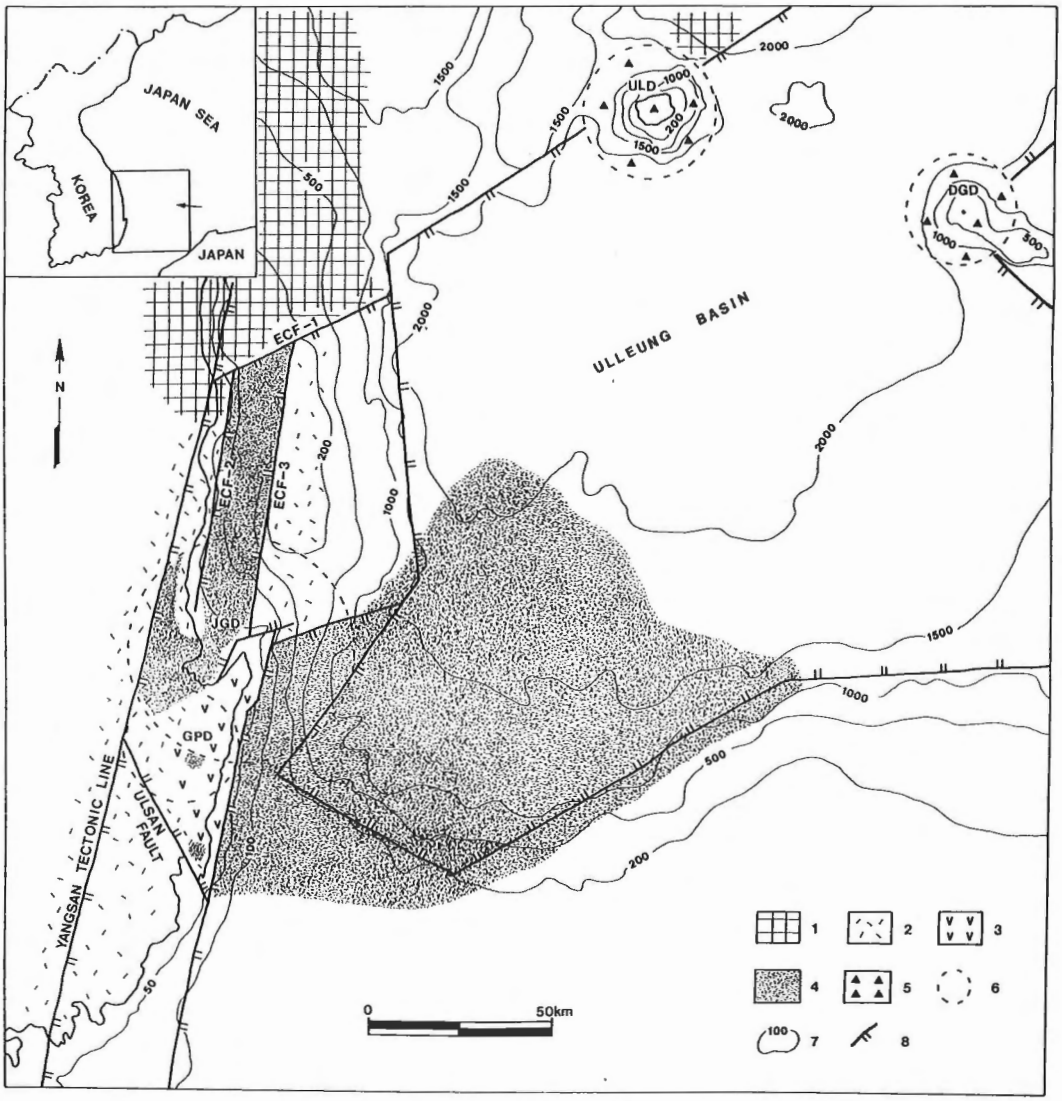


Fig. 3. Geologic map of the Pohang-Ulsan Graben and its environs.
1 : Pre-Cambrian rocks, 2 : Cretaceous-Paleogene plutonic and volcanic rocks, 3 : Early Miocene volcanic rocks, 4 : late Early-Middle Miocene marine sediments, 5 : Pliocene volcanic rocks, 6 : Dome, 7 : Isobath, 8 : Fault, DGD: Dogdo Dome, ECF : East Coast Fault, GPD : Gampo Dome, JGD : Janggi Dome, ULD : Ulleung Dome. Modified after Huntec (1968) and Bersenev and Krasny (eds., 1988).

present southeastern coast of the Korean Peninsula.

(2) The Early Miocene time: Heavy volcanic activity occurred only in the Yangnam Basin, and the Pohang Basin was in a state of quiet upland condition. The volcanic activity in the Yangnam Basin was bimodal in composition, that is, dacitic and andesitic-basaltic. The dacitic volcanic activity occurred during the period from the lower through the upper parts of the Early Miocene sequence, while the andesitic-basaltic volcanic activity occurred during the period from the middle through the upper parts of the Early Miocene sequence. The andesitic-basaltic volcanic activity, Eoil Basalts Volcanic Activity, occurred mainly under water, and this suggests that the Yangnam Basin underwent fresh water invasion and existed as a large lake during most of the Early Miocene time.

Huzioka (1972) reported the Janggi Flora (Changgi Flora, Huzioka, 1972) of the Geumgwangdong Shale Member of the Ocheon Formation, and stated that all of the Janggi species are assumed to be deciduous species of the Arcto-Tertiary Geoflora. The Janggi Flora is correlated with the Aniai-type Flora of Japan. The palyno-floras of the Jeondong Formation and the Geumgwangdong Shale Member of the Ocheon Formation are assignable to NP-1 zone in Japan, indicating cool-temperate climate (Yamanoi, 1992).

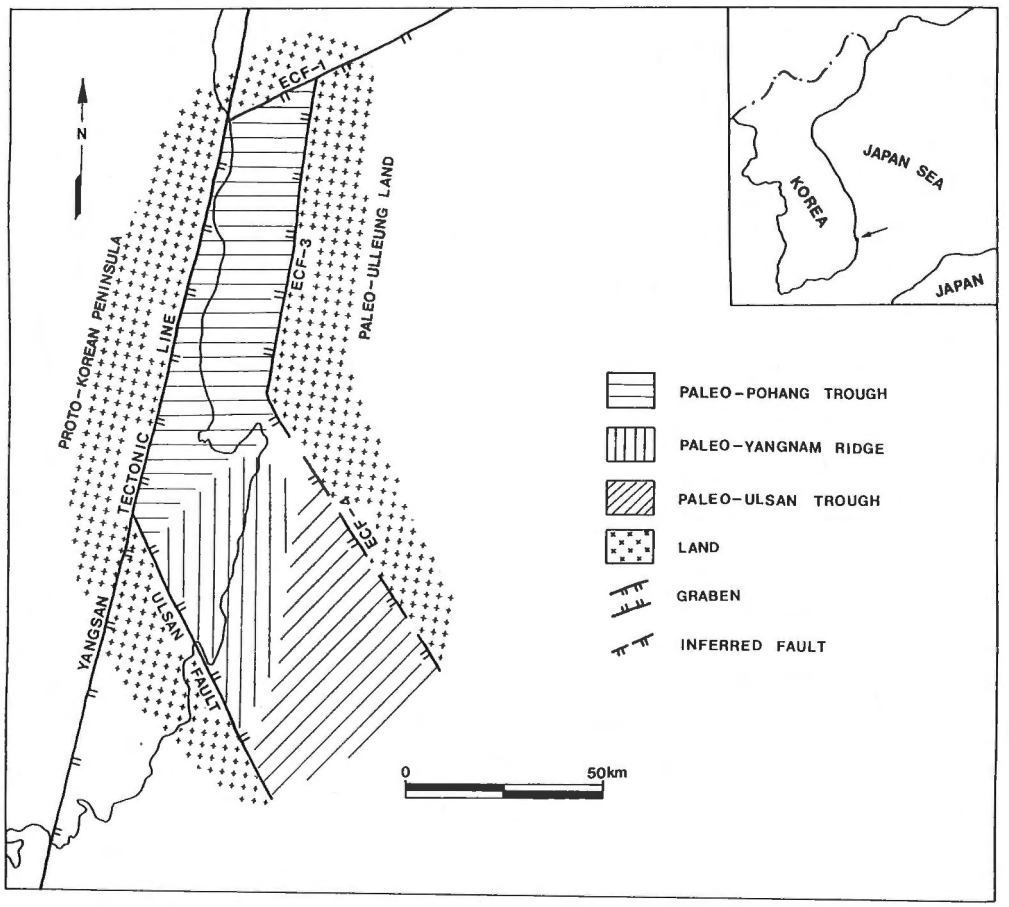


Fig. 4. Paleogeographic map of the Pohang-Ulsan Graben in the Middle Miocene. ECF : East Coast Fault.

In the late time of this epoch (17 Ma-16 Ma), the Pohang Basin began to subside, and the Yeonil Marine Transgression started to advance into the Yangnam and Pohang basins, which brought the warm water elements of the *Vicarya-Anadara* fauna into the embayments.

(3) The Middle Miocene time: The subsidence of the Pohang Basin more advanced, and the basin resulted in an open sea.

The short time interval in the early Middle Miocene (ca. 16 Ma) during which sea water temperatures were highest in the Proto-Japan Sea area is called the tropical spike by Itoigawa (1989). This tropical spike is considered to have been an event during the period when the mangrove flora and fauna cohabited with the Arcid-Potamid fauna in Southwest Japan.

The Yeonil Group yields *Vicarya-Anadara* fauna which has a character in common with the Arcid-Potamid fauna in Japan, but mangrove swamp fauna and flora are not found. The reason of this fact can be explained in two ways: temporal and spatial points of view, as Yamanoi (1992) and Lee (1992). Lee (1992) stated that the Pohang Basin was indistinct in degree of the embaymental development, influenced by higher energy of open sea and the mangrove swamp could not be developed, and also that the Ulsan Basin (Ulsan area, herein), which was more stable in environment than that of the Pohang Basin, might undergo the effect of the open sea by geographical elements.

Tectonic History of the Yangnam and Pohang Basins

The Early-Middle Eocene events are represented by the dacitic volcanic activity occurred all over the Yangnam and Pohang basins. The Early Miocene events are characterized by the dacitic and andesitic-basaltic bimodal volcanic activities, especially the subaqueous andesitic-basaltic volcanic activity, occurred in the Yangnam Basin. The Middle Miocene events are concerned with the Yeonil Marine Transgression.

Volcanic activity

Volcanic events occurred in the Early-Middle Eocene and in the Early Miocene times. The Early-Middle Eocene volcanic activity is dacitic in composition and its products underlie the Yangnam and Pohang basins. The Early Miocene volcanic activity is bimodal in composition: dacitic and andesitic-basaltic, and occurred only in the Yangnam Basin. The majority of the dacitic products comprises volcaniclastic rocks, such as welded tuffs and volcanic breccias. The andesitic-basaltic products contain a lot of hyaloclastites, hyalotuffs and peperites, and the activity occurred mainly under water.

Marine Transgression

The marine transgression started to advance in the late Early Miocene. In the Middle Miocene, the Pohang Basin was an somewhat deep open sea, but the Yangnam Basin region was a sublittoral shallow sea environment.

Radial faulting

two radial and concentric fault systems are recognized in the Yangnam and Pohang basins, and they are named Gampo Radial Fault System (GRFS) and Janggi Radial Fault

System (JRFS), respectively (Fig. 2). These two radial fault systems contact each other by the Moriryeong Fault. The radial faults of GRFS converge into the area where the Janghang Formation is distributed, and the radial faults of JRFS converge into the northeastern offshore of the Janggi Peninsula. These two radial fault systems were formed by the dome-like uplifting, and the two domes are named Gampo and Janggi domes, respectively (Figs. 2 and 3).

Komuro and Fujita (1980) experimented on the formation of the radial and concentric fractures, and stated that radial and concentric faults are formed at the top of the dome -like uplifting. Komura (1987) experimented on the formation of radial and ring fractures, and concluded that the ascending magma body leads to a polygonal cauldron bounded by radial and concentric fractures, whereas the contracting magma body produces a circular cauldron surrounded by ring fractures.

The Gampo Dome was cut by the Moriryeong Fault (Tateiwa, 1924) which is one of the radial faults of the Janggi Dome, and the Gampo Dome was formed prior to the Janggi Dome. The so-called Yangnam Basin is nearly the eastern half of the Gampo Dome, and the so-called Pohang Basin is approximately the western quarter of the Janggi Dome.

Summary of tectonic history

The geologic events occurred in the Yangnam and Pohang basins reflect the tectonic history of the Pohang-Ulsan Graben, and are enumerated as follows in chronological order:

(1) Early-Middle Eocene dacitic volcanism on land: The Wangsan Formation was deposited.

(2) Oligo-Miocene rifting of the Pohang-Ulsan Graben between the Proto-Korean Peninsula and Paleo-Ulleung Land. The Paleo-Ulleung Land had existed until the Late Pliocene (Yoon, 1992b).

(3) Early Miocene dacitic and andesitic-basaltic volcanisms on land and under water: The Beomgogni and Janggi groups were deposited.

(4) Upheaval of the Yangnam Basin: The Beomgogni and Janggi groups were eroded and the terrestrial Danguri Conglomerate and Gangdong Formation of the Yeonil Group were deposited.

(5) Yeonil Marine Transgression: Marine transgression started to advance into the Pohang-Ulsan Graben in the late Early Miocene, and subsequently, in the Middle Miocene, the graben became an open sea and the Paleo-Pohang and Paleo-Ulsan troughs and Paleo -Yangnam Ridge were formed. The Cheongogsa, Hagjeon and Heunghae formations of the Yeonil Group in the Pohang Basin are the uplifted parts of the marine sediments which were deposited in the Paleo-Pohang Trough, while the Sinhyeon Formation in Eoil and Ulsan areas of the Yangnam Basin is the uplifted parts of the marine sediments on the Paleo-Yangnam Ridge.

(6) Uplifting of the Gampo and Janggi domes: Radial fault systems were formed, and the Paleo-Pohang and Paleo-Ulsan troughs and Paleo-Janggi Ridge were destroyed. The age of this uplifting is unknown yet, but is presumed to be Mio-Pliocene.

The tectogenesis of the Pohang-Ulsan Graben is diapiric (Yoon, 1991), and named Eoil Orogeny because it is represented by the Eoil Basalt Volcanic Activity. The Eoil Orogeny

is correlated to the Green Tuff Orogeny in Japan. The Yangsan Tectonic Line is the western wall of the Sado-Pohang Belt (Shimazu et al., 1990) in which the Neogene diapiric tectogenesis occurred.

References

Bersenev, I.I. and Krasny, L.I. (eds.), (1988), Geologicheskaya dna Yaponskogo morya (scale 1 : 2, 500,000). Akad. Nauk SSSR. (in Russian).

Chough, S.K., Hwang, I.G. and Choe, M.Y., (1990), The Miocene Doumsan Fan-Delta, southeast Korea: A composite fan delta system in back-arc margin. *Jour. Sed, Petrol.*, 60 (3), 445-455.

Huntec Ltd., Toronto, Canada, (1968), Report on the offshore gheophysical survey in the Pohang area, Republic of Korea. *ESCAP/CCOP Tech. Bull.*, **1**, 1-12, figs. 1-9, pls. 1-6.

Huzioka, K., (1972), The Tertiary floras of Korea. *Jour. Mining Coll., Akita Univ.*, Ser. A, **5** (1), 1-83, pls. 1-14.

Itoigawa, J., (1989), Tropical spike in early Middle Miocene (ca. 16 Ma) of Southwest Japan. *In* Liu, G., Tsuchi, R. and Lin, Q. (eds.), Proc. Internat. Sym. Pacific Neogene Continental and Marine Events, IGCP-246, Nanjing Univ. Press, 19-26.

Jin, M.-S., Kim, S.-J. and Shin, S.-C., (1988), K/Ar and fission-track datings for volcanic rocks in the Pohang-Kampo area. Res. Rep. KR-87-27, Research on isotope geology, Korea Inst. Ener. Resour., 51-88. (in Korean with English abstract).

Kim, B.K., (1965), The stratigraphic and paleontologic studies on the Tertiary (Miocene) of the Pohang area, Korea. *Jour. Seoul Univ., Sci. Tech.* Ser., 15, 32-121.

———— (1970), A study on the Neogene Tertiary deposits in Korea. *Jour. Geol. Soc. Korea,* **6** (2), 77-96. (in Korean with English abstract).

———— and Yoon, S., (1978), Some molluscan fossils from the uppermost part of the Neogene deposits of the Pohang Basin, Korea. *Jour. Geol. Soc. Korea,* **14** (2), 1-12.

Kim, K.H., Matsuda, J.-i., Nagao, K., Won, J.K. and Lee, M.W., (1986), Paleomagnetism and K-Ar age of volcanic rocks from Guryongpo area, Korea. *Jour, Korean Inst. Mining Geol.*, **19** (3)., 231-237.

Kim, W.H., (1990), Significance of Early to Middle Miocene planktonic foraminiferal biostratigraphy of the E-core in the Pohang Basin, Korea. *Jour. Paleont. Soc. Korea,* **6** (2), 144-164.

Lee, S.H., (1987), The Tertiary stratigraphy of the southernmost part of the Guryongpo Peninsula. M.Sc. thesis, Dept Geol., Graduate School, Pusan Nat., Univ., 1-44. (in Korean with English abstract, unpublished).

Lee, Y.G. (1992), Paleontological study of the Tertiary molluscan fauna in Korea. *Sci. Rep. Inst. Geosci., Univ. Tsukuba,* 13, 15-125.

Park, S.-J., (1988), The Tertiary stratigraphy of the Janggi district. M.Sc. thesis, Dept. Geol., Graduate School, Pusan Nat. Univ., 1-42. (in Korean with English abstract, unpublished).

Park, Y.D. and Yoon, H.D., (1968), Explanatory text of the geological map of Ulsan Sheet, 1 : 50, 000, Geol. Surv. Korea, 1-20, 1-5, pls. 1-20, 1 map. (in Korean with English text).

Shibata, K., Uchiumi, S. and Nakagawa, T., (1979), K-Ar age results-1. *Bull. Geol. Surv. Japan,* **30** (12), 675-689.

Shimazu, M., Yoon, S. and Tateishi, M., (1990), Tectonics and volcanism in the Sado-Pohang Belt from 20 to 14 Ma and opening of the Yamato Basin of the Japan Sea. *Tectonophysics,* 181, 321-330.

Tamanyu, S., (1985), Geothermy of Korea. *Chishitsu News, Geol. Surv. Japan,* 366, 50-57. (in Japanese, original title translated).

Tateiwa, I., (1924), Geological atlas of Chosen, no 2, Ennichi, Kyuryuho and Choyo sheets, 6 p., 3 maps, Geol. Surv. Gov. Gen. Chesen.

Tsuchi. R., (1988), Neogene bio-chronostratigraphy and its bearing on the opening of the Sea of Japan. *Jour. Paleont. Soc. Korea,* 4 (1), 50-54.

Tsuda, K., (1965), Neogene molluscan assemblages in the Inner Zone of Northeast Japan, with special reference to the Middle Miocene assemblages. *Fossils, Palaeont. Soc. Japan,* 10, 20-23, table 1. (In Japanese).

Um, S.H., Lee, D.W. and Bak, B.S., (1964), Explanatory text of the geological map of Pohang Sheet, 1 : 50,000, Geol. Surv. Korea, 1-21, 1-10, 5 pls., 1 map. (in Korean with English text).

Yamanoi, T., (1992), The palyno-flora of early Middle Miocene sediments in the Pohang and Yangnam basins, Korea. In Ishizaki, K. and Saito, T. (eds.), Centenary of Japanese Micropaleontology, Terra Sci. Publ., Tokyo, 473-480.

Yi, S., (1992), Miocene calcareous nannoplankton from the Pohang Basin, Korea. Ph.D. thesis, Chungnam Nat. Univ., 1-119. (unpublished).

Yoon, S., (1975), Geology and paleontology of the Tertiary Pohang Basin, Pohang district, Korea. Part 1. Geology. *Jour. Geol. Soc. Korea,* 11 (4), 187-214.

——— (1976a), The geological and paleontological study of the Tertiary deposits of the Janggi-Eoil district of Korea. No. 1. Stratigraphy and geologic age of the Songjeon Formation. Busan Nat. Univ., Univ. Jour., 21, Nat. Sci. ser., 11-19.

——— (1976b), The Tertiary deposits of the Ulsan Basin. No. 1. Tertiary deposits in the eastern block. *Jour Coll. Liberal Arts and Sci., Busan Nat. Univ.,* 15, Nat. Sci. Ser., 67-71.

——— (1979), Neogene molluscan fauna of Korea. *Mem. Geol. Soc. China.* 3, 125-130.

——— (1980), The Tertiary stratigraphy of the southeast marginal area of the Pohang Basin, Korea. Rep. Korea Sci. Engin. Found., 1-21, 1 map. (in Korean with English abstract, unpublished).

——— (1982), Tertiary stratigraphy of the Eoil Basin, Korea. *Jour. Geol. Soc. Korea,* 18 (4), 173-180.

——— (1986), Tectonic history of the Tertiary Pohang and Yangnam basins, Korea. *In Nakagawa,* H., Kotaka, T. and Takayanagi, Y. (eds.), Kitamura Commem. Essays Geol., 637-644.

——— (1989), Tertiary stratigraphy of the southern Korean Peninsula. *In* Liu, G., Tsuchi, R. and Lin, Q. (eds.), Proc. Internat. Sym. Pacific Neogene Continental and Marine Events, IGCP-246, Nanjing Univ. Press, 195-207.

——— (1991).Geologic events of the Tertiary Yangnam and Pohang basins, Korea, with a remark on the origin of the Yamato Basin of the Japan Sea. *Saito Ho-on Kai Spec. Pub.,* 3 (Proc. Shallow Tethys 3), 303-309.

——— (1992a), Paleoenvironmental change of the Tertiary Yangnam and Pohang basins of the southern Korean Peninsula. *Mem. Geol. Soc. Japan,* 37, 117-124.

——— (1992b), Volcanism and tectonics of the Ulleung Island, Korea, with a note on the formation of the Japan Sea. Proc. 5th Internat. Congr. Pacific Neog. Stratigr. and IGCP Project 246. (in print).

——— and Rhee, S.H., (1982), Discovery of *Vicarya* from the Tertiary Pohang Basin, Korea. *Jour. Geol. Soc. Korea,* 18 (1), 49-52.

Yun, H., (1986), Emended stratigraphy of the Miocene formations in the Pohang Basin, Part 1. *Jour. Paleont. Soc. Korea,* 2 (1), 54-69.

Geographic Names

Andongni＝安洞里
Auil＝Eoil
Bangsalli＝芳山里
Beomgogni＝凡谷里
Bomunji＝普門池
Bugpyeong＝北坪
Changam＝倉岩
Cheongogsa＝泉谷寺
Chunbuk＝川北
Churyeong＝楸嶺
Daegock＝大谷
Daljeon＝達田
Dangsari＝堂舍里
Danguri＝丹邱里
Doeumsan＝禱陰山
Donghae-myeon＝東海面
Duho＝斗湖
Eedong＝Idong
Eoil＝魚日
Eoilli＝魚日里
Gampo＝甘浦
Gangdong＝江東
Geumgwangdong＝金光洞
Gilju＝吉州
Girimsa＝祇林寺
Gonggaesan＝孔開山
Guryongpo＝九龍浦
Gwangmyeondong＝光明洞
Gyeongsang＝慶尚
Hagjeon＝鶴田
Hakrim＝鶴林
Hasouri＝下西里
Heunghae＝興海
Hudongni＝厚洞里
Hwabongri＝華峰里
Hyotongni＝孝洞里
Ibamdong＝立岩洞
Idong＝梨洞
Janggi＝長鬐
Janghang＝獐項
Jeondong＝典洞
Jeongcheolli＝井泉里
Kuryongpo＝Guryongpo
Mahyeolli＝馬峴里
Manghaesan＝望海山
Manghaisan＝Manghaesan
Moriryeong＝毛里嶺
Myeongcheon＝明川
Nultairi＝訥臺里
Ocheon＝烏川
Pansalni＝Bangsalli
Pohang＝浦項
Ryukan＝Yonghan
Sangjeongdong＝上政洞
Senpoku＝Chunbuk
Seoam＝西庵
Seog-dong＝石洞
Sinhyeon＝新峴
Songjeon＝松田
Songhacdong＝松鶴洞
Ulsan＝蔚山
Waeupni＝臥邑里
Wangsan＝旺山
Yangnam＝陽南
Yangsan＝梁山
Yeonghae＝寧海
Yeonil＝延日
Yongdongni＝龍洞里
Yonghan＝龍汗