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Sedimentological Study on the Early Jurassic Shallow Marine Facies in Southwest Japan and the Comparison with Daedong Supergroup in South Korea

by

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Contents

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Abstract

Sedimentological studies, especially petrographic analyses, are carried out on the Early Jurassic Yamaoku, Higuchi, and Toyora Groups in the Inner Side of Southwest Japan and the Daedong Supergroup in South Korea. Based on this study, the sedimentary environment and the relation to tectonism of Southwest Japan and South Korea are discussed.

The Yamaoku Formation is represented by shallow marine sediments of regressive cycle judging from grain-size analyses. Remarkable differences of geologic structure and sediment composition between the Yamaoku and the succeeding early Cretaceous terrestrial beds indicate a middle to late Jurassic crustal movement correlated to the Daebo movement in South Korea. On the other hand, the geologic structure and sediment composition of the Toyora Group indicate that the Triassic movement was stronger than the post-Toyora crustal movement. This Triassic movement corresponds to the Songrim movement in South Korea.

The Daedong Supergroup is a product of the intermontain basin. The characteristic grain-size distribution of sandstones is confirmed to be well comparable to that of the Pleistocene lacustrine-delta sands of the Kobiwako Group around Lake Biwa. Almost all the sandstones of the Daedong Supergroup and the late Paleozoic-middle Triassic Pyeongan Supergroup are highly quartzose assignable to quartz sandstone, while all of the sandstones in Southwest Japan belong to lithic or feldspathic wacke or arenite. Judging from the absence of K-feldspar in the sandstones and common occurrence of orthoquartzite clasts in the conglomerate in South Korea, the Sinian orthoquartzite was once widely distributed around the Ogcheon belt and the present Sea of Japan region.

Abundant occurrence of sand-grains and gravels of acidic volcanic rocks as well as interbeds of acidic tuffs in the Yamaoku Formation suggest the presence of acidic volcanic mountains in the provenance. The Inner Side of Southwest Japan most probably occupied a convergent zone along the margin of Asian continent during the Jurassic time and the Jurassic basin in South Korea was in a backarc basin region. The middle to late Jurassic tectonic movement resulted in an upheaval of all over the Inner Side of Southwest Japan and South Korea may be related to the southward shifting of the convergent zone.

I. Introduction

Recently, the mutual relation between Japan and Korea have been discussed from the view point of metamorphic belt (HIROI, 1981) and paleomagnetism (YASKAWA, 1975; SASAJIMA, 1981).

This paper aims first to describe the petrographic properties of the lower Jurassic clastic rocks of Southwest Japan and South Korea, because hitherto no detailed sedimentological studies of those rocks have been carried out yet, in spite of the fact that the Jurassic tectonism has recently been considered to be significant in Southwest Japan as in Korea. The next is to consider a mutual relation between the two provinces from the view point of sedimentology.

For this purpose the lower Jurassic of the shallow marine or deltaic facies were examined in the Inner Zone of Southwest Japan, such as the Yamaoku Formation in Okayama Prefecture, the Higuchi Group in Shimane Prefecture and the Toyora Group in Yamaguchi Prefecture, and the lower Jurassic Daedong Supergroup of terrestrial origin in Korea were examined.

The sedimentological analyses of CM pattern, sorting-skewness diagram and log-probability curve of grain size of sandstones were made in detail for considering depositional environments. The rock and mineral compositions of conglomerates and sandstones were also examined. The grain size analyses and mineral composition of sandstones were based on 500 grains in thin section. The analytical procedure of CM pattern, sorting-skewness diagram and log-probability curve were made following the methods of PASSEGA (1957; 1977), FRIEDMAN (1961) and VISHER (1969), respectively.

The sedimentological studies on the Carboniferous-Triassic Pyeongan Supergroup in South Korea, the early Cretaceous Kwanmon Group and the fluvio-lacustrine deposits of the Plio-Pleistocene Kobiwako Group in Southwest Japan have also been carried out for comparison.

II. Geological Setting and Stratigraphy

A. Southwest Japan

1. General Geology (Fig. 1)

Southwest Japan is divided into the Inner Zone on the Japan Sea* side and the Outer Zone on the Pacific side by the Median Tectonic Line. The Inner Zone is subdivided into four geologic belts, from north to south, the Hida, Chugoku, Tamba-Mino, and Ryoke belts. The Hida and Tamba-Mino belts are damarcated by the Hida marginal belt, and the Chugoku and Tamba-Mino belts by the Maizuru structural belt.

The Hida belt is composed of the metamorphic rocks of low pressure type and granitic rocks (the Funatsu granite). The Chugoku belt is composed of the Sangun high pressure metamorphic rocks and non-metamorphosed Paleozoic and Mesozoic rocks. The Tamba-Mino belt is composed of non- or weakly metamorphosed upper Paleozoic to middle Mesozoic strata.

The Ryoke belt consists mostly of metamorphic rocks of low pressure type and granites. Within the Inner Zone, Cretaceous to Paleogene felsic plutonic and volcanic rocks are widely distributed.

The study areas of Lower Jurassic strata are located in the Chugoku blet. The distribution of Jurassic strata in Japan is shown in Fig. 1 and their general correlation in the Inner Zone of Southwest Japan is shown in Fig. 2.

2. The Yamaoku Area

2-1. General Geology (Figs. 3 and 4)

This area is constituted by the Sangun metamorphic rocks, the Lower Jurassic Yamaoku Formation, the Upper Jurassic (?) Osayama serpentinite, the lower Cretaceous Kyomiyama Formation, and the upper Cretaceous Sogahara volcanic rocks

* The Japan Sea is called the East Sea in Korea.

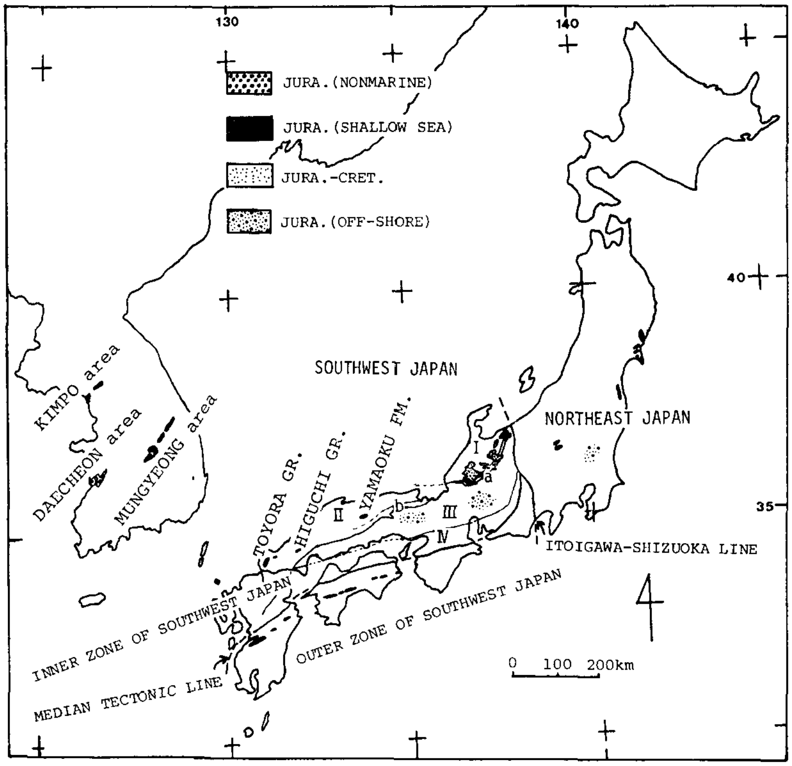


Fig. 1. Index map showing the distribution of Jurassic strata in Japan and South Korea. I: Hida belt, II: Chugoku belt, III: Tamba-Mino belt, IV: Ryoke belt, a: Hida-marginal belt, b: Maizuru structural belt.

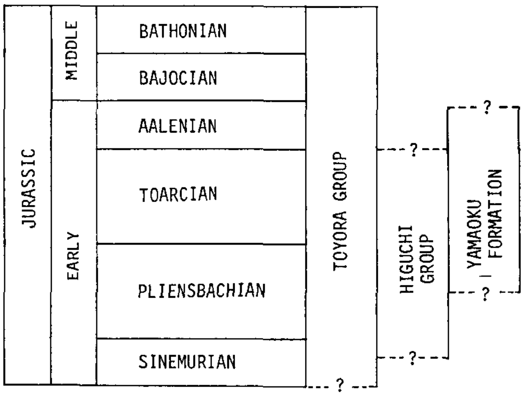


Fig. 2. Age of the Lower Jurassic strata in the Inner Side of Southwest Japan.

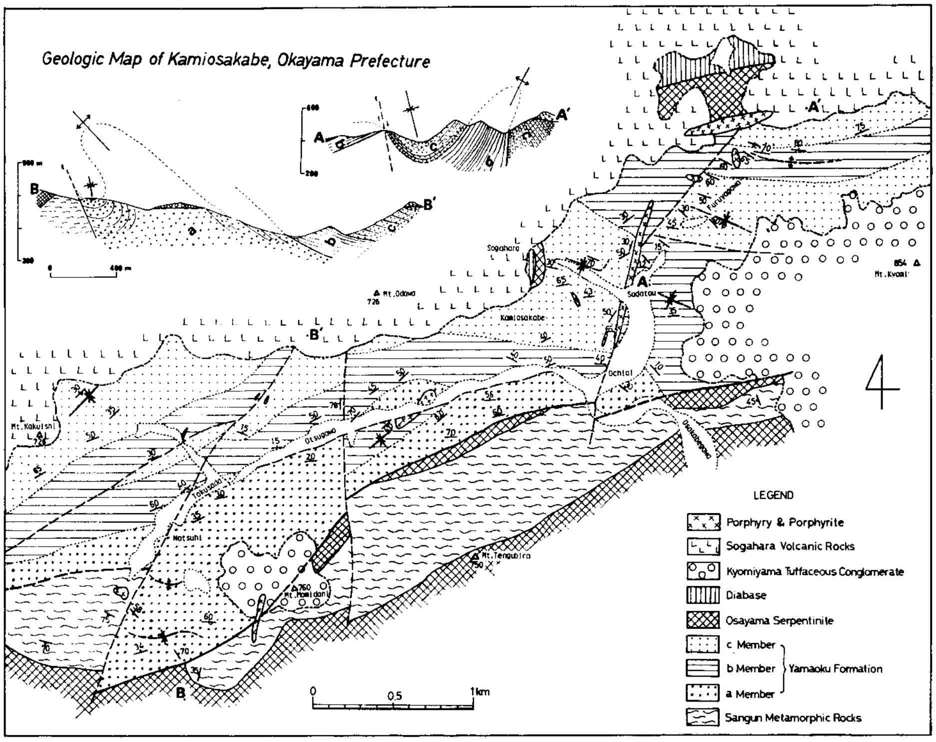


Fig. 3. Geological map of the Yamaoku area.

(Fig. 4). Except for geologic map sheets (YAMADA, 1951; HIROKAWA et al., 1973; and others) only two papers dealt with the geology of the study area (KONISHI, 1954; SATO, 1954). KONISHI first determined the age as early Jurassic for the sandstone-shale alternations of this area and named them the Yamaoku Formation. The stratigraphy of the Yamaoku Formation will be described in the next section (2-2) in detail.

The Sangun Metamorphic Rocks

The Sangun metamorphic rocks, mostly of psammitic origin, are products of low temperature regional metamorphism of the greenschist facies. They occur in close association with the Osayama sperpentinite.

Kyomiyama Tuffaceous Conglomerate Formation

Tuffaceous conglomerates and green or reddish tuffaceous shale, about 200 m in total thickness, are distributed around Mt. Kyomi, and these are named the Kyomiyama tuffaceous conglomerate Formation (YU, 1980). The conglomerate contains gravels of schist, serpentinite, sandstone and shale of various sizes with tuffaceous muddy matrix. The strata are nearly horizontal with a dip of less than ten degrees,

Age	Stratigraphic subdivision
Upper Cretaceous	Dyke rocks Intrusion Sogahara volcanic rocks
Lower Cretaceous	Kyomiyama tuffaceous conglomerates
Upper Jurassic ?	Diabase Intrusion Osayama serpentinite
	Fault
Lower Jurassic	Yamaoku Formation: c, b, a
	Fault
Paleozoic	Sangun Metamorphic rocks

Fig. 4. Stratigraphic division of the Yamaoku area.

and overlie the Yamaoku Formation with a remarkable angular unconformity. The formation is considered to be a part of the Lower Cretaceous Kwanmon Group distributed extensively in Chugoku region.

Sogahara Volcanic Rocks

Rhyolitic and andesitic volcanic rocks occur in the northern part of the study area and are named the Sogahara volcanic rocks (Yu, 1980). Welded tuff and lava are main components, and they are lithologically assigned to the Cretaceous volcanic rocks which widely occur in Southwest Japan. In addition to these volcanic rocks, porphyrite and acidic dykes are scattered, some of which intruded along NNE fault.

Serpentinite

Serpentinite is widely exposed around Mt. Osayama to the south of mapped area, and is named the Osayama serpentinite (Yu, 1980). Serpentinite is also found in the northern part of this area.

Granite

Granite is distributed broadly to the north of the study area. The hornfels of the Yamaoku Formation is believed to be due to the effect of this granite.

2-2. The Yamaoku Formation

Before KONISHI (1954) first pointed out the geologic age of this formation as Early Jurassic based on the similarity of both biofacies and lithofacies to those of the Liassic Kuruma Group in Hida region, it had been believed to be Triassic.

The late Liassic age (Toarcian or later) was suggested by HAYAMI (1957, 1958, 1961) on the basis of bivalve fossils. *Isognomon* sp. identical with *Isognomon* b sp. described by HAYAMI (1957) from the Shinadani Formation of the Kuruma Group have been newly found near the top of Member "a".

The formation is in fault contact with the Sangun metamorphic rocks. It is a future problem whether or not the former covers directly the Sangun metamorphic rocks unconformably, although the latter is unconformably overlain by the Lower Jurassic Toyora Group in the west of the Chugoku Belt. The fault between the Sangun metamorphic rocks and the Yamaoku Formation also cuts the Kyomiyama tuffaceous conglomerate, but it may be the result of the reactivation of the fault.

The Yamaoku Formation, about 660 m thick, strikes EW or NE-SW and is strongly folded. It is composed mainly of sandstone and shale with conglomerate intercalations and is divided into three members, namely, the Members "a", "b" and "c", in ascending order, on the basis of sandstone/shale ratio (Fig. 5).

There are four conglomerate layers which were used as key bed by KONISHI (1954). However, they often change laterally into coarse-grained sandstone and do not indicate a distinct traceable horizon.

Member "a", about 225 m thick, is composed of sandstone-rich alternation of sandstone and shale, coarse- to medium-grained sandstone, and shale. Conglomerate is intercalated at several horizons. The sandstone is mostly massive but small-size cross lamination and grading are rarely observed on polished rock samples. Shallow-sea molluscan fossils are crowded in the upper part (Pl. 1, Fig. 1). In the columnar section of route 2 (Fig. 5) sandstone shows upward coarsening from medium size to coarse size. The boundary between Member "a" and "b" is defined at the base of the sequence consisting of shale and muddy alternation

Member "b" is primarily composed of shale and shale-rich alternation. It is about 185 m in thickness. The shale is thinly laminated. Bioturbation is developed mainly in this member. The sandstone of the alternation is fine-grained and individual beds are less than 50 cm in thickness. The shale-rich alternation of the lower part is composed of fine-grained sandstone, in beds 5–15 cm thick, and shale, in beds 3–20 cm thick. The acidic tuffaceous sandstones, 5–10 cm thick, rarely occur in this member. They have the same acidic volcanic fragments as those of conglomerate and sandstone. One pectinid fossil was found from black shale.

The boundary between Members "b" and "c" is defined at the base of more than 26 m thick, coarse-grained sandstone of Member "c".

Member "c", about 250m thick, is composed mainly of sandstone and sandstone-

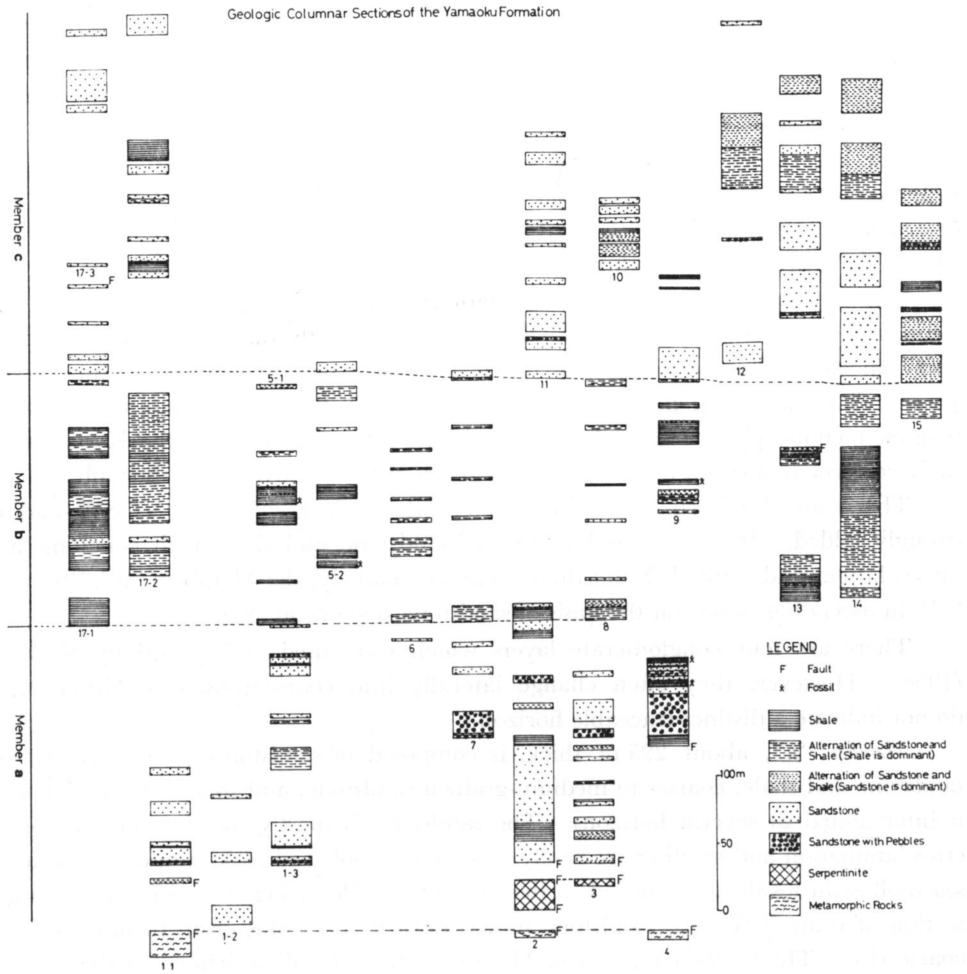


Fig. 5. Columnar sections of the Yamaoku Formation.
Number at the base of each column iudicates route number.

rich alternation of sandstone and shale accompanied with shale-rich alternation (Pl. 1, Fig. 2). The lower part of this member is composed of coarse-grained sandstone and sandstone-rich alternation. The middle part is made of both sandstone-rich and shale-rich alternations, and the upper part is represented by massive coarse-grained sandstone and sandstone-rich alternation. Conglomerate is intercalated in the lower and the middle parts of this member. Shale bed is thinly laminated. The sandstone-rich alternation consists of shale, in beds 2–5 cm thick, and sandstone, in beds 1–1.5 m thick. The shale-rich alternation is composed of shale, in beds 10–15 cm thick, and sandstone, in beds 5–20 cm thick.

3. The Toyora Area

3-1. General Geology

This area is constituted by the Sangun metamorphic rocks, Carboniferous Toyohigashi Group, the Lower Jurassic Toyora Group, the upper Jurassic to the lowest Cretaceous Toyonishi Group, and the lower Cretaceous Kwanmon Group (Fig. 6).

The Sangun Metamorphic Rocks and the Toyohigashi Group

The Sangun metamorphic rocks consist of greenschist and black schist. The Toyohigashi Group consists of sandstone, sandy shale, slate, quartzite, and breccia conglomerate. The both make the basement of the Toyora Group.

The Toyonishi Group

The Toyonishi Group first named by MATSUMOTO (1949) covers the Toyora Group disconformably. It is composed of conglomerate, sandstone, and shale, 650 to 900 m in total thickness. This group yields many plants of the Ryoseki type and brackish-water molluscan fossils, and the age of this group is considered to range from the latest Jurassic to the earliest Cretaceous (MATSUMOTO, 1949; MATSUMOTO *et al.*, 1982).

The Kwanmon Group

The Kwanmon Group covers the Toyonishi Group with a slightly oblique unconformity. This group is divided into the Wakino Subgroup, below, and the Shimonoseki Subgroup, above.

The Kwanmon Group as a whole corresponds to the Gyeonsang (Kyeongsang, Gyongsang) Supergroup in South Korea from its lithofacies, fresh-water molluscs

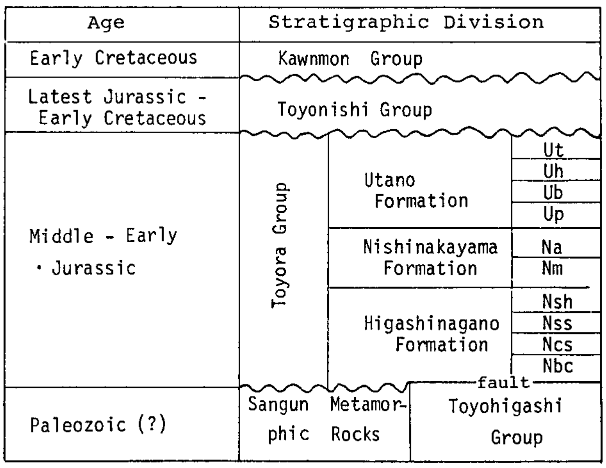


Fig. 6. Stratigraphic division of the Toyora area.

and estheriids. Furthermore, the Wakino Subgroup is correlated with the Nakdong Series, the lower part of the Gyeongsang, and the Shimonoseki Subgroup probably with the Silla Series, the upper part of the Gyeongsang (KOBAYASHI, 1936; TANAKA and NOZAWA, ed., 1977). The depositional environment of the Kwanmon Group and the Gyeongsang Supergroup are well known as non-marine, fluvio-lacustrine deposits. Since the Early Cretaceous time, the Inner Zone of Southwest Japan joined to Korea to form a distinct geologic province in the marginal part of the Asian continent.

3-2. The Toyora Group

The lower Jurassic marine sediments consisting of sandstone, shale, and alternation of sandstone and shale were first named the Toyora Group by YABE (1920). Since YOKOYAMA's study (1904) many papers concerning this group have made important contributions to the Lower Jurassic biostratigraphy in Japan (KOBAYASHI, 1926; HIRANO, 1971, 1973a, b; TAKAHASHI, 1973 and others). However, precise sedimentological studies have not yet been thoroughly carried out. The geology and stratigraphy of this area are based on HIRANO's papers (1971, 1973, a, b) (Fig. 6). The Toyora Group is distributed in two areas, northern and southern, separated by a fault of NW-SE direction called the Tabe Fault (KOBAYASHI, 1936). In this paper, the writer treated mainly the northern district.

The Toyora Group reaches about 1900 m in maximum thickness and rests unconformably on the Sangun metamorphic rocks. The strata mostly have NE-SW strike and NW dip, showing monoclinal structure except in the Utano-dani and Ishimachi, where they form synclinal and anticlinal structures. Based on the sedimentary cycle, it is divided into three formations in ascending order, namely, the Higashinagano Formation of the transgressive phase, the Nishinakayama Formation of the inundative phase and the Utano Formation of the regressive phase (MATSUMOTO, 1949). The age of the Toyora Group ranges from Sinemurian to Bathonian as evidenced by ammonoid zones (HIRANO, 1973, a, b).

According to HIRANO (1971), the Higashinagano Formation, about 400 m thick, consists of four lithologic units, Nbc, Ncs, Nss, and Nsh in ascending order. Each unit is characterized by conglomerate, coarse-grained sandstone, fine-grained sandstone, and sandy shale, respectively, showing upward fining sequence.

The Nishinakayama Formation, about 250 m thick, consists of clayshales with alternating shale and sandstone in the upper part (Na) and thinly or paper-like bedded shale in the middle and lower part (Nm) (Pl. 2, Fig. 3). Ammonites are commonly contained.

The overlying Utano Formation is composed of silty shale, sandy shale, and alternating beds of shale and sandstone. It contains a less amount of ammonites than the Nishinakayama Formation. It is about 400 m thick in the eastern area, but attains to 1100 m in the west. Groove cast and prod cast are rarely seen (Pl. 2, Fig. 4),

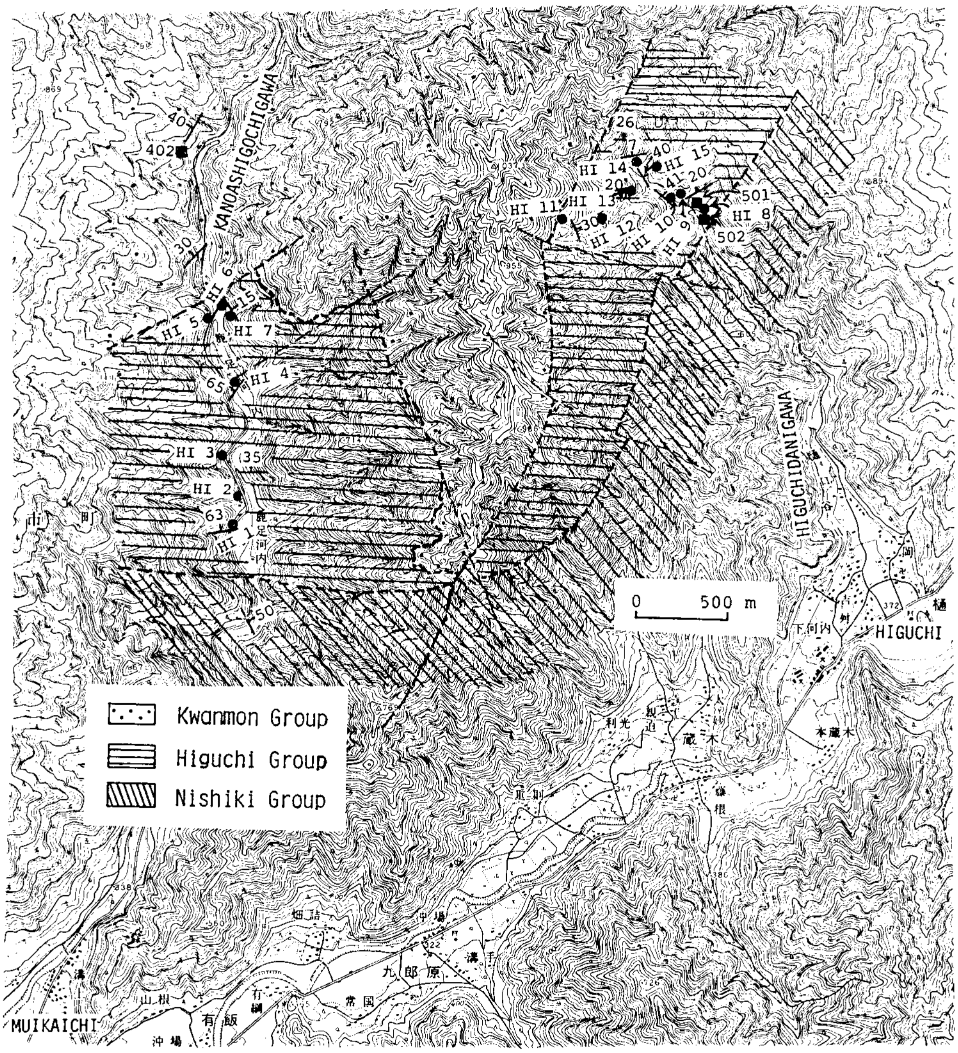


Fig. 7. Geological map and sampling locality os the Higuchi area (modified from Hirano et al., 1978).

showing a current direction from N50E. This formation is subdivided into four members, Up, Ub, Uh and Ut, in ascending order.

It is noteworthy that the Toyora Group did not suffer severe folding. Moreover, the molasse type deposits of upper Triassic Mine Group in adjacent area directly cover the Sangun metamorphic rocks and/or the Permian rocks. Therefore, it is natural to consider that the pre-Toyora disturbance was more intense than the post-Toyora disturbance.

4. The Higuchi Area

4-1. General Geology (Fig. 8)

The present area is constituted by various kinds of sedimentary rocks which were formerly considered to be of younger Paleozoic. IMAMURA *et al.* (1966) first reported the existence of the Jurassic rocks in this area, and named them the Higuchi Group, based on two samples of ammonites obtained from gravels of a river floor. These were preliminarily considered to indicate early Jurassic age by SATO (in IMAMURA *et al.*, 1966). After then, MIKAMI and MIYAGAWA succeeded in collecting several amonites and bivalves from exposures of the Higuchi Group. Describing those ammonites, HIRANO *et al.* (1978) confirmed the Early Jurassic age (Pliesbachian) of the fauna.

4-2. The Higuchi Group

The Higuchi Group is in fault contact with the Permian? Nishiki Group and

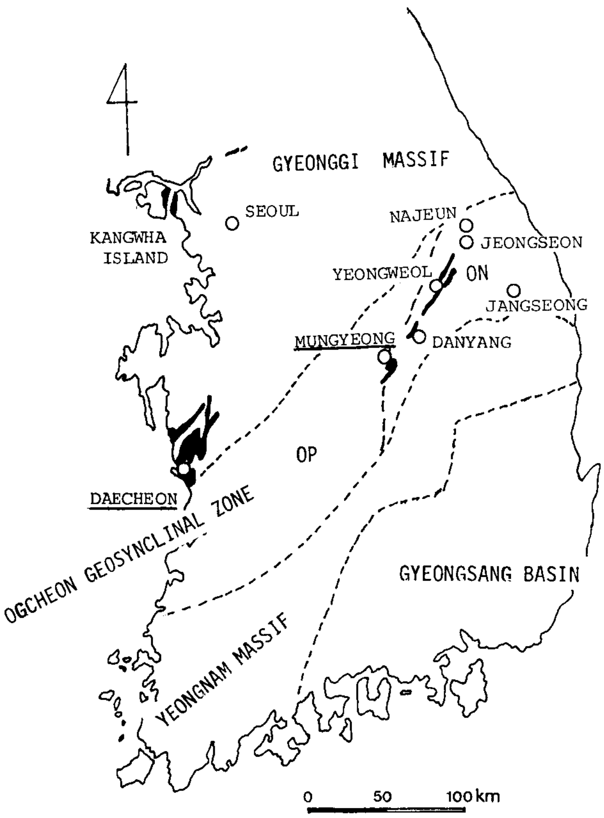


Fig. 8. Geological division and distribution of the lower Jurassic Daedong Supergroup in South Korea.

unconformably overlain by the Kwanmon Group (Fig. 7). It is divided into two formations. The Lower Formation, about 600 m thick, is composed of conglomerate and sandstone. The Upper Formation, about 290 m thick, is composed of black sandy shale, shale and fine- to coarse-grained sandstone. IMAMURA *et al.* (1966) reported that conglomerate and thinly bedded tuffaceous rock were intercalated in the Upper Formation.

B. South Korea

1. General Geology

South Korea is divided into four geological provinces, from north to south, the Gyeonggi massif, the Ogcheon (Okchen) geocynclinal zone, the Yeongnam massif, and the Gyeongsang sedimentary basin, and in addition the small Tertiary basins are scattered (KIM, 1974, 1975) (Fig. 8). The Geonggi and Yeongnam massifs are composed of Precambrian schists and gneisses. The Ogcheon geosynclinal zone stretches diagonally across the Korean Peninsula in the central part of South Korea.

The Ogcheon System consisting of metamorphic rocks occupies the southwestern portion of Ogcheon geosynclinal zone, and Joseon and Pyeongan Supergroups of Cambrian to Triassic age are distributed in northeastern portion of the zone. KOBAYASHI (1953) called the two zones as "Metamorphosed Ogcheon zone" and "Non-metamorphosed Ogcheon zone", respectively and thought that the former represents a metamorphic facies of the latter. But some authors insist the Precambrian age for the Ogcheon System (KIM, 1970; REEDMAN and UM, 1975; KIM and YU, 1977). KIM (1970) designated the metamorphosed part as the "Palaeogeosynclinal zone" and the non-metamorphosed part, the "Neogeosynclinal zone". The age of the Ogcheon System is still controversial among Korean geologists. The Jurassic Daebo and Cretaceous Bulkuksa granites are scattered in both zones.

The Gyeongsang basin occupies the southeastern part of the peninsula and is made up of a thick series of Cretaceous terrestrial sedimentary rocks associating with andesitic volcanic rocks and tuff. The Bulkuksa granite intrudes randomly into the sediments in the basin.

A few small Tertiary basins are scattered in the eastern coastal area and Jeju (Saishu) Island off the peninsula. The Neogene rocks are composed of marine sedimentary rocks in association with basaltic flows. The general stratgraphy of South Korea is given in Fig. 9. The lower Jurassic Daedong Supergroup in Mungyeong and Daechon areas is the subject of the present study.

The Mungyeong area in the Ogcheon zone is located in North Geyongsando (Fig. 8). This district is famous for coalfiled. The coal seams are intercalated in Pyeongan and Daedong Supergroups. The limestones of the Cambro-Ordovician Joseon Supergroup is overlain by the Carboniferous-Triassic Pyeongan Supergroup with

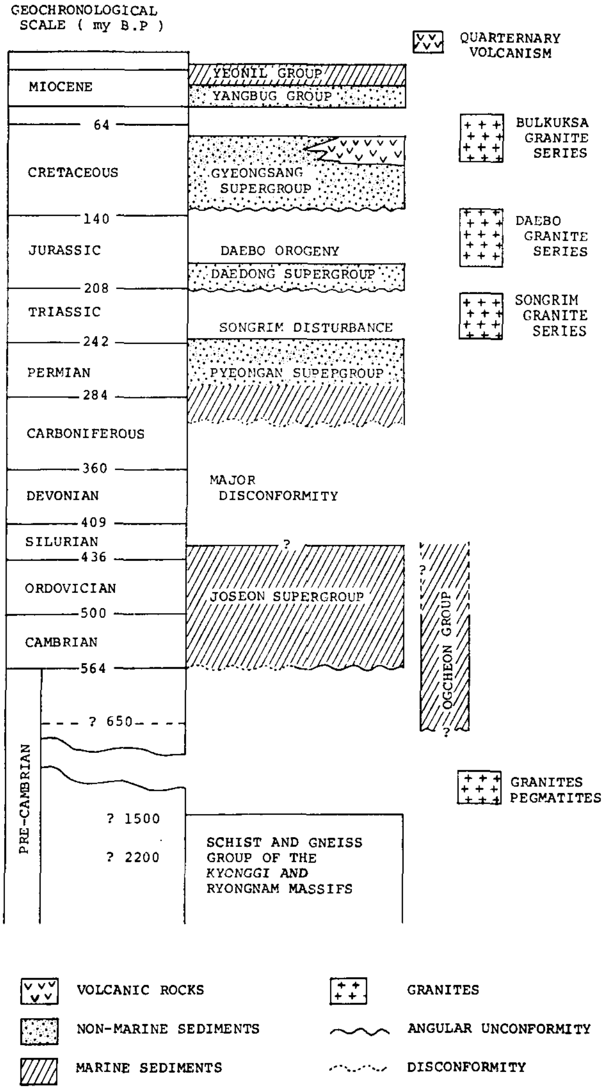


Fig. 9. Stratigraphic classification of South Korea (modified from REEDMAN and UM, 1977).

unconformity, and is in contact with the Daedong Supergroup by overthrust on the west portion of this area.

2. The Daedong Supergroup

The Daedong Supergroup has been thought to be of fluvial or lacustrine origin in developing coal seams, rich land flora and complete lack of marine fossils. It is generally referred to as the early Jurassic in age (Organizing Committee of IGCP/

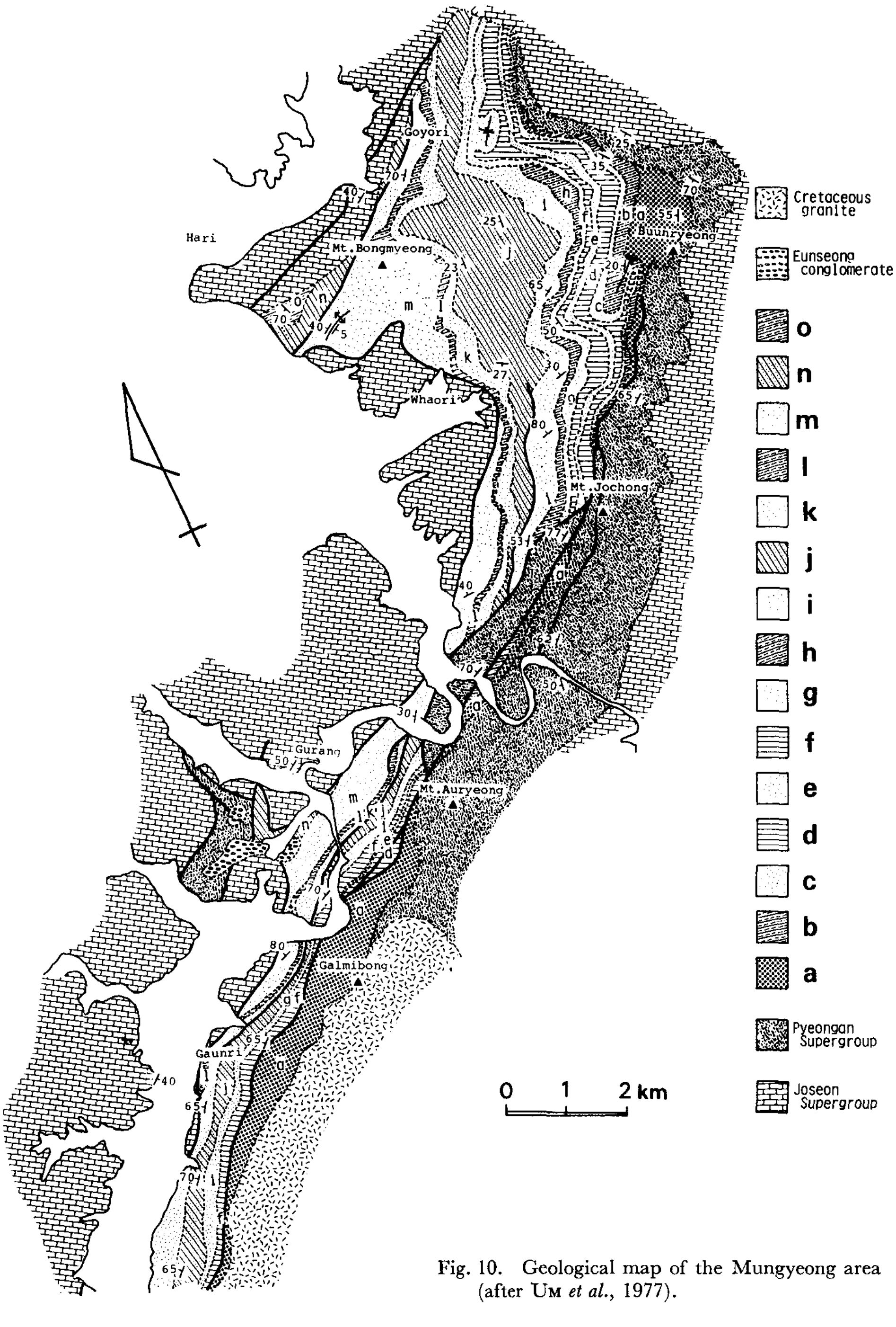


Fig. 10. Geological map of the Mungyeong area (after UM *et al.*, 1977).

CPPP and KIGAM 1966), but some authors thought it to range from late Triassic to early Jurassic (Kobayashi, 1930; Chang, 1975; Um *et al.*, 1977; Tateiwa, 1976). In any cases, the age of the Daedong Supergroup is inserted between the most important two disturbances in Korea, namely, the Songrim and the Daebo orogenies. Therefore, it is important for understanding the Mesozoic disturbance in Southwest Japan in relation to Korean Peninsula. The geologic map of Mungyeong area (Fig. 10) and the stratigraphic division (Fig. 11) are mainly based on Um *et al.* (1977).

In Mungyeong area, the Daedong Supergroup is divided into seven formations on

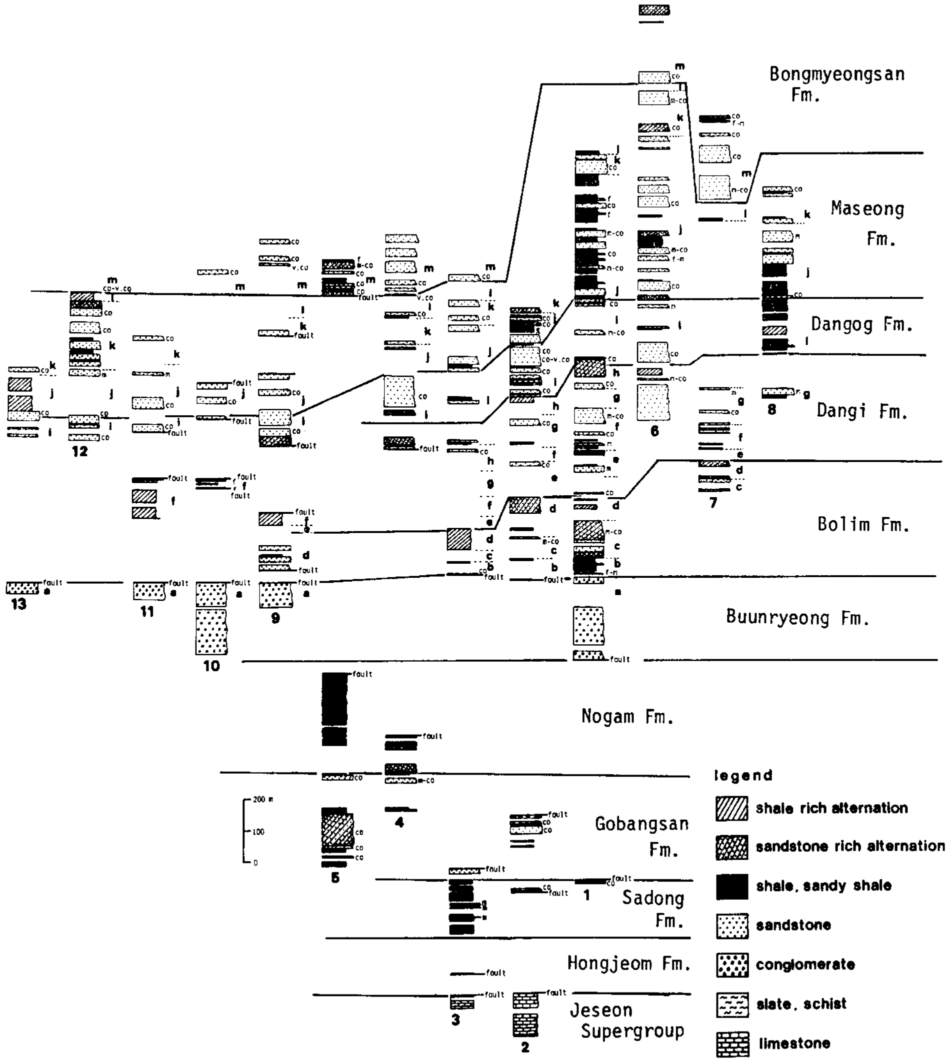


Fig. 11. Columnar sections of the Daedong Supergroup in the Mungyeong area.

lithological characters, namely Buunryeong Conglomerate, Bolim, Dangi, Dangog, Maseong, Bongmyeongsan and Bongmyeongri Formations, in ascending order. Um *et al.* (1977) subdivided them into fifteen zones (symbols a–o in Fig. 11). The Buunryeong Conglomerate Formation ("a") overlies unconformably the Pyeongan Supergroup. The Bolim Formation is subdivided into shale zone ("b"), sandstone zone ("c") and coal-bearing zone ("d"). The Dangi Formation is subdivided into lower sandstone zone ("e"), coal-bearing zone ("f"), upper sandstone zone ("g") and shale zone ("h"). The Dangog Formation ("i") is mainly composed of white-gray coarse-grained quartzose sandstone. The Maseong Formation is subdivided into alternation zone composed of alternating black shale and white-gray medium- to coarse-grained sandstone ("j"), sandstone zone ("k") and shale zone ("l"). The Bongmyeongsan formation ("m") is composed mainly of gray coarse-grained sandstone with pebble-bearing sandstone and some black shale. The Bongmyeongri Formation is subdivided into alternation zone ("n") and shale zone ("o").

Generally the sandstone zones mentioned above are composed of gray, or white-gray coarse-grained quartzose sandstone, with a few thin black shales, and the shale zones consist of black shale with some coal seam intercalations. The alternation zones are composed of gray, medium- to coarse-grained quartzose sandstone and black shale with some coal seams. Sole marks occur very rarely in the Daedong Supergroup. Undulatory small ripple mark was found in "i" zone (Plate 3, Fig. 3).

In Daecheon area, the Daedong Supergroup is called the Nampo Group which is composed of thick conglomerates, coarse-grained sandstones and shales. A few data were obtained there and these will be described together with those of Mungyeong area.

3. The Pyeongan Supergroup

The Pyeongan Supergroup overlies the Joseon Supergroup with parallel or angular unconformity and overlain by the Daedong Supergroup with angular unconformity. The Pyeongan Supergroup is divided into four; the Hongjeom, the Sadong, the Gobangasan and the Nogam Formations in ascending order by lithological characters, especially color, and by paleontological data (Fig. 12).

The Hongjeom Formation consists mainly of red sandstone and shale with interbeds of greenish gray quartzose sandstone, shale, and light gray or variegated limestone. It varies between 150 m and 500 m in thickness. This formation is mostly marine, but according to Reedman and Um (1975), the basal member of this formation is supposed to be non-marine in places.

The Sadong Formation consists mainly of gray to dark gray quartzose sandstone, gray shale, coaly shale, and coal seam with thin dark gray limestone beds. The lower part of this formation is supposed to be marine but the upper part is non-marine, containing important coal seams in South Korea. The thickness ranges from 100 to

	Geologic Age	Stratigraphic Division of Pyeongan Supergroup
Early–Middle Triassic	Ladinian	Nogam Formation
	Anisian	
	Scythian	
Permian	Tatarian	Gobangsan Formation
	Kazanian	
	Kungurian	
	Artinskian	Sadong Formation
	Sakmarian	
Late Carboniferous	Stephanian	
	Westphalian	Hongjeom Formation

Fig. 12. Subdivision of the Peyongan Supergroup.

200 m.

The Gobangsan Formation is in sharp contact with the underlying Sadong Formation, and locally overlies the Sadong Formation unconformably. It consists mainly of white, green to red quartzose and gray or reddish gray shale, and varies in thichness from 500 to 1,000 m (Organizing Committee of IGCP/CPPP and KIGAM, 1977).

The Nogam Formation (Greenstone Series) consists mainly of greenish quartzose sandstone and shale with conglomerate leneses. This formation varies greatly in thickness reaching a maximum of 3,000 m. The Gobangsan and Nogam Formation are both considered to be terrestrial.

III **Petrographic Analyses on the Clastic Rocks**

A. The Yamaoku Formation

1. Conglomerates

Conglomerates of the Yamaoku Formation are grouped into three, that is, P-1,

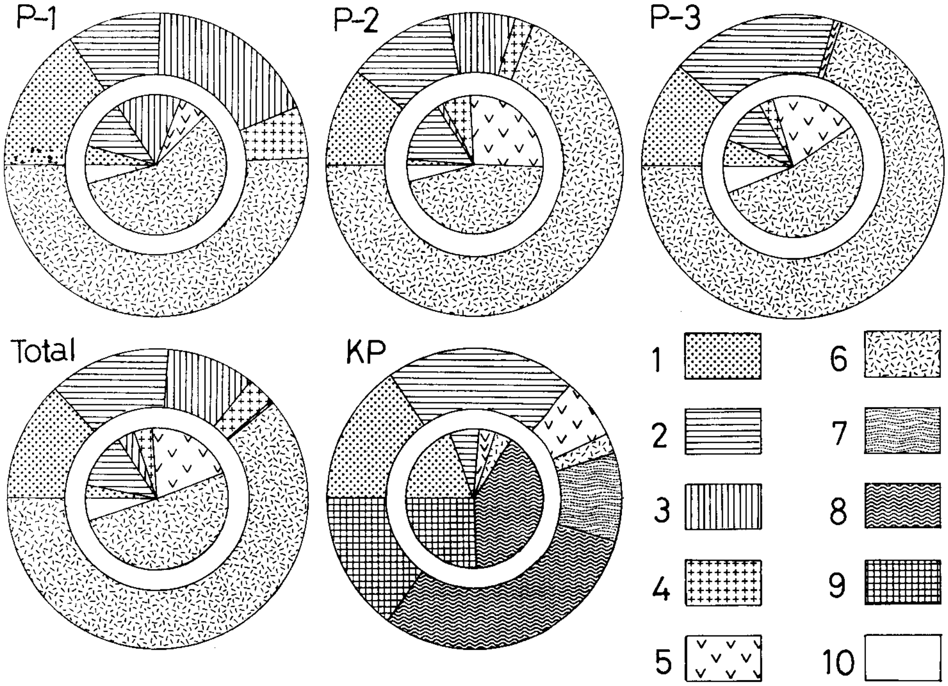


Fig. 13. Composition of clasts of conglomerate. P-1~3 and Total: Yamaoku Formation, KP: Kyomiyama tuffaceous conglomerate Formation. Outer cirlce identified by hand lens, and inner circle under microscope. 1: sandstone, 2: shale, 3: chert, 4: granitic rocks, 5: andesitic volcanic rocks, 6: acidic volcanic rocks, 7: serpentinite, 8: crystalline schist, 9: quartz rock, 10: others.

P-2, and P-3; P-1 belongs to lower part of the Member "a", P-2, middle to upper part of the Member "a"; P-3, lower to middle part of the Member "c" (PI. 1, Fig. 3). The clasts of conglomerate were examined by magnifying glass (size larger than 5 mm, mostly 10 mm) and under microscpoe (size ranging from 2 to 20 mm). The size is relatively small, mostly less than 4 cm. 368 clasts were examined in the field (Fig. 13, outer circle). The roundness of the KRUMBEIN's classification (KRUMBEIN, 1941) ranges from 0.5 to 0.8 and is mostly well rounded. No remarkable compositional change can be detected among the three groups. They comprise acidic volcanic rocks, sandstone, shale, chert, granite and intermediate volcanic rocks in descending order of total amount. The acidic volcanic rocks are most abundant, occupying more than 60 per cent of the total clasts, while the intermediate volcanic rocks are only 0.3 per cent in amount.

The composition of 376 clasts from fifteen localities examined under the microscope is shown as inner circle of Fig. 13. The composition is very similar to that examined in the field excepting a more common occurrence of intermediate volcanic rocks and a less amount of sandstone and chert. The both are characterized by a large amount of acidic volcanics. The amount of chert has a tendency to decrease from P-1 to P-3. It is noticeable that the clasts of schist and serpentinite were not found at all in the Yamaoku Formation.

A lenticular body of pebble-bearing tuffaceous shale, about 10 m long and 1 to 1,5 m thick, is observed at one locality in the Member "b". It also has acidic volcanic rocks, tuff, shale, sandy shale and quartz rock, ranging from 2 to 100 mm in size.

For comparison, the conglomerates of the lower Cretaceous Kwanmon Group (Kyomiyama conglomerate Formation) were also examined (Fig. 13, KP).

It is a remarkable fact that they contain abundant schists and some serpentinite. Fine- to coarse-grained sandstone, reddish shale and intermediate volcanic rocks were also observed in the clasts, but acidic volcanic rocks occupy only a few per cent of the total amount. The clasts of the Kwanmon Group are generally larger in size and more angular in shape than those of the Yamaoku Formation.

2. Grain Size Distribution of Sandstones

Grain size analyses on thin section by Nikon Profile projector were made on fifty-one sandstone samples of the Yamaoku Formation, that is, sixteen samples (1-16) of Member "a", ten (17-26) of Member "b", and twenty-five (27-51) of Member "c".

Mean ($M\phi$), sorting ($\delta\phi$), and skewness ($\alpha\phi$) were calculated from Inman (1952) method, namely, $M\phi=\frac{\phi 16+\phi 84}{2}$, sorting $\delta\phi=\frac{\phi 84-\phi 16}{2}$, and skewness $\alpha\phi=\frac{M\phi-Md\phi}{\delta\phi}$. Grains smaller than 5ϕ (0.031 mm) in maximum length are treated as matrix. The sandstones are concentrated in the field of fine- to medium-grained sandstone in Wentworth (1922) scale. Mean phi of the Member "b" is smaller than that of Member "a" and "c", and the matrix is larger in amount (Table 1). The sorting ranges from 0.40 to 0.95, and mainly "moderately well sorted" of Folk (1966).

Skewness mainly ranges from -0.25 to 0.25 and is "nearly symmetrically skewed"*. In the sorting versus skewness diagram (Fig. 14), most of the sandstones

Table 1. Various parameters of sandstones of Yamaoku Formation in terms of mean value calculated from Appendix table 1.

Member	PHI 1	PHI 16	MEDIAN PHI	PHI 84	MEAN PHI	SORTING	SKEWNESS	MATRIX-2
c (25)	0.49	1.44	2.08	2.73	2.07	0.65	-0.03	21.6
b (10)	1.06	1.96	2.58	3.24	2.60	0.64	-0.01	25.2
a (16)	0.13	1.09	1.70	2.31	1.70	0.81	0.01	15.5
Total (51)	0.49	1.43	2.06	2.70	2.06	0.63	-0.01	20.4
Range	-0.65~ 2.25	-0.35~ 2.9	0.4~ 3.55	1.1~ 3.95	0.45~ 3.42	0.4~ 1.05	-0.85~ 0.44	5.6~ 74.0

* The reason why both the arenite and wacke are nearly symmetrical skewed is not clear.

are plotted in beach sand realm of FRIEDMAN (1961). The distribution pattern on CM diagram (Fig. 15) suggests the transport by rolling and graded suspension (Class I, IV and V of PASSEGA & BYRAMJEE, 1969). Nearly all the sandstones examined contain a relatively large amount of muddy matrix (smaller than 5ϕ) ranging from

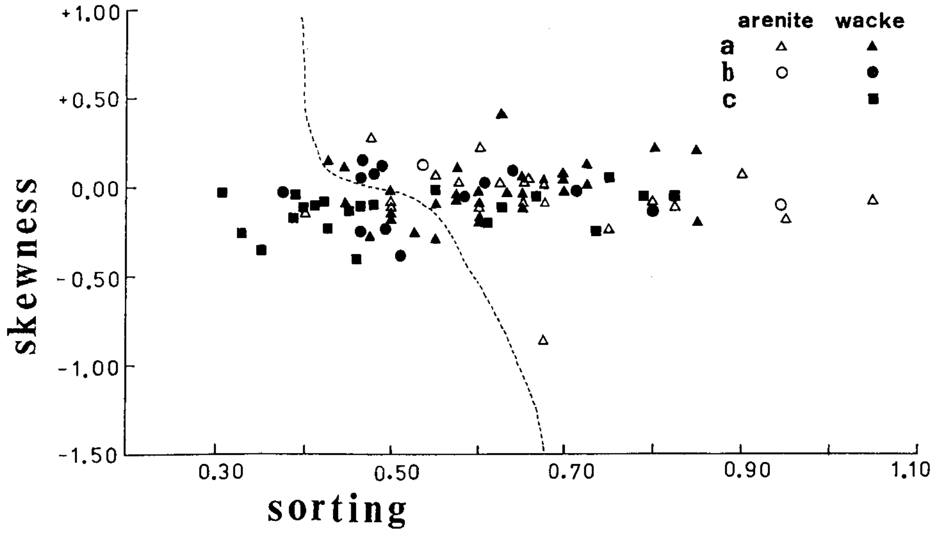


Fig. 14. Skewness-sorting diagram of the Yamaoku Formation (a), Higuchi Group (b), and Toyora Group (c).

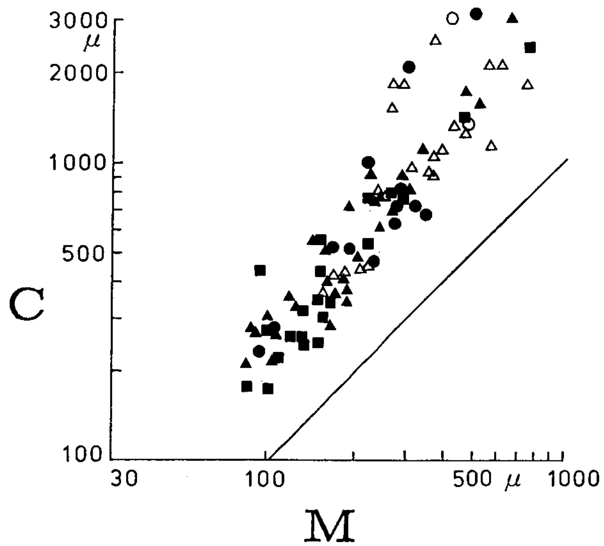
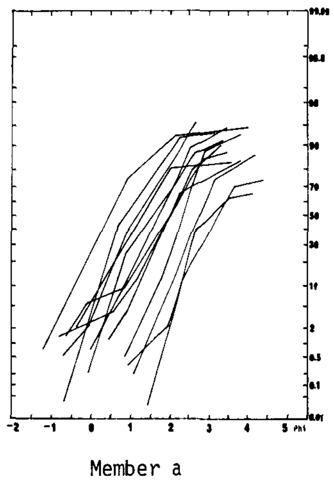
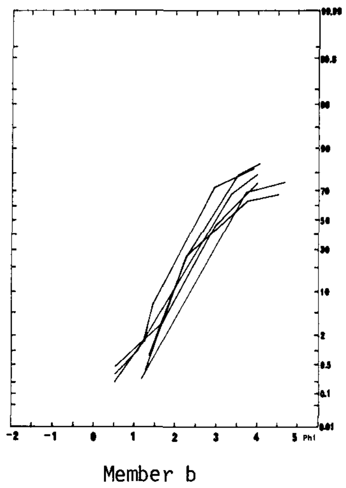


Fig. 15. CM diagram of the Yamaoku Formation, Higuchi and Toyora Groups. Symbols same as in Fig. 14.

3.6% to 43.4%. Many of log-probability curve shapes (Fig. 16) show a similar pattern consisting of two "populations", namely, moderately sorted "saltation population" and rather poorly sorted "suspension population"*. This pattern is similar to that of fluvial or delta distributary sands or sanastones shown by VISHER (1969), although sandstones of Member "a" and "c" are generally coarser in grain-size than those of VISHER's examples. This type is especially common in Member "c".





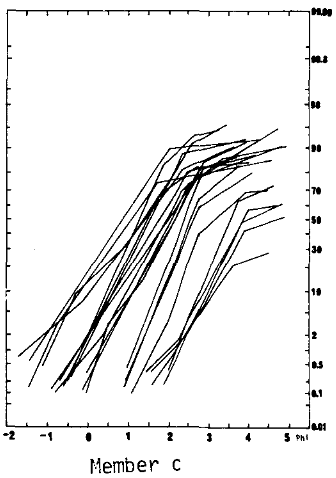


Fig. 16. Log-probability curves of sandstones of the Yamaoku Formation.

* The usage of such populations by Visher is a matter of criticism. They may not represent true populations as noticed by BLATT *et al.* (1972). However, the distribution pattern is still useful for considering the sedimentary environment.

Most of the other curves have "intermediate (mixed?) population" between saltation and suspension. Such type of distribution curve is similar to that reported by NAKAZAWA *et al.* (1979) from the lower Cretaceous sandstones which were considered as shallow marine origin based on the molluscan fossils and the development of trough-type cross lamination. This curve shape is common in Member "a" which yields shallow marine or brackish-water molluscs, such as *Bakevellia magnissima*, *Isognomon* sp. and *Eomiodon vulgaris*. The sedimetological analyses stated above indicate a shallow marine and delta or fluvial environments for the Yamaoku Formation. A transgression-regression cycle is suggested by log-probability curve shapes.

3. Mineral Composition of Sandstones

Though many compositional classifications of sandstone have been proposed, OKADA's (1971) classification is here adopted.

Mineral composition were observed on thin sections made on forty-eight sandstone samples (Table 2). A staining method by sodium cobaltinitrite (BAILEY and STEVENS, 1960; NORMAN, 1974) was spplied for distinction of plagioclase and potash feldspar. Accessory minerals include biotite, muscovite, zircon and opaque minerals.

As shown on QFR (quartz-feldspar-rock fragment) ternary diagram (Fig. 17) the sandstones are classified as lithic and feldspathic arenite and wacke. There is no distinct vertical difference in composition throughout the Yamaoku Formation.

Table 2. Mean composition of sandstones of each member and maturity index Q/(F+R) and provenance index F/R.

Member	Mono-Quartz	Poly-Quartz	Total Quartz	Plagio-clase	Potash Feldspar	Total Feldspar	Acidic Volcanic Rocks	Intermediate Volcanic Rocks	Chert
c (22)	20. 10	2. 02	22. 13	24. 29	1. 80	26. 09	20. 11	2. 86	0. 65
b (10)	19. 64	1. 72	21. 28	20. 80	0. 50	21. 30	17. 22	1. 66	0. 52
a (16)	19. 93	2. 61	22. 55	22. 32	2. 01	24. 33	23. 32	5. 38	0. 50
Total (48)	19. 95	2. 15	22. 07	22. 90	1. 60	24. 50	20. 58	3. 45	0. 57
Range	9. 4~ 35. 8	0. 0~ 9. 4	11. 2~ 45. 2	11. 2~ 35. 4	0. 0~ 7. 0	11. 6~ 42. 4	10. 8~ 36. 0	0. 0~ 12. 4	0. 0~ 3. 2

Member	Carbonate	Granite	Shale	Other Rock Fragment	Total Rock Fragment	Accessory Mineral	Matrix	Q/(F+R)	F/R
c (22)	0. 30	0. 11	0. 44	5. 69	30. 01	4. 31	17. 52	0. 40	0. 92
b (10)	0. 10	0. 10	0. 08	6. 38	26. 06	4. 76	26. 54	0. 46	0. 83
a (16)	0. 11	0. 45	0. 30	6. 32	36. 41	3. 25	13. 41	0. 39	0. 75
Total(48)	0. 20	0. 22	0. 32	6. 04	31. 32	4. 05	18. 03	0. 41	0. 84
Range	0. 0~ 3. 8	0. 0~ 2. 6	0. 0~ 1. 8	1. 0~ 15. 2	17. 6~ 57. 8	0. 0~ 16. 8	3. 6~ 43. 4	0. 15~ 0. 97	0. 21~ 1. 59

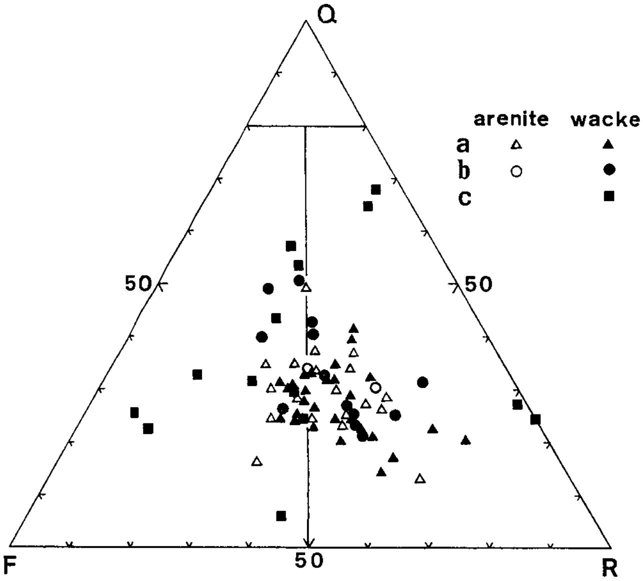


Fig. 17. QFR (quartz-feldspar-rock fragment) diagram of sandstones of the Yamaoku Formation (a) and the Higuchi (b) and Toyora (c) Groups.

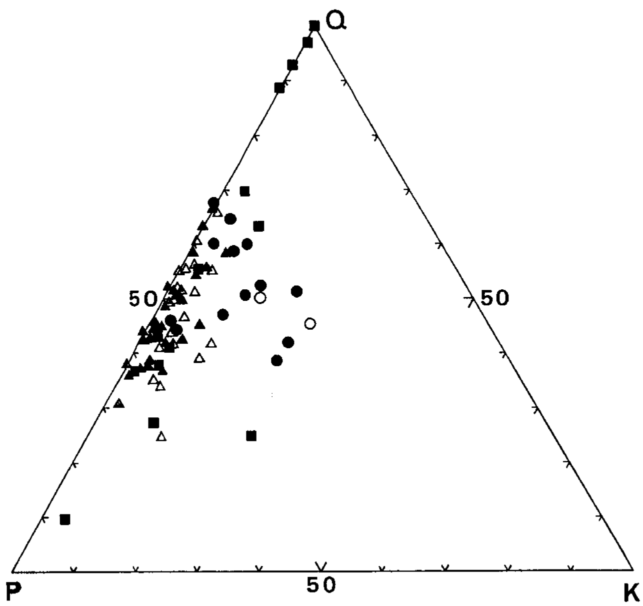


Fig. 18. QPK (quartz-plagioclase-potash feldspar) diagram of sandstones of the Yamaoku Formation and the Higuchi and Toyora Groups. Symbols same as in Fig. 17.

The sandstones are characterized by a small amount of potash feldspar (Fig. 18).

Quartz content range from 11.2 to 45.2% of the total constituents and 22.07% on an average. Most of quartz grains are monocrystalline, and polycrystalline quartz occupies only a few per cent. According to BLATT (1967), monocrystalline quartz of granular gravel to medium-sand size are considered to be derived much more from massive plutonic rocks than from gneisses or schists. He also described that polycrystalline quartz from gneisses will be formed of a greater number of smaller quartz crystals than that from massive plutonic rocks or schists. In the study area, polycrystalline quartz grains are commonly formed of a few crystals. Therefore, quartz grains are suggested to be derived mainly from massive plutonic rocks. Feldspar ranges from 11.6 to 42.4% with the average 24.5% of the total constituents. Potash feldspar includes orthoclase, microcline, sanidine and perthite. Rock fragments occupy 31.32% on an average and range from 17.6 to 57.8%. Acidic volcanic grains, composed mainly of rhyolitic materials, occupy about 65% of the whole rock fragments (Pl. 1, Fig. 4). Andesitic volcanic grains occupy 11%, chert occupies about 2%, and grains of carbonate, granite and shale are few. Biotite, muscovite, zircon and other opaque minerals occupy 4.05% on an average and range from 0 to 16.8% of the

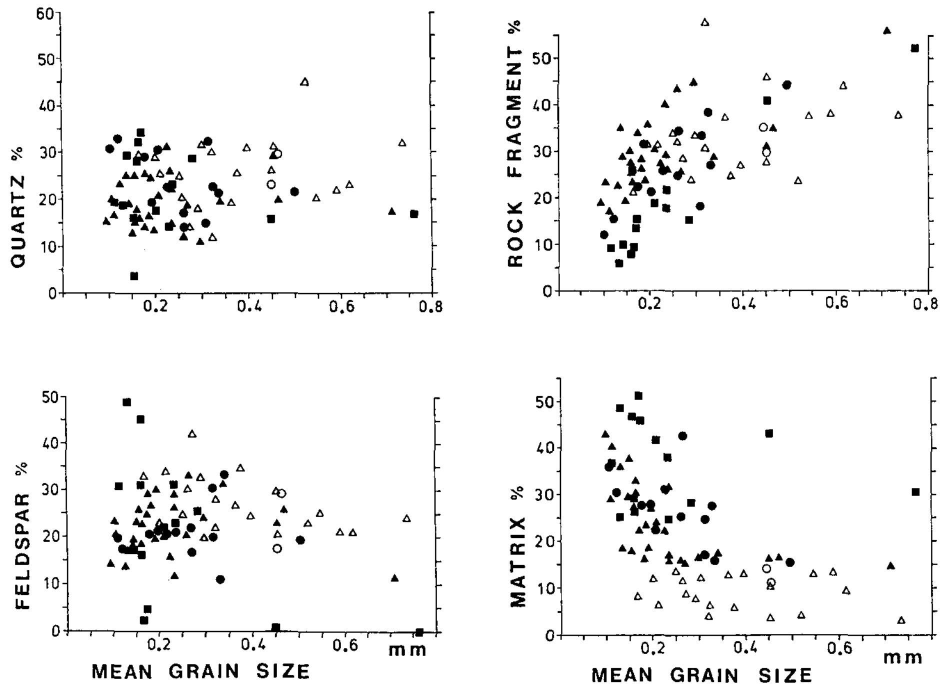


Fig. 19. Diagrams showing the relation of quartz, feldspar, rock fragment, and matrix versus mean grain size of sandstones of the Yamaoku Formation, and the Higuchi and Toyora Groups. Symbols same as in Fig. 17.

Table 3. Correlation coefficient of monocrystalline quartz (MONOQZ), polycrystalline auartz(POLYQZ), tatal quartz (TTLQZ), plagioclase (PLAGIO), potash feldspar (KFELD), total feldspar (TTLFELD), acidic volcanic rocks (ACIDVOLC), intermediate volcanic rocks (INTVOLC), granite, shale, other rock fragments (OTHERFRG), total rock fragments (TTLROCK), accessory minerals (ACCESRY), and matrix to mean grain size of sandstones of Yamaoku Formation. 1: mean grain-size in mm, 2: in phi unit.

SPSS BATCH SYSTEM

FILE YAMAOKU3 (CREATION DATE = 03/03/81) SEDIMENTOLOGICAL DATA OF THE YAMAOKU FORMATION

- - - - - - - - - - - - P E A R S O N C O R R E L A T I O N C O E F F I C I E N T S - - - - - - - - - - - -

1

	MONOQZ	POLYQZ	TTLQZ	PLAGIO	KFELD	TTLFELD	ACIDVOLC	INTVOLC	CHERT	CARBONAT
MEANMM	0.1841	0.5149	0.3202	0.0241	-0.0321	0.0118	0.5332	0.4463	0.2777	-0.0297
	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)
	P=0.105	P=0.000	P=0.013	P=0.435	P=0.414	P=0.468	P=0.000	P=0.001	P=0.028	P=0.421

	GRANITE	SHALE	OTHERFRG	TTLROCK	ACCESRY	MATRIX2
MEANMM	0.2517	0.0503	-0.0608	0.5493	-0.3315	-0.5973
	(48)	(48)	(48)	(48)	(48)	(48)
	P=0.042	P=0.367	P=0.341	P=0.000	P=0.011	P=0.000

2

	MONOQZ	POLYQZ	TTLQZ	PLAGIO	KFELD	TTLFELD	ACIDVOLC	INTVOLC	CHERT	CARBONAT
MEAN	-0.1929	-0.5196	-0.3290	-0.1445	-0.0618	-0.1388	-0.5285	-0.4522	-0.2445	-0.0099
	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)	(48)
	P=0.095	P=0.000	P=0.011	P=0.164	P=0.338	P=0.173	P=0.000	P=0.001	P=0.047	P=0.473

	GRANITE	SHALE	OTHERFRG	TTLROCK	ACCESRY	MATRIX2
MEAN	-0.2673	-0.1157	0.0068	-0.5719	0.3091	0.7083
	(48)	(48)	(48)	(48)	(48)	(48)
	P=0.033	P=0.217	P=0.482	P=0.000	P=0.016	P=0.000

(COEFFICIENT / (CASES) / SIGNIFICANCE) (A VALUE OF 99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED) total constituents. The matrix is composed mainly of clay minerals such as chlorite and sericite, and subordinately of detrital grains smaller than 0.031 mm (5ϕ) in maximum diameter. The amount of matrix is variable ranging from 3.6 to 43.4%, and 18.03% on an avarage.

The index of provenance factor (F/R) (PETTIJOHN, 1957) is considered to show the relative importance of the plutonic and supracrustal rocks as detritic contribution in sandstone.

Mean values of the index of provenance factor are 0.92 (member a), 0.83 (member c) and 0.75 (member c). It shows that supracrustal rocks are more important factor than plutonic rocks, but on such a complicated basement structure as in this area it is difficult to have a reliable conclusion.

Maturity index formulated as Q/(F+R) (PETTIJOHN, 1957) is listed in Table 2.

It is pointed out by several workers that the composition of sandstone is related to the grain size (FOLK, 1954; SHIKI, 1959; OKADA, 1966). The relation of quartz, feldspar, rock fragment and matrix contents to mean grain size is examined (Fig. 19). Nearly the same relationship is obtained in all members, irrespective of grain size. Rock fragments increase in abundance with the rising grain size. It is well kown that matrix increases in accordance with decrease of grain size. This tendency is also recognizable in this study. However, there is no definite relation between quartz or feldspar and grain size. Correlation coefficient of constituent mineral versus mean grain size is listed in Table 3. That of rock fragments is 0.549 and of matrix is —0.597; these are coincided with the results of Fig. 19 stated above.

It is worthy of note that the cluster analysis clearly shows the intimate relation of chert with rock fragments but not with quartz (Fig. 20). The results of trend surface analysis, descriptive statistics, discriminant analysis, and factor analysis were published elsewhere (NISHIWAKI and YU, 1981). By the cluster analysis, the mineral compositions of the sandstones were grouped into four. 1) mono- and polycrystalline quartz, and granitic rock, 2) plagiocalse, potash feldspar, accessory minerals, carbonate rocks and shale, 3) acidic and intermediate volcanic rocks, chert and other rock fragments, 4) matrix. Granitic rock is grouped together with quartz, but is small in amount. Matrix is grouped independently. In factor analysis (Table 4), chert is also separated from quartz.

4. Scanning Electron Microscope Observation on Shales

Scanning electron microscopy (SEM) has been used extensively to study the surface features of detrital mineral grains, especially quartz grain, in relation to depositional environment or transportation mechanism (KRINSLEY and McCOY, 1977; WHALLEY, ed., 1978). Another course of SEM study in sedimentology is a clay fabric analysis on muddy sediments considering that the fabric reflects the transportion and deposition mechanisms (O'BRIEN, 1971; O'BRIEN *et al.*, 1980).

```
TREE PRINTED OVER CORRELATION MATRIX (SCALED 0-100).
CLUSTERING BY AVERAGE DISTANCE METHOD.
   VARIABLE
NAME     NO.
             -------------------------------------/
MONOQZ  (  1) 65 69/61 49 40 56 56/35 57 40 31/29/
                  /              /           /  /
             ----/              /           /  /
POLYQZ  (  2) 70/42 48 31 47 51/59 46 57 51/31/
               /              /           /  /
              /              /           /  /
GRANITE (  9)/58 50 48 47 50/49 48 45 40/33/
                           /           /  /
             -------------/           /  /
PLAGIO  (  3) 73/61/52 55/40 52 39 36/24/
               /  /     /           /  /
              /  /     /           /  /
KFELD   (  4)/55/57 68/46 41 54 47/28/
               /     /           /  /
              /     /           /  /
ACCESRY ( 12)/44 47/43 43 27 42/53/
                  /           /  /
             ----/           /  /
CARBONAT(  8) 64/42 46 55 51/44/
               /           /  /
              /           /  /
SHALE   ( 10)/44 56 57 44/40/
                        /  /
             ----------/  /
ACIDVOLC(  5) 67/62 49/29/
               /     /  /
              /     /  /
CHERT   (  7)/56 32/39/
                  /  /
             ----/  /
INTVOLC (  6) 59/37/
               /  /
              /  /
OTHERFRG( 11)/51/
               /
              /
MATRIX2 ( 13)/
```

Fig. 20. R-mode cluster analysis of sandstone components of the Yamaoku Formation (after NISHIWAKI and YU, 1981)

In the Yamaoku Formation, clay fabric was observed on eighty-seven specimens from thirty-one localities. The specimens were observed from three directions in respect to bedding plane, that is, upper surface, bottom surface and cross view, to get more information than that obtained from one direction.

The primary clay fabrics are apt to be modified by diagenetic process (compaction and recrystallization) and later tectonic forces, and it is difficult to consider the sedimentary mechanism of ancient sediments as stated by REINECK and SINGH (1975), and NAKAZAWA *et al.* (1980). An example of electron photomicrographs is shown in Plate 2, Fig. 1. The clay flakes show strongly preferred orientation of various directions. Clay mineral composition was also examined on four samples by X-ray diffraction method. It consists almost entirely of illite which has 2θ peak at 8.8. These results show diagenetic alteration of clay minerals and rearrangement of clay flakes by later tectonic forces. Accordingly the clay fabric does not, unfortunately, preserve the original texture to suggest the sedimentary process.

B. The Toyora Group

1. Conglomerates

Sixteen thin sections of the conglomerates from seven localities were examined, and 156 clasts are identified (Fig. 21). The conglomerates are confined to the Nbc Member, the lowest member of the Toyora Group. The basal conglomerate bed resting on the Sangun metamorphic rocks comprises abundant schist clasts attaining to 60% of the total. Granite is common and acidic volcanic rocks, shale, chert, and intermediate volcanic rocks are small in amount. Granite, occupying 38% of the total clasts, shows strongly crushed texture, and is considered to have been derived from the sheared granite of the Nagato Tectonic Zone which is located northeastward from the study area. Pebbles and boulders are angular, but gravels smaller than 16 mm are rounded.

The conglomerates of the Toyohigashi, the Toyonishi and the Kwanmon Groups were also examined supplementarily (Figs. 21). Those of the Toyonishi Group are composed mainly of chert, shale and sandstone. Only a few samples were observed, but it should be mentioned that the schist clast is practically absent in the Toyonishi and Kwanmon Groups, and only one grain of schist in the Toyohigashi Group.

2. Grain Size Distribution of Sandstones

Grain size analyses were made on thin sections of twenty-four sandstones from the Toyora Group (Table 5).

The sandstones are mostly fine- to medium-grained except for those of the Nbc Member. Mean phi of the Nishinakayama Formation is slightly smaller than the other formations. The grains are generally subrounded, sorting is mainly "well sorted" ranging from 0.31 to 0.83 and skewness ranges from −0.39 to 0.22 (average −0.10) and is "negative skewed" or "nearly symmetrical skewed".

The sandstones spread over beach and river sands on skewness-sorting diagram

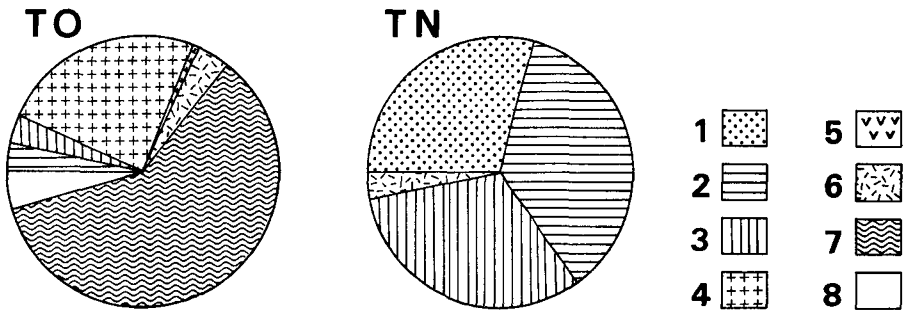


Fig. 21. Composition of conglomerate clasts of the Toyora (To) and Toyonishi (TN) Formations. 1: sandstone, 2: sxhale, 3: chert, 4: granitic rocks, 5: intermediate volcanic rocks, 6: acidic volcanic rocks, 7: crystalline schist, 8: others.

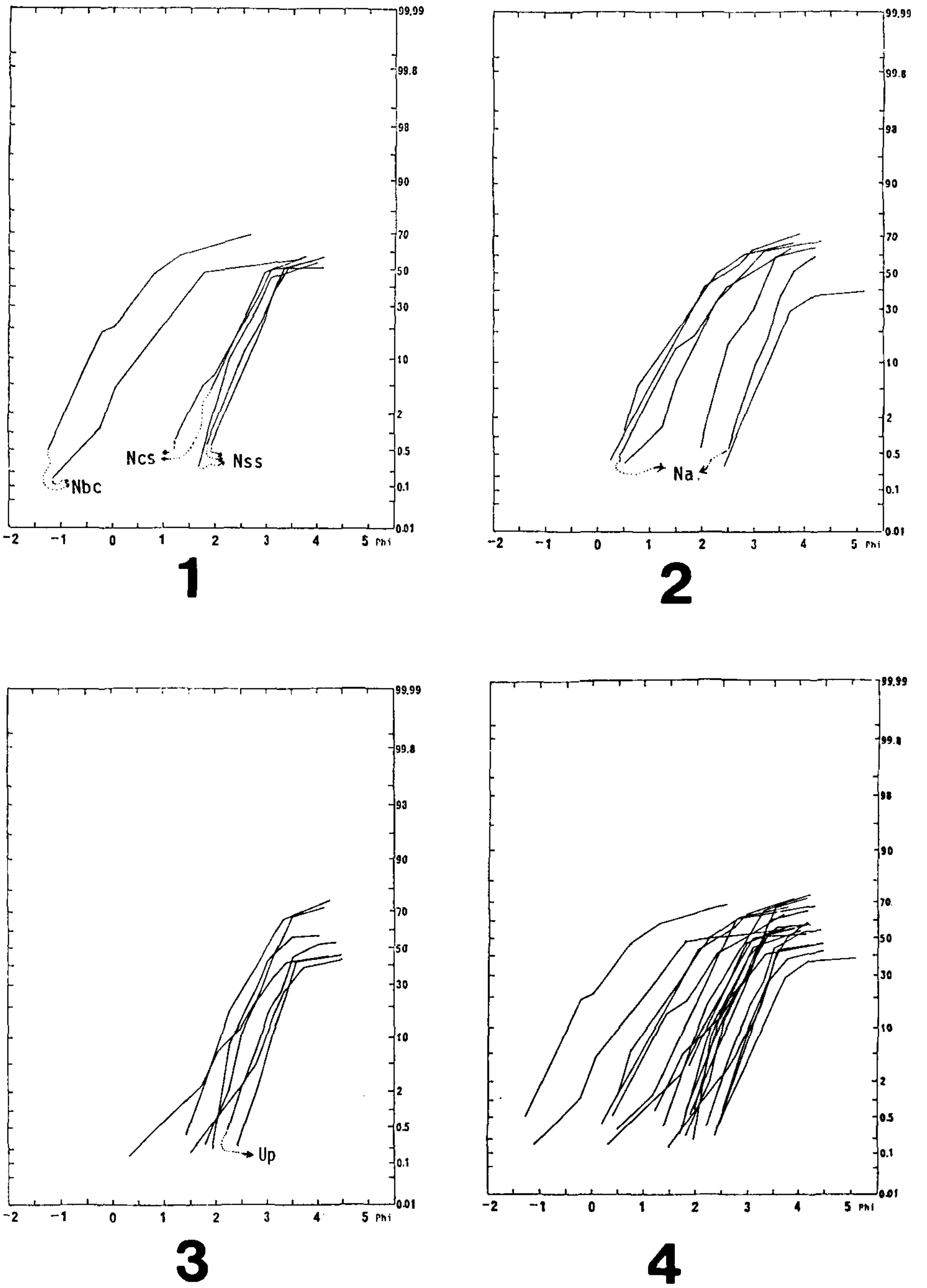


Fig. 22. Log-probility curves of sandstones of the Higashinagano (1), Nishinakayama (2), Utano (3) Formations and the total (4).

Table 4. Variables related to each factor, of which absolute values of factor loadings are greater than 0.5.

Factor	Positive	Negative
1	plagioclase poatsh feldspar	matrix
2	quartz, granite	matrix
3	intermediate volcanic rocks	accessory mineral
4	acidic volcanic rocks	
5	chert	other rock fragment

(Fig. 17). CM diagram (Fig. 15) shows the sandstones were mostly transported by graded suspension with rolling. Log-probability curves show various patterns (Fig. 22). The one similar to acient fluvial sandstones of FRIEDMAN (1961) characterizes the middle (Ncs) and upper (Nss) members of the Higashinagano Formation and a part of the Utano Formation. Shallow marine curve shape identical with that presumed in the Yamaoku Formation is found in the Nishinakayama and Utano Formations. Curves of the lower member (Nbc) of Higashinagano and many of the Nishinakayama and Utano Formations are characteristic in having more than two break points in the "saltation population". This type cannot be compared to any curve shapes described by VISHER. It is noteworthy that such type characterizes terrestrial sandstones of the Daedong and Pyeongan Supergroups in South Korea as will be described later.

The sandstones of the Toyora Group are generally finer in grain-size and contains more matrix than those of the Yamaoku Formation and the Higuchi Group. This may reflect the lower energy condition. INAZUMI (1981) assumed the calm and stable sedimentary environment for the shales of the Toyora Group based on the uniform chemical composition. Although the Toyora Group contains the sandstones having both shallow marine and fluvial patterns of log-probability curves, the common occurrence of marine fossils (ammonites and bivalves), unconformable relation with the Sangun metamorphic rocks on the east, and the presence of clasts of sheared granite

Table 5. Mean values of grain-size, sorting, skewness and matrix of sandstones of Higashinagano (a), Nishinakayama (b), and Utano (c) Formations. Two sandstone samples from the basal part of Higashinagano Formation are excluded.

Formation	PHI 1	PHI 16	MEDIAN PHI	PHI 84	MEAN PHI	SORTING	SKEWNESS	MATRIX
c (7)	1.86	2.51	3.00	3.39	2.95	0.45	-0.12	45.6
b (7)	1.10	1.99	2.57	3.13	2.56	0.57	-0.06	40.1
a (5)	1.61	2.27	2.76	3.14	2.71	0.43	-0.13	45.8
Total (19)	1.51	2.26	2.78	3.23	2.74	0.49	-0.10	43.6

similar to that of the Nagato tectonic zone to the northeast, suggest a shallow-sea embayment condition for the group in the main.

3. Mineral Composition of Sandstones

Mineral composition of sandstones was examined on seventeen thin sections. Comparing the mineral composition of the Toyora Group with that of the Yamaoku Formation, matrix is much more abundant, rock fragments are less in amount, especially of acidic and intermediate volcanic rocks. The upward decrease of rock fragments may show a decreasing relief of the provenance.

Mineral composition plotted on QFR diagram (Fig. 23) indicates that the sandstones of the Toyora Group in the northern part excepting the Higashinagano Formation (Nbc, Ncs, Nss Members) are feldspathic wacke. The sansdtones of this group in the southern part, are diversed, classified as feldspathic arenite and wacke and lithic wacke. The sandstones of the Higashinagano Formation differ from those of all other members of the Toyora Group in a very low content of feldspar (Nbc and Ncs) or high content of quartz (Ncs and Nss). In QPK diagram (Fig. 23), sandstones are generally low in the content of potash feldspar. The total mineral composition is given in Table 6. Excepting characteristic Nbc Member, quartz occupies 19.0% of the total constituents on an average. It is mostly monocrystalline except for that of the Higashinagano Formation. Polysryctalline quartz grains are mainly formed of a few crystals. Quartz grains that have dust ring were found in one sample in the southern part. Potash-feldspar is absent in the lower member of Higashinagano Formation. Rock fragments, occupying 14.1% on an average, consist of acidic volcanic rocks, intermediate volcanic rocks, granite, schist, chert, shale, carbonate, and other rock fragments. Schist grains are limited to the lowermost part of the Higashinagano Formation as in the case of the conglomerate, and granite is not found

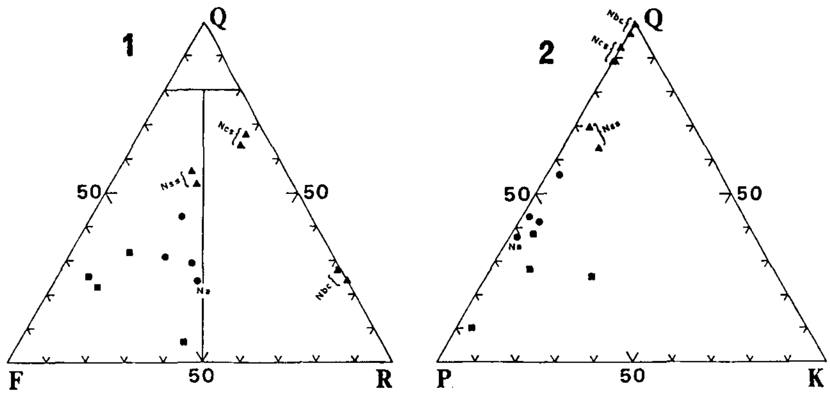


Fig. 23. QFR (1) and QPK (2) diagrams of sandstones of the Toyora Group, square: Utano Formation, circle: Nishinakayama Formation; trianlge: Higashinagano Formation.

Table 6. Mineral composition of sandstones of Higashinagano (a), Nishinakayama (b) and Utano (c) Formations shown by mean values, and Q/(F+R) and F/R.

Formation	Mono Quartz	Poly Quartz	Total Quartz	Plagio-clase	Potash Feldspar	Total Feldspar	Acidic Volcanic Rocks	Intermediate Volcanic Rocks
c (4)	13.7	0.4	14.1	32.6	6.6	39.2	1.5	0.0
b (4)	19.3	2.0	20.4	23.4	1.4	24.8	7.7	3.2
a (4)	21.4	9.4	22.7	7.5	1.4	8.9	1.8	0.0
Total (12)	18.1	3.9	19.0	21.1	3.1	24.3	3.6	1.1

	Granite	Schist	Chert	Other Rock Fragment	Total Rock Fragment	Accessory Mineral	Matrix	Q/(F+R)	F/R
c (4)	0.4	0.0	0.1	5.4	12.2	7.9	23.9	0.29	4.65
b (4)	1.6	0.0	1.0	4.0	18.2	2.4	33.4	0.48	1.38
a (4)	0.0	0.6	3.6	5.9	11.8	0.6	47.9	1.55	0.89
Total (12)	0.7	0.2	1.6	5.1	14.1	3.6	36.9	0.77	2.31

in the Higashinagano Formation. Schists are derived from the Sangun metamorphic rocks which are unconformably overlain by the Higashinagano Formation.

The index of provenance factor is variable ranging from 0.16 to 9.70, and has 2.3 on an average (Table 6). The maturity index ranges from 0.06 to 2.03 with the average 0.77 (samples from the southern part are excluded). Relation of quartz, feldspar, rock fragment and matrix contents versus mean grain size is shown in Fig. 19. The content of rock fragments increases in proportion to an increase of grain size, but there is no distinct relation between the grain size and the abundance of quartz or feldspar like as the Yamaoku Formation.

C. The Higuchi Group

1. Conglomerates

The conglomerates were examined on only seven thin sections from four localities and 57 clasts were identified. The conglomerates comprise clasts of shale, chert, intermediate volcanic rocks, acidic volcanic rocks, and sandstone (Fig. 24, left). Shale is most predominant attaing to about a half of the total. Chert and intermediate volcanic rocks occupy each 11% of the total. Therefore, sedimentary rocks are main components of the conglomerates. The size of clasts are variable from 2 mm up to 80 cm. The roundness of clasts is angular to subrounded, and that smaller than 20 mm is subrounded (0.4 to 0.5). A few conglomerates of the Kwanmon Group in the study area, were also examined for comparison (Fig. 24 right). Although the data of the Kwanmon Group are poor, the composition is different from that of the Higuchi Group, in a larger amount of sandstone (28%) and intermediate volcanic rocks (24%), and a less amount of shale (24%) than those of the latter.

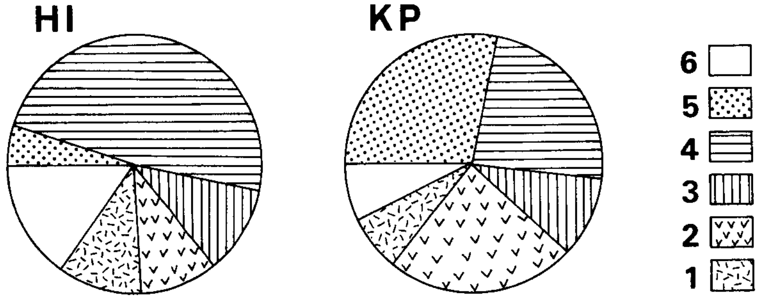


Fig. 24. Composition of conglomerate clasts of the Higuchi (HI) and Kwanmon (KP) Groups. 1: acidic volcanic rocks, 2: andesitic volcanic rocks, 3: chert, 4: shale, 5: sandstone, 6: others.

2. Grain Size Distribution of Sandstones

Grain size analyses were made on fifteen thin sections. As the detailed stratigraphy has not been established yet, the sandstones are treated as a whole.

They are mainly medium- to coarse-grained. The sorting is mainly "well sorted" to "moderately well sorted" ranging from 0.38 to 0.95. The skewness ranges from 0.36 to 0.18 and is mainly "nearly symmetrical skewed". In skewness-sorting diagram (Fig. 17) the sandstones are plotted in the field of both beach and river sands of FRIEDMAN (1961). Log-probability curves (Fig. 25) show various patterns including those suggestive of fluvial, surf zone, and "shallow marine". The grain-size and matrix content are more similar to those of the Yamaoku Formation than to

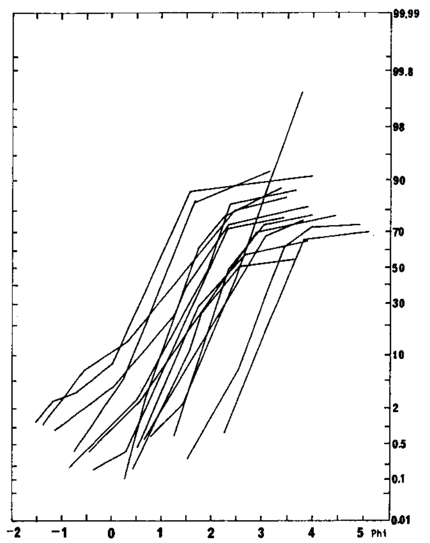


Fig. 25. Log-probability curves of snadstones of the Higuchi Group.

Table 7. Composition of conglomerate clasts of the Yamaoku Formation, Higuchi and Toyora Groups examined under the microscope.

Locality	Numbers of Thin Section		Acidic Volcanic Rocks	Intermediate Volcanic Rocks	Granite	Schist	Chert	Shale	Sandstone	Others	Total	Roundness
YAMAOKU	30	Mean Size	5.9	5.6	6.1	—	4.6	4.3	7.5	2.3	5.5	
		Total	141	54	12	—	11	36	9	13	276	0.5—0.7
		Frequency	51	20	4	—	4	13	3	5	100	
HIGUCHI	7	Mean Size	4.4	2.5	—	—	6.3	4.5	8.5	2.	4.2	
		Total	5	6	—	—	6	29	2	9	57	0.4—0.5
		Frequency	9	11	—	—	11	51	4	16	102	
TOYORA	16	Mean Size	4.4	8.	3.6	3.9	6.2	6.0	—	2.6	4.	
		Total	6	1	38	94	5	5	—	7	156	0.4—0.7
		Frequnecy	4	1	24	60	3	3	—	5	100	

Table 8. Composition of conglomerate clasts of the Kwanmon Group in Yamaoku, Higuchi and and Toyora areas examined under the microscope.

Locality	Numbers of Thin Section		Acidic Volcanic Rocks	Intermediate Volcanic Rocks	Schist	Chert	Shale	Sandstone	Others	Total	Roundness
YAMAOKU	2	Mean Size	3.	10.	4.7	—	4.	3.2	3.	4.1	
		Total	1	1	11	—	2	4	7	26	0.3—0.6
		Frequency	4	4	42	—	8	15	27	100	
HIGUCHI	4	Mean Size	14.5	12.3	—	7.3	3.7	7.8	3.7	8.	
		Total	2	7	—	3	7	8	2	29	0.5—0.6
		Frequency	7	24	—	10	24	28	7	100	
TOYORA	2	Mean Size	2.5	—	—	—	2.3	2.	—	2.3	0.4—0.6
		Total	3	—	—	—	7	1	—	11	

those of the Toyora Group. The pattern on CM diagram (Fig. 15) is also similar to that of arenite of the Yamaoku Formation, but the data are poor.

The Higuchi Group as a whole is considered to have deposited in a shallow marine enviroment near the coast, taking the occurrence of ammonoids and bivalves in consideration as well.

3. Mineral Composition of Sandstones

Mineral composition was examined on fifteen thin sections.

Comparing with that of the Yamaoku Formation, it is revealed that acidic volcanic rocks are much less in amount, and other kinds of grains such as intermediate volcanic rocks, shale, granite, chert and potash feldspar are more than the Yamaoku Formation. Schist grains which are absent in the Yamaoku Formation are contained though small in amount, being at most 2.4% of the total constituents. The content of matrix is between that of the Yamaoku Formation and the Toyora Group.

Based on QFR diagra (Fig. 17), the sandstones are classified as feldspathic and lithic arenite and wacke. Lithic wacke is more predominant than fedslpathic wacke. In QPK diagram (Fig. 18) potash feldspar ranges from 0 to 13.4% of the total constituents and 5.9% on an average. It includes orthoclase, microcline and perthite. Quartz consists mostly of monocrystalline quartz. Polycrystalline quartz grains are mainly formed of a few crystals. Rock fragments are relatively large in amount occupying 27.5% on an average.

It is evident that the amount of rock fragments increases with rising grain size, while that of matrix decreases. Quartz and feldspar have no distinct relation to the grain size (Fig. 19).

D. Comparison of Sediments among the Yamaoku, Toyora and Higuchi Areas

1. Conglomerates

Comparing the composition of conglomerates in the Yamaoku, Higuchi and Toyora areas, acidic volcanic rocks are abundant in the Yamaoku Formation, and shale is predominant in the Higuchi Group. Schist is characteristic in the basal member of the Toyora Group but absent in the Yamaoku and a few in the Higuchi. On the other hand, in the Kwanmon Group schist clasts are most common in the Yamaoku area, volcanic rocks including andesitic rocks become more important in the Higuchi area, and sedimentary rocks are abundant in the Toyora area. This fact indicates a complex nature of the provenance of the early Jurassic and also of the Cretaceous.

2. Grain-size Distribution of Sandstones

Sorting and skewness are not different among the three lower Jurassic groups. Roughly speaking, sorting is concentrated between 0.5 and 0.7, namely "moderately well sorted'' and skewness is mostly between 0.1 and −0.1, that is, ''nearly symmetrical skewed''. However, the sandstones of the Toyora Group is finer in grain-size and more in matrix content than those of the other two. Log-probability curves are similar between the Yamaoku Formation and the Higuchi Group, but those of the Toyora Group are somewhat different in having ''miscellaneous curve shapes'' which are characterized by the presence of more than two break points in ''saltation population''. Accordingly the Yamaoku and the Higuchi areas were under relatively similar environment but different from the Toyora area, at least, the sandstones are concerned.

3. Mineral Composition of Sandstones

The amount of quartz and feldspar is almost same among three groups, but that of the potash feldspar of the Higuchi Group is a little more than the Yamaoku Formation and the Toyora Group. Acidic volcanic rocks of the Yamaoku Formation are much more abundant than those of the other two groups, while intermediate volcanic rocks are most common in the Higuchi Group, and nearly absent in the Yamaoku Formation. Thus the characteristics of mineral composition of sandstones coincide with those of conglomerates.

Almost all the sandstones of the Toyora Group are classified as wacke due to a large amount of muddy matrix, while those of the other two belong to wacke and arenite. There is no remarkable relation between quartz content and mean grain size in all three groups. Feldspar has also no distinct relation to mean grain size of sandstone. Rock fragments and matrix show a distinct relation to mean grain size, namely the former increases in abundance with rising of grain size, but the latter is reverse.

E. The Daedong Supergroup

1. Conglomerates

a). The Mungyeong Area

Seven localities in ''a'' zone and four localities in ''m'' zone were observed, and 100 clasts were identified (Fig. 26).

The size of clasts mostly ranges from 2 to 60 mm. The roundness ranges from 0.4 to 0.8, mostly ''sub-rounded'' and ''rounded''. Quartzose sandstone is most predominant attaining to 57% of the total clasts and shale is the next main component. Metamorphic rocks are scarce; only one schist clast was found in ''a'' zone in the field.

Conglomerates were also examined on thirty-four thin sections from twelve localities, and 74 clasts were identified. The component of ''a'' zone is more variable than that of ''m'' zone. Orthoquartzite grains which have dust ring are commonly found in the quartzose sandstone clasts. Tuffaceous shale, siltstone, inetrmediate

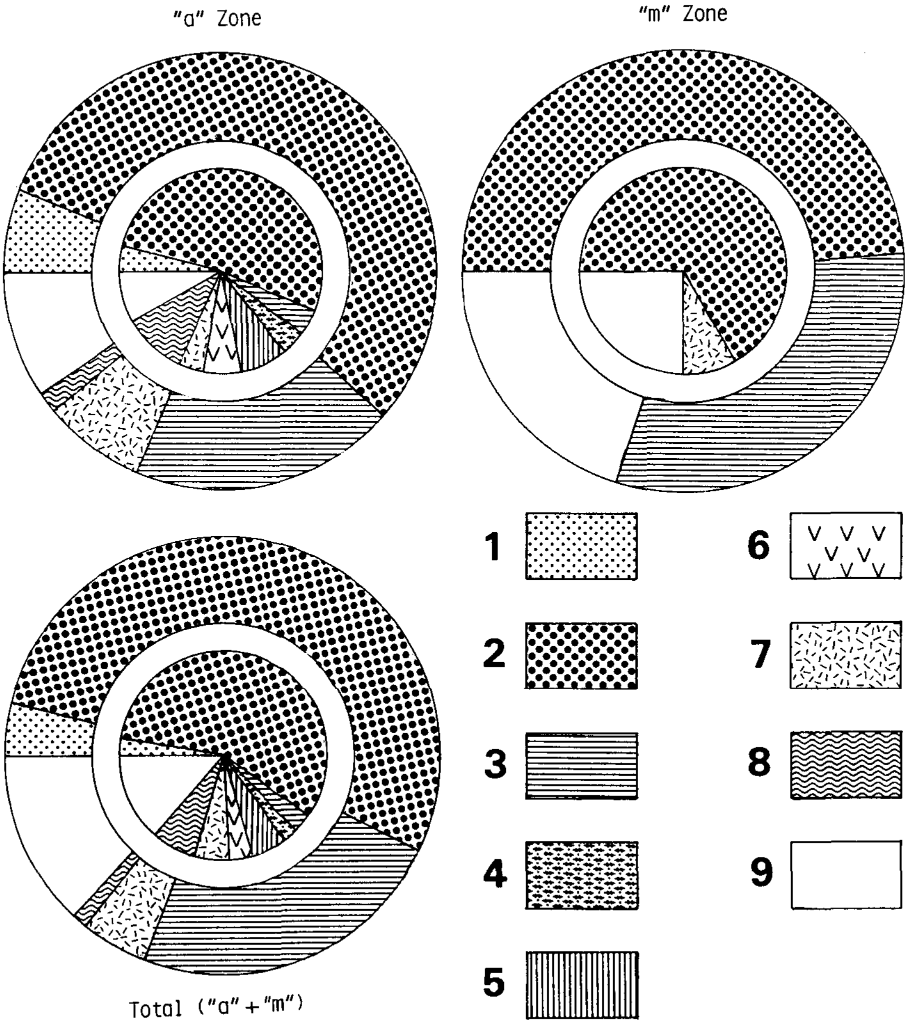


Fig. 26. Composition of conglomerate clasts of the Daedong Supergroup in Mungyeong area. Outer circle identified by hand lens and inner circle by microscope. 1: sandstone, fine-grained with much matrix, 2: quartz sandstone, 3: shale, 4: tuffaceous shale, 5: siltstone, 6: intermediate volcanic rocks, 7: acidic volcanic rocks, 8: crystalline schist, 9: others.

volcanic rocks, schist, and fine-grained sandstone with high content of matrix appear in "a" zone, but not in "m" zone. Matirx of conglomerate of "a" zone has schistosity and suffers low-grade metamorphism as shown by the presence of secondary muscovite. Matrix of conglomerate of "m" zone is composed of medium- to coarse-grained quartzose sandstone. The roundness ranges mainly from 0.4 to 0.6.

b) The Daecheon Area

The conglomerates of the lower part of the Hanaeri Formation and the Eunseong conglomerate were examined for comparison. They are supposed to be the upper part of the Daedong Supergroup according to UM *et al.* (1977). The observed samples are very few, but the composition of conglomerates is as a whole similar to that of Mungyeong area.
Quartzose sandstone is smaller in amount and rhyolitic volcanic rocks, and quartz rock are more common than in the Mungyeong Area.

c) The other Area

The Jurassic Sapyeongri conglomerate in Dayang area situated about 30 km NE away from Mungyeong area is believed to belong to the Bansong Group of the Daedong Supergroup. According to PARK and CHEONG (1975), the constituents of the Sapyeongri conglomerate are mainly quartzite and sandstone, and subourdinately shale, siltsone, limestone, granite, chert and volcanic clasts in that order. They described that the depositional realm of the Sapyeongri conglomerate was a lake environment, and the materials were derived from the lower Gabangsan Formation of Pyeongan Supergroup, which is located to the east or southeast of the depositional basin. The

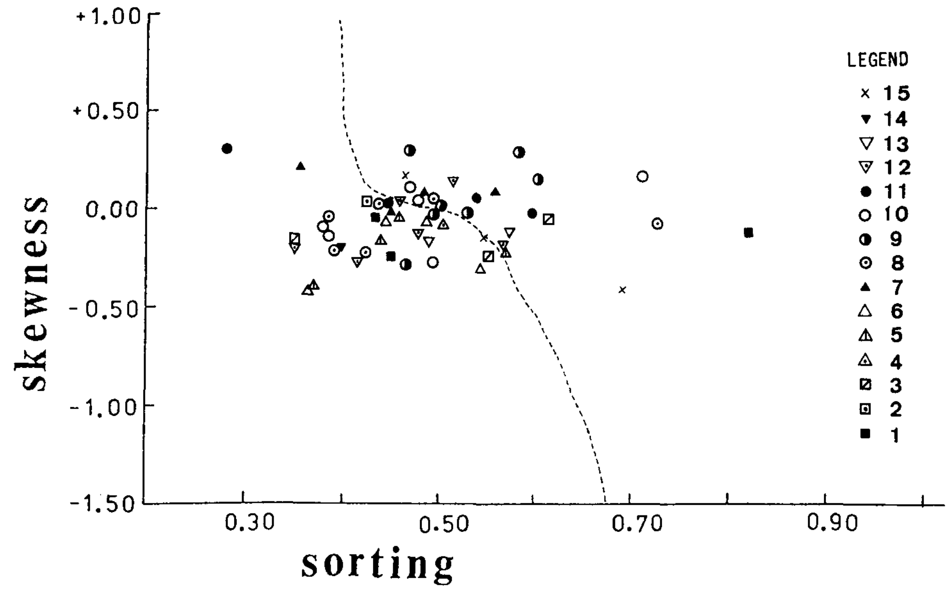


Fig. 27. Skewness-sorting diagram of sandstones of the Daedong Supergroup in Mungyeong and Daecheong areas.
1: "b", 2: "c", 3: "d", 4: "e", 5: "f", 6: "g", 7: "h", 8: "i", 9: "j", 10: "k", 11: "l", 12: "m", 13: "n", 14: "o", zones, respectively, and 15: Daechon area.

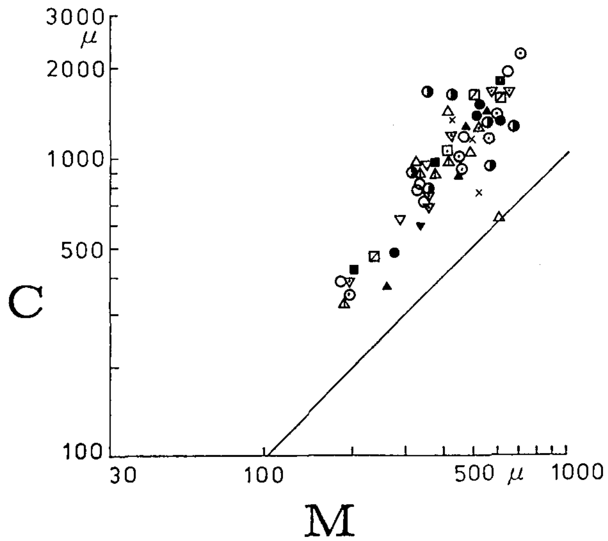


Fig. 28. CM diagram of sandstones of the Daedong Supergroup in Mungyeong and Daecheong area, symbols same as in Fig. 27.

composition of the Sapyeongri conglomerate is different from that of Mungyeong area in having limestone clasts at places but no metamorphic rocks at all.

KIM and PARK (1968) described briefly the Bansong Group of the Daedong Supergroup in Kangwha Island (Fig. 8). According to them, the conglomerates of this group are composed of quartzitic rocks (45%), medium-grained sandstone (30–35%), blackish shale (12%), and vein quartz (8%), and do not contain gneiss and granite clasts. Matrix of conglomerates is arkosic sandstone.

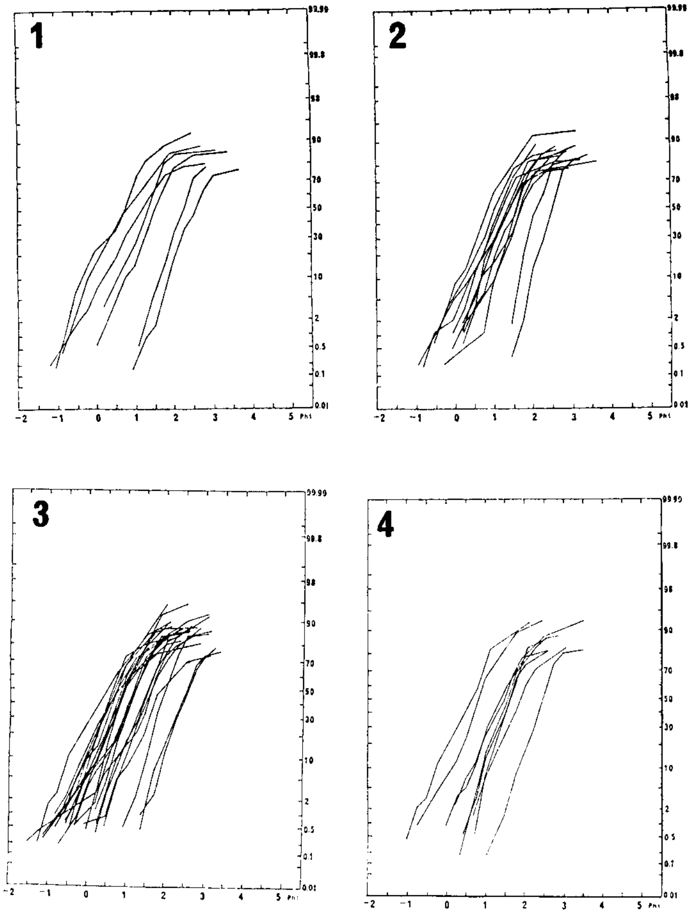
The other conglomerates of the Daedong Supergroup were briefly described from Yeongweol area (YOSHIMURA, 1940) and from Jeongseun area (HISAKOSHI, 1943) but the details were not given.

2. Sandstones

a) Grain Size Distribution of Sandstones

Grain size analyses are made on fifty-two sandstone samples of the Daedong Supergroup in Mungyeong area. The sandstones are mainly coarse-grained and the grains are mostly subrounded to rounded. On skewness-sorting diagram (Fig. 26), nearly equal numbers of the sandstones are plotted in river sand and beach sand realms of FRIEDMAN. Sorting is mainly "well sorted" to "moderately well sorted" ranging from 0.28 to 0.83. Skewness ranges from −0.40 to 0.32, but mainly "nearly symmetrically skewed". On CM diagram most of the sandstones are plotted on the field of rolling and graded suspension (I, IV and V of PASSEGA, 1957).

Shapes of several log-probability curves are similar to those of the channel and



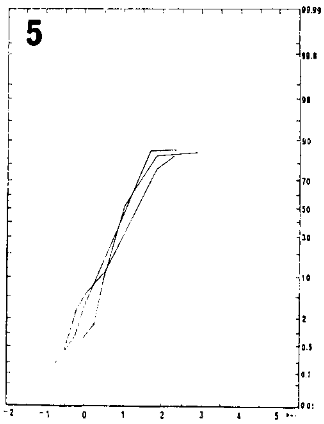


Fig. 29. Log-probability curves of sandstones of the Daedong Supergroup in Mungyeong and Daechong areas. 1: from "b" to "d" zones, 2: from "e" to "h" zones, 3: from "i" to "l" zones, 4: from "m" to "o" zones in Mungyeong area, and 5 in Daecheong area.

fluvial sands but most of them are allied to the "miscellaneous curve shape" of the Toyora Formation in having several break points in "saltation population" (Fig. 29-1~4). The sandstones in the Daechon area are essentially same as in the Myungeyong area (Fig. 29-5). Such miscellaneous curve is considered to characterize fluviolacustrine or fluvial sands in the intermontain basin because this type is commonly found in the lacustrine delta sands of the Pleistocene Kobiwako Group in Southwest

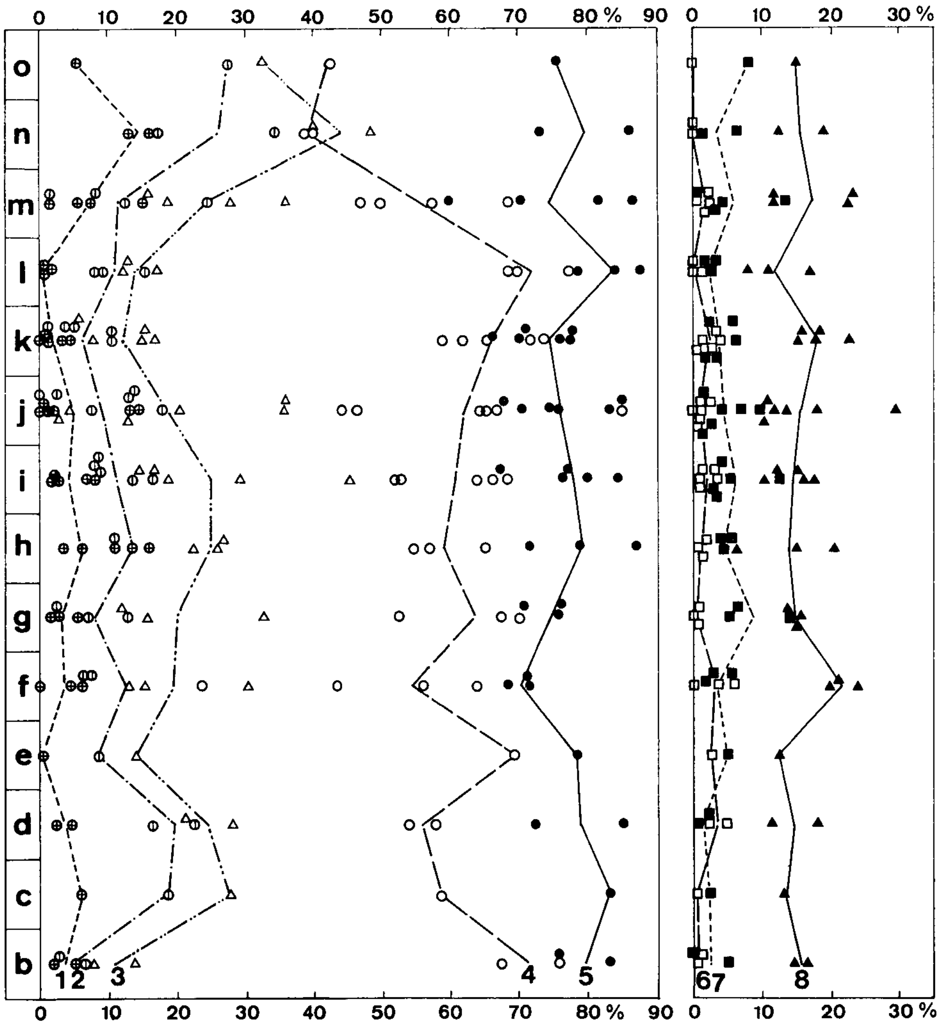


Fig. 30. Stratigraphic variation of the amount of each component of sandstones, the Daedong Supergroup in Mungyeong area. 1: finely crystallin quartz, 2: coarsely crystalline quartz, 3: polycrystalline quartz (finely plus coarsely crystalline), 4: monocrystalline quartz, 5: polycrystalline plus monocrystalline quartz, 6: feldspar, 7: rock fragment, 8: matrix.

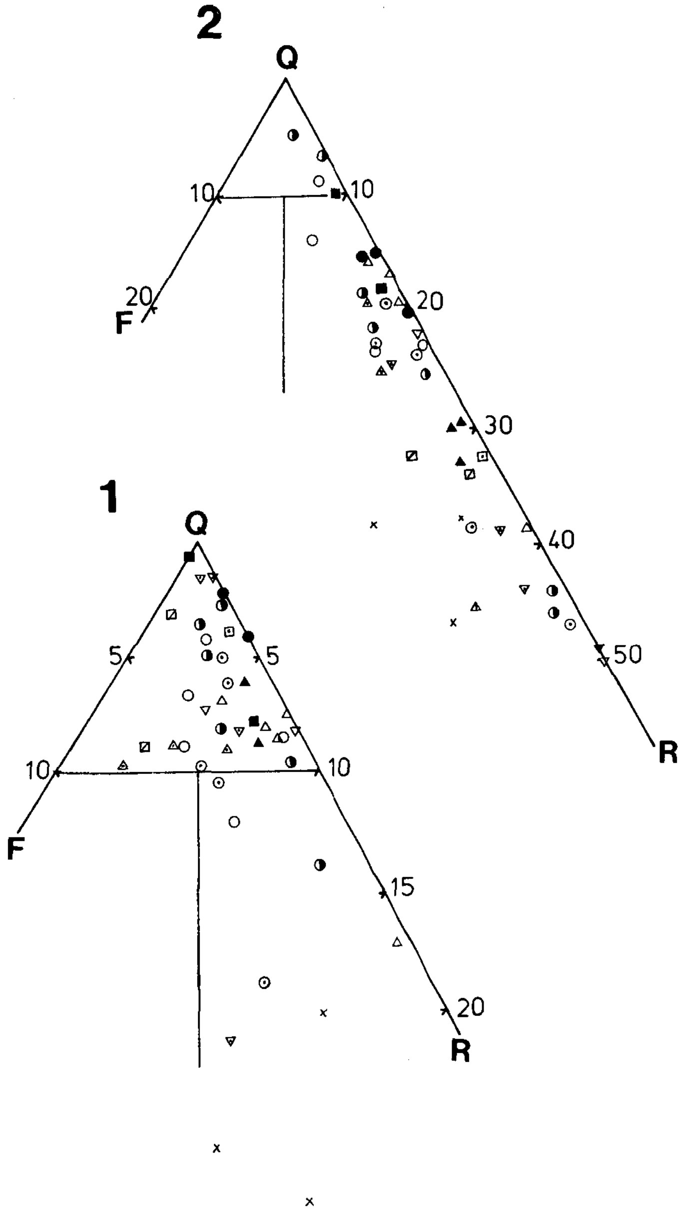


Fig. 31. QFR diagrams of sandstones of the Daedong Supergroup in Mungyeong and Daecheong areas. 1: Q=monocrystalline quartz only, 2: Q=monocrystalline plus polycrystalline quartz. Symbols same as in Fig. 27.

Japan (see Fig. 41).

b) Mineral Composition of Sandstones

Mineral composition analyses were made on fifty-two sandstone samples by a thin section method. Sample number of 1 to 52 belong to from "b" to "o" zones. Monocrystalline quartz is much more than polycrystalline quartz ranging from 38.8 to 85% of total amount with the average 60.5%.

Rock fragments of granite, acidic volcanic rocks, chert, sandstone and shale are very small in amount. Most of other unidentified rock fragments are probably acidic volcanic rocks. Tourmaline and zircon grains, though a few in number, generally appear in Mungyeong area. Polycrystalline quartz is subdivided into fine ($<3\phi$) and coarse ($>3\phi$) ones. Many of coarsely crystalline quartz grains are referred to as orthquartzite. Polycrystalline quartz is treated in two ways, namely, as quartz and as rock fragment. The vertical variation of the amount of polycrystalline quartz and other components of the Daedong Supergroup is shown in Fig. 30. The change of the amount of finely polycrystalline quartz and that of coarsely polycrystalline quartz are very similar to each other but reverse to that of monocrystalline quartz.

Based on QFR diagram (Fig. 31–1), on which quartz represents monocrystalline plus polycrystalline quartz, the sandstones are largely classified as quartz arenite and quartz wacke, and partly lithic wacke or arenite of OKADA (1971). And in QFR

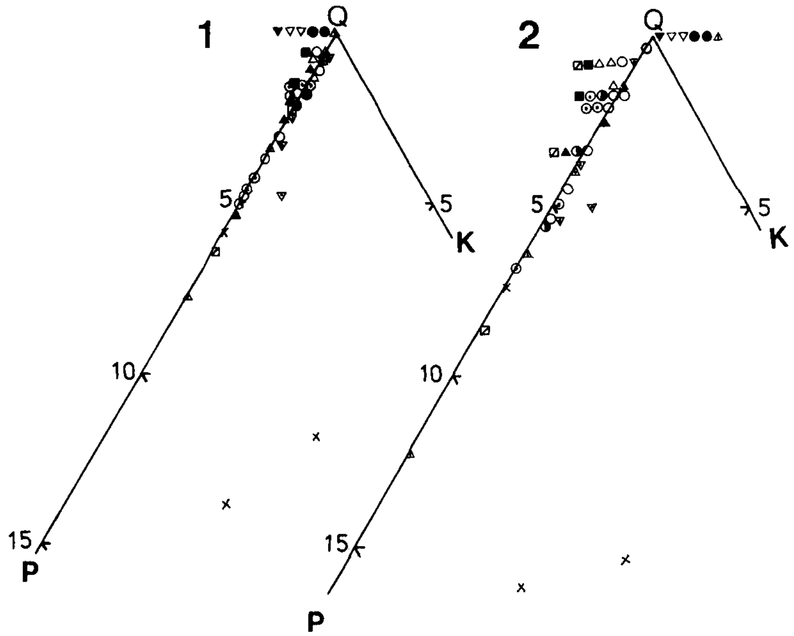


Fig. 32. QPK diagrams of sandstones of the Daedong Supergrooup. 1: Q= monocrystalline quartz only, 2: Q=poly- plus monocrystalline quatrz.

diagram, on which quartz including only monocrystalline (Fig. 31-2), the sandstones are mostly classified as lithic arenite and lithic wacke, both nearly in equal amount, and only a few samples belong to quartz arenite or wacke. In QFR diagram there is no difference between fine- and coarse-grained sandstone. It is a remarkable fact that almost all sandstones lack K-feldspar (Fig. 32). Plagioclase is small in amount, mostly less than 4%.

The index of provenance factor ranges from 0.00 to 3.67, when quartz includes monocrystalline and polycrystalline quartz, with the average 0.60. If polycrystalline quartz is treated as rock fragment, the index of provenance factor ranges from 0.00 to 0.57 with the average 0.11. It is suggested that supracrustal rocks are more important factor than plutonic rocks. The maturity index is 17.31 on an average when polycrystalline quartz is included in quartz but reduces to 3.93 when it is excluded. The latter value is considered to be better for the maturity index, because quartzose sandstone is considered to be a main source rock of quartz grains.

Mineral composition of several sandstones from the Daedong Supergroup in Daecheon (Figs. 31, 32) is similar to those of Mungyeong area, however a small amount of potash feldspar is contained. Othoquartzite grains also appear in the Daecheon area.

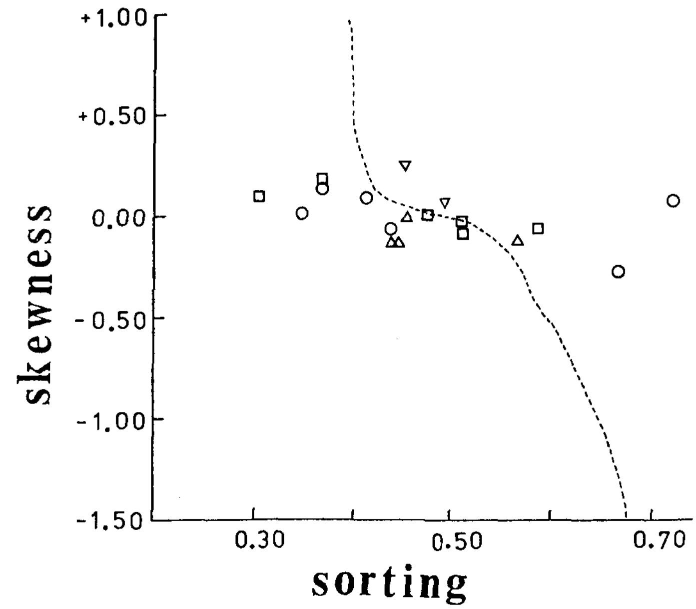


Fig. 33. Skewness-sorting diagram of sandstones of the Pyeongan Supergroup. Triangle: Nogam Formation, circle: Gobansan Formation, square: Sadong Formation, reversed triangle: Hongjeom Formation.

F. Preliminary Analyses of Grain Size and Mineral Composition of the Pyeongan Supergroup

To clarify the sedimentological characters of the Daedong Supergroup, sandstones of the Pyeongan Supergroup were also examined. Eighteen sandstone samples collected from Mungyeong, Danyang, Najeun and Jangseong areas (Fig. 8) were examined.

1. Grain Size Distribution of Sandstones

Grain size analyses were made on eighteen thin sections. Almost all the sandstones are coarse-grained and the sand grains are subrounded to rounded.

On skewness-sorting diagram (Fig. 33), two samples of the Hongjeom Formation are plotted in the overlap realm of beach and river sand; six samples of the Sadong Formation are plotted in beach sand and in the overlap realm, six samples of the Gobangsan Formation are plotted in the beach and river sand, and four samples of the Nogam Formation are plotted in the overlap realm of beach and river. All are plotted on I and IV of CM diagram (rolling and graded suspension).

Sorting of sandstones of the Pyeongan Supergroup is mainly "well sorted" ranging from 0.30 to 0.72, and skewness is mainly "nearly symmetrical skewed" ranging from 0.11 to 0.27. Log-probability curves of the Pyeongan Supergroup (Fig. 35) is quite similar to those of the Daedong Supergroup consisting of fluvial and miscellaneous patterns.

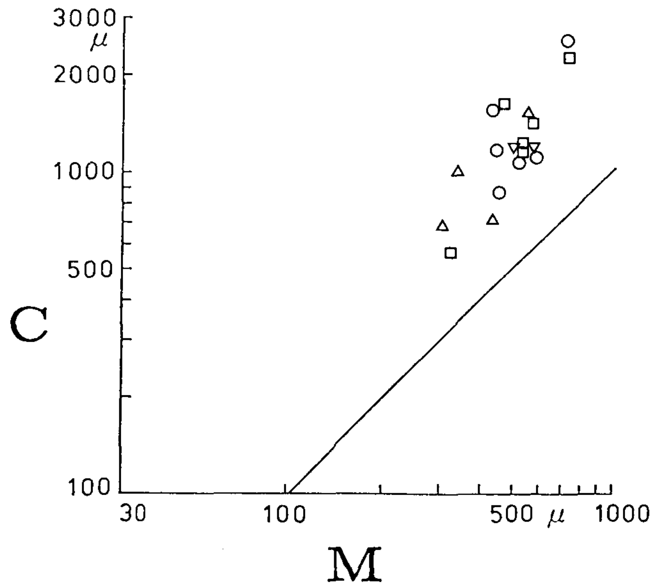


Fig. 34. CM diagram of sandstones e the Pyeongan Supergroup. Symbols same as in Fig. 33.

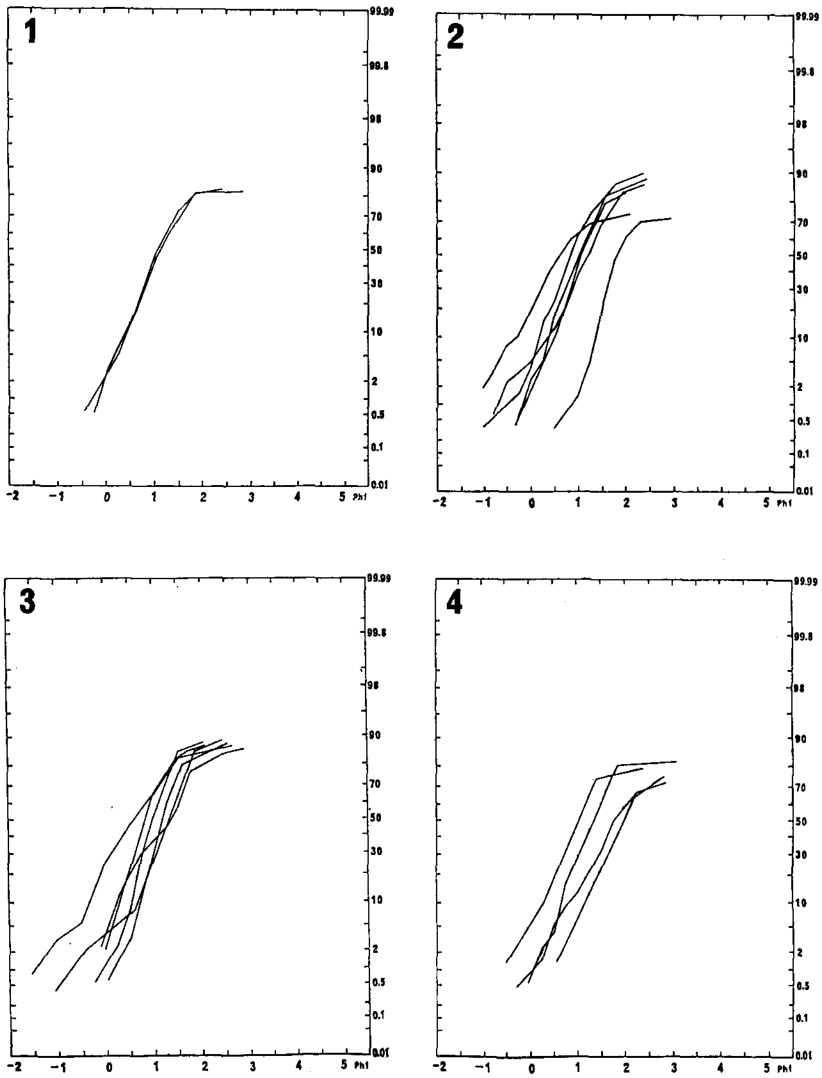


Fig. 35. Log-probability curves of sandstones of the Pyeongan Supergroup. 1: Honjeom Formation, 2: Sadong Formation, 3: Gobangsan Formation, 4: Nogam Formation.

2. Mineral Composition of Sandstones

Mineral composition analyses were made on the same thin sections as used for grain size analysis. It should be mentioned that mineral compositions of those formations are very similar to each other. Based on QFR diagram (Fig. 36-1), all the sandstones of the Pyeongan Supergroup are rich in total quartz (mono- + polycrystal-

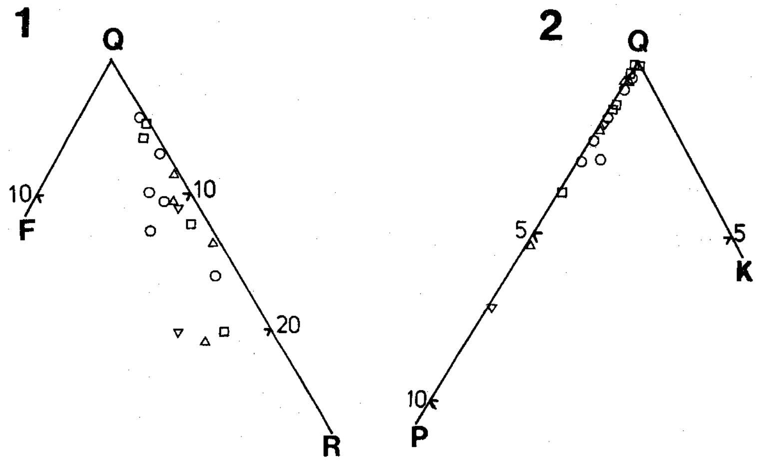


Fig. 36. QFR (1) and QPK (2) diagrams of sandstones of the Pyeongan Supergroup. Symbols same as in Fig. 33.

line quartz), and belong to quartz wacke. CHEONG (1967) also reported that the sandstones of the Sadong Formation in the Samcheog coalfield contain 80% quartz of the total sand grains. Sandstones of this supergroup are all devoid of potash feldspar except for one sample which contains 1.6% potash feldspar (Fig. 36-2). These diagrams also show that there is no distinct difference vertically and areally as well.

Undulatory extinction quartz is predominant and orthoquartzite grains commonly appear in whole samples. Most of the quartz is represented by monocrystalline quartz. Rock fragments cannot be exactly identified other than acidic volcanic rocks. Tourmaline grains are commonly found though small in amount.

The index of provenance factor is variable, but it is suggested that supracrustal rocks are more important factor than plutonic rocks. The maturity index is wholly larger than 3.84.

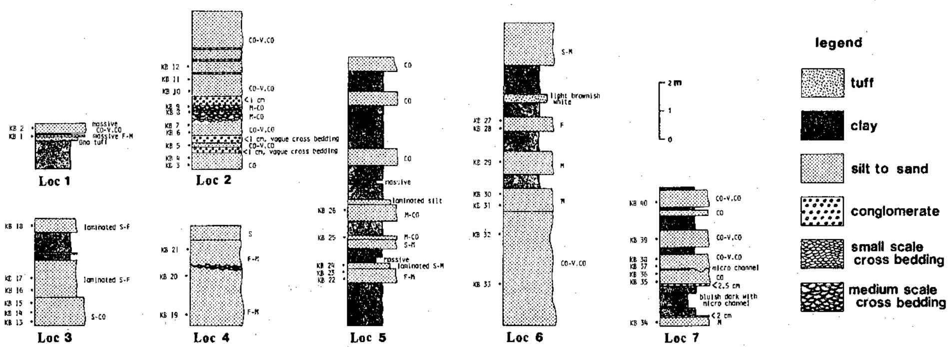


Fig. 37. Columnar sections (after YOKOYAMA *et al.*, 1979) and sampling horizons (KB 1-40) of the Ogoto sands of the Katata Formations, Kobiwako Group.

Comparing the mineral composition of the Pyeongan Supergroup with that of the Daedong Supergroup, mineral composition is very similar to each other. Therefore, the provenance of the Pyeongan and the Daedong Supergroup in the study area was not markedly changed in spite of the fact that they cover a long geological time.

G. Preliminary Grain Size Analysis of the Kobiwako Group and Comparison with the Daedong Supergroup

As stated before, log-probability curve shapes of sandstones of the Jurassic Daedong Supergroup of South Korea are characteristic. As the Daedong Supergroup is generally supposed to be a product of the intermontain basin, the grain-size analysis of the fluvial and lacustrine Plio-Pleistocene Kobiwako Group in Southwest Japan was carried out for comparison.

1. Stratigraphy of the Kobiwako Group

The Kobiwako Group is one of the representative fluviolacustrine sediments of Plio-Pleistocene age in Southwest Japan. It is widely distributed in the hilly land around and also beneath the Lake Biwa, the largest lake in Japan. It consists mainly of clay, sand and gravel with peat and volcanic ash intercalations. The sedimentary environment of that group is lacustrine and fluvial. According to YOKOYAMA *et al.*

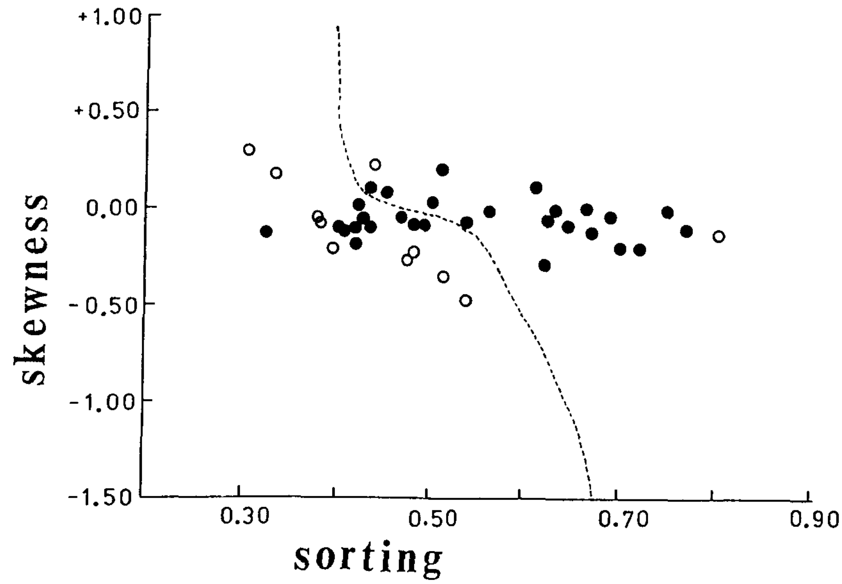


Fig. 38. Skewness-sorting diagram of Ogoto sands. Solid circle: medium- to very coarse-grained sands, open circle: silt and fine-grained sand.

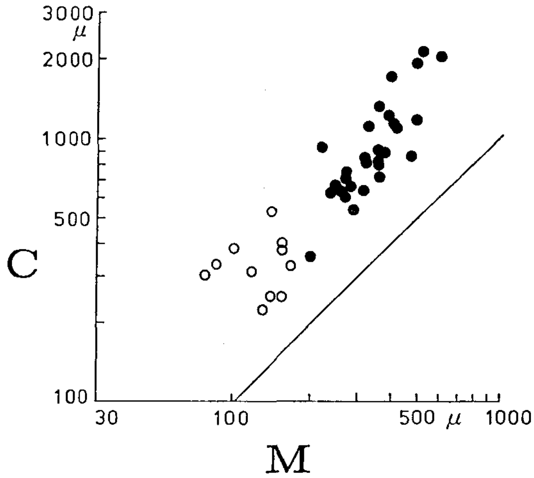


Fig. 39. CM diagram of Ogoto sands. Symbols same as in Fig. 38.

(1979), the Kobiwako Group is divided into seven formations in ascending order; the Shimagawara, the Iga-Aburahi, the Sayama, the Gamo, the Yokaichi, the Katata and the Takashima Formations. The Katata formation is divided into three members in ascending order; the Wani sands, the Minamisho clays and the Ryuge sands and gravels (YOKOYAMA, 1969). The Minamisho clays is subdivided into the Ogoto clays, the Ogoto sands and the Kamiogi clays in ascending order. The Ogoto sands considered to be of lacustrine delta origin were selected for study.

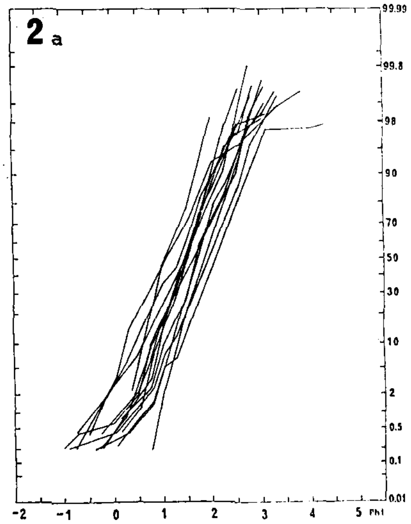
2. Grain Size Analysis of the Ogoto sands

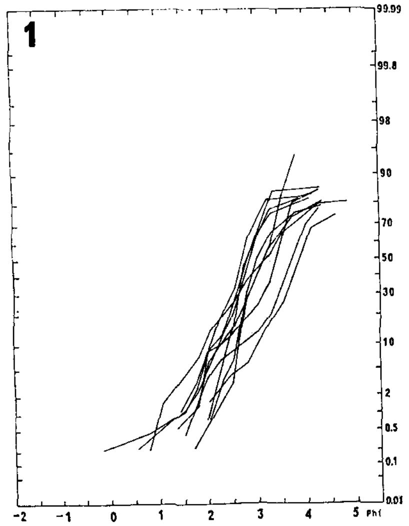
Grain size analyses are made on forty samples of the Ogoto sands from Shiga hill by thin section method (Fig. 37)*.

The grains are subangular to well rounded. In skewness-sorting diagram (Fig. 38), coarse silt to fine-grained sand are mostly plotted in beach sand realm, and medium- to very coarse-grained sands are mainly plotted on river sand region. Sorting is mainly "well sorted" and "moderately well sorted" ranging from 0.31 to 0.81. Skewness ranges from 0.48 to 0.31 and is mainly "nearly symmertical skewed". CM diagram shows that the sands deposited from rolling and graded suspension.

Log-probability curves comprise three different curve shapes. One of them is very similar to "miscellaneous shape" of the Daedong and Pyeongan Supergroups and a part of the Toyora Group in having several break points in "saltation population" part and relatively large amount of muddy matrix. This pattern is most common in

* A special technique is needed to make thin section for such loose Pleistocene sands as follows. Sand samples were consolidated by using P-Resin and Cyanobond. It was necessary to repeat polishing, air dry and consolidation several times. The last polishing was done by corundum 3,000 and let it about one day's air dry. A thin diamond saw, 0.5 mm thick, was used for cutting.





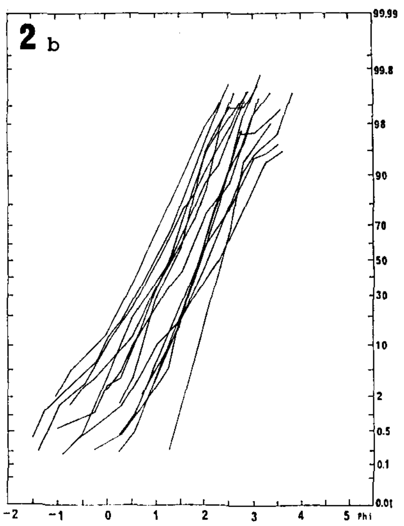


Fig. 40. Log-probability curves of silts and sands of the Ogoto sands. 1: silt and fine-grained sands, 2: medium to very cosrae-grained sands (2a: sample no. from 2 to 22, 2b: sample no. from 23 to 40).

finer-grained sediments (coarse silt to fine sand) (Fig. 40-1). A part of the coarser-grained sediments (medium- to coarse-grained sand) show a similar pattern, but the matrix is very poor being less than 2% in amount. Most of the coarser-grained ones are characterized by lacking in coaser and finer populations. They are grouped into two different types of grain-size distribution, such as represented by a nearly straight line and that has several break points. The last type is also found in the Daedong Supergroup.

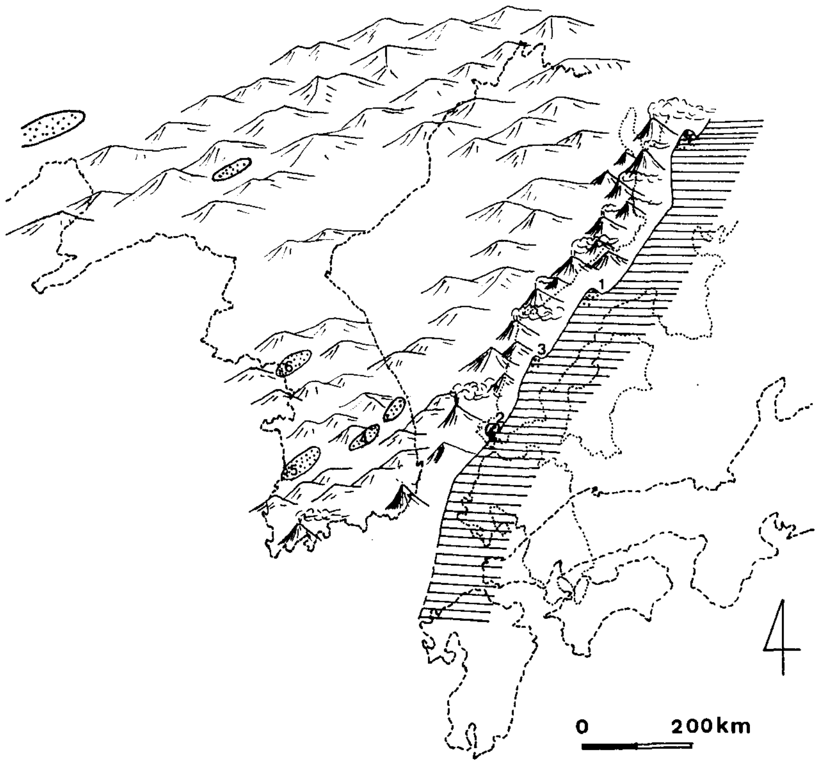


Fig. 41. Palaeogeographic reconstruction of early Jurassic age in Japan and South Korea. 1: Yamaoku, 2: Toyora, 3: Higuchi, 4: Mungyeong, 5: Daecheon, 6: Kangwha, a: Kuruma (northernmost embayment). (Relative position of Japan and South Korea is based on SASAJIMA, 1981).

All these curve shapes mentioned above are considered to represent fluvial or fluviolacustrine environments, because both the Ogoto Sands and the Daedong Supergroup consist of the sediments in the intermontain basin.

IV. Consideration and Implication to the Tectonic Development of the Inner side of Southwest Japan and South Kora

It is a current opinion that the Sea of Japan has been generated by backarc spreading (e.g., MURAUCHI, 1971; UYEDA and KANAMORI, 1979; SASAJIMA, 1981, etc.). According to the recent paleomagnetic sutdy of OTOFUJI (person. comm., 1981*) the opening of the Sea of Japan started at the earliest Miocene accompanied by the

* The result has recently been pubilshed. OTOFUJI, Y. and MATSUDA, T. (1983), Paleomagnetic evidence for the clockwise rotation of Southwest Japan. *Earth. Planet. Sci. Let.*, **62**, 349-359.

clockwise rotation of the Japanese Islands. If so, the Inner Side of Southwest Japan is believed to have been located at the margin of the Asian continent during the pre-Neogene times. The following consideration is based on such geographic situation.

As discussed in the foregoing chapters, the lithofacies and grain-size distribution as well as fossil evidences of the lower Jurassic deposits distributed in the Sea of Japan side of the Inner Side of Southwest Japan indicate shallow coastal or inlet or even deltaic environments. On the other hand, a large part of the so-called geosynclinal deposits which are widely developed in the more southward part in the Inner Zone, have now been clarified to be Jurassic in age (MIZUTANI *et al.*, 1981, etc.). Accordingly, the lower Jurassic shallow-sea deposits studied in this paper are considered to have fringed the Asian continent.

The composition of coarse-grained clastic rocks of the Yamaoku Formation suggests the acidic magmatism in the provenacne. Namely, the conglomerates of the formation are composed of more than 50% of acidic volcanic clasts, and the sandstones also contain abundant acidic volcanic grains which occupy about 65% of the whole rock fragments. Furthermore, acidic tuffaceous sandstone occurs in the Yamaoku Formation. Consequently it is assumed that acidic volcanism took place before and/or during the deposition of the Yamaoku Formation. Acidic magmatism in the early Jurassic time is also known in the Hida massif as indicated by the Funatsu granite and abundant volcanic clasts of the lower Jurassic Kuruma Group. Some acidic tuffs are recently found in the Kuruma Group (YAMADA and TAKIZAWA, 1981). Therefore, it is presumed that the volcanic mountains existed behind those sedimentary basins. The clasts which are referred to the Sangun metamorphic rocks were not found at all in the Yamaoku Formation, suggesting that the Sangun metamorphic rocks were not exposed there. This is endorsed by a heavy mineral analysis by SATO (1951). Based on the heavy mineral composition, he assumed the presence of acidic plutonic rocks of shallow facies, but according to him there is no heavy minerals derived from "high grade" metamorphic rocks. On the contrary, the Kyomiyama tuffaceous conglomerate Formation, which overlies the Yamaoku Formation with a remakable unconformity, contains abundant schist clasts and some serpentinite. A marked structural contrast between the Yamaoku Formation and Kyomiyama tuffaceous conglomerate Formation shows that after the deposition of the Yamaoku Foamation, there was an intense period of folding and faulting. This crustal movement accompanied by serpentinite intrusion resulted in an uplift and denudation of the Sangun metamorphic rocks.

Such a remarkable crustal movement is also confirmed around the Hida belt in the Inner Zone of Central Japan. The thick molasse deposits of the lower Jurassic Kuruma Group show the uplift of the source area accompanied with a strong subsidence of the depositional site. The group is bordered by serpentinite with the adjacent metamor-

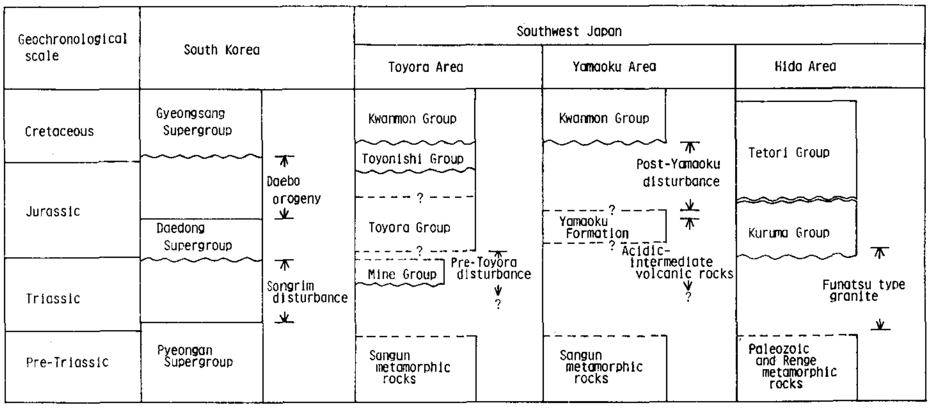


Fig. 42. Correlation chart of Jurassic and Cretaceous strata and tectonic movements in Southwest Japan and South Korea.

phic rocks of the Hida marginal belt which is considered to be a tectonic serpentinite mélange zone (CHIHARA *et al.*, 1979). On the other hand, the middle to uppe Jurassic Tetori Group contains many blocks derived from the mélange zone (SOHMA *et al.*, 1981). It should be mentioned that the abundant orthoquartzite gravels of most probably Precambrian age (SHIBATA, 1979) first appear in the upper Jurassic Tetori Group. These facts suggest that significant disturbance occurred during middle to late Jurassic age. The hornblende ages of the gabbro in the Sangun metamorphic rocks are 228 and 248 m.y. (SHIBATA *et al.*, 1977). This is believed to be the age of metamorphism. On the other hand, K-Ar age of muscovite of the Sangun metamorphic rocks is middle Jurassic ranging from 169 to 175 m.y. (SHIBATA and IGI, 1969). This age is assigned to represent the upheaval of the Sangun metamorphic rocks. Such a remarkable Jurassic disturbance may be correlated to the middle to late Jurassic Daebo orogeny accompanied by intense acidic plutonism, which is referred to as the most remarkable event in the Korean Peninsula (Fig. 42).

The feature of the crustal movement around the Toyora Group is somewhat different. Here the Triassic movement seems to be more significant than of the late Jurassic, judging from the geologic structure and lithofacies of the lower Jurassic Toyora Group and the upper Triassic Mine Group. The conglomerates of the lowest member of the Toyora Group (basal member of Higashinagano Formation) has many schist gravels attaining to about 60% of the total. The schist clasts are derived from the Sangun metamoprhic rocks. In mineral composition of sandstones, schist grains occupy more than 30% in the basal unit (Nbc Member), then they decrease abruptly to less than 1% in the succeeding members (Ncs and Nss) of the Higashinagano Formation. In the overlying Nishinakayama and Utano Formations, the schist clasts were not found at all. Accordingly the Sangun metamorphic terrain in this area was uplifted before the Jurassic and submerged during the deposition of the

Nishinakayama and the Utano Formations. In the overlying Toyonishi and Kwanmon Groups the schist clasts were also not found at all.

Mineral composition of sandstones of the Toyora Group is characterized by a small amount of granite, chert, acidic and intermediate volcanic rocks, and matrix reaches to 30% in an average. The abundant matrix and low content of rock fragments suggest that this group was formed in an inland sea surrounded by a low relief land. According to INAZUMI (1980) a relatively uniform chemical composition of shale of this group suggests a calm and stable sedimentary envieonment at the time of deposition as mentioned already. The thinly laminated bedded shale from the Nishinakayama Formation (Plate 2, Fig. 3) also supports the calm environment.

Granite grains of the Higashinagano Formation are brobably derived from the Nagato Tectonic Zone. On the other hand, MURAKAMI *et al.* (1977, 1980) supposed the western extension of the Hida and the Hida marginal belt in the source area of the upper Permian and upper Triassic conglomerates near Toyora basin. Granitic pebbles of the Mine Group has 200 m.y. K-Ar age. Recently 220 m.y. age has been obtained from the granite of the Yeongnam massif in South Korea (LEE, 1980). Therefore, it is possible that the granite was derived from South Korea. The Triassic movement in Southwest Japan seems to correspond to the Songrim disturbance in Korea.

The conglomerates of the Higuchi Group are composed of more than 50% of shale clasts with subordinate chert, sandstone, acidic and intermediate volcanic clasts. However, the mineral composition of sandstones shows that intermediate and acidic volcanic grains are main component of the rock fragments.
Schist supposed to be Sangun metamorphic rocks appears in a very small amount. The Sangun metamorphic rocks must have been exposed locally in the provenance during the deposition of this group. The constituents of rock fragments suggest the supracrustal supply from the provenance, such as sedimentary rocks and volcanic rocks.

The Daedong Supergroup was examined mainly in the Mungyeong area. The conglomerates contains abundant quartzose sandstone reaching more than 50% of total clasts. Quartz grains occupy more than 60% of whole grains of sandstones. It is worthy of note that the metamorphic rocks such as crystalline schists and gneiss are very small in amount as clasts in conglomerates and absent in sandstones. The character of sandstones is very similar to that of the Pyeongan Supergroup.
Mineral composition of sandstones of the Pyeongan Supergroup is also very similar to that of the Daedong Supergroup. The provenance of a large amount of quartzose sandstone of the Daedong and Pyeongan Supergoups is an important problem.

DICKINSON *et al.* (1979) stated that quartzose sands were derived from recycled cratonic sources. According to BOND and DEVAY (1980) the depositional setting of the quartzose sandstnes was most likely a passive continental margin and the predominant source of the quartzose sandstones was probably a potassic plutonic and/or metamorphic terrane.

However, the absence of potash feldspar in the sandstones of Daedong Supergroup strongly denies the presence of granitic rocks as main component in the source area, but the wide distribution of the sedimentary quartzose rocks is postulated if we notice the common occurrence of quartz sandstone grains and clasts. The Moscovian fusulinid limestone gravels found in the Sapyeongri Formation of lower Jurassic Daedong Supergroup (CHEONG and PARK, 1979) suggest that at least a part of the sediments were derived from the Pyeongan Supergroup. KOBAYASHI (1953) explained that quartzose sandstone clasts of the conglomerates were originated from the lower Gobangsan Formation of the Pyeongan Supergroup. But the origin of quartze sandstone of the Pyeongan group is a problem. The quartzite is found in the basal unit of Cambro-Ordovician Joseon Supergroup which is called the Jangsan quartzite. The quartzite bed ranges from 50 to 200 m in thickness, but if considering the thickness of quartzose rocks of the Pyeongan and Daedong Supergroups, it seems to be too thin for the source rocks. Judging from the common occurrence of aeolian quartzose sandstone clasts in the sandstone and conglomerates, the Precambrian Sinian rocks must have played an important role in the provenance.

It is worthy of note that the occurrence of orthoquartzite pebbles of 202 m.y. is reported from the Toyonishi Group and a large amount of orthoquartzite gravels, one of which has 778 m.y. age, are found in the Tetori Group in Japan (TOKUOKA and OKAMI, 1979; SHIBATA, 1979; OKADA, 1981). Furthermore, the provenance of the clastic sediments of upper Paleozoic in Sikhote-Alin was supposed not only to the west but also to the east and southeast of the basin, namely, in the present Japan Sea region (BELYAVSKIY & GROMOY, 1962; CHANG, 1978). Therefore, it is suggested that a considerable part of quartzose sandstones of the Daedong and Pyeongan Supergroups were derived from the Precambrian orthoquartzites distributed around the Ogcheon belt and the Japan Sea, although these are not found at present.

It is noteworthy that the rock types of the provenance of the lower Jurassic are different between Japan and Korea. The provenance of the Daedong Supergroup is characterized by quartzose sandstones, while that of the lower Jurassic in Japan is considered to be constituted by various rocks such as acidic and intermediate volcanic rocks and various kinds of sedimentary rocks. Metamorphic rocks are contained to a very narrow area in the Toyora area. However, acidic volcanic clasts are also found in the Daedong Supergroup, and orthoquartzite gravels occur abundantly in the middle to upper Jurassic Tetori Group. These facts suggest that the landmass between southwest Japan and South Korea is areally heteroropic in composition.

It is supposed that in the Early Jurassic age, the Inner Zone of Southwest Japan occupied a coastal area in front of the continental arc, and in the Cretaceous age, that area became inland area, and marine sedimentary basins shifted to the

Shimanto belt, that is, the Pacific Ocean side. This indicates the southward shifting of subduction zone. At the same time acidic volcano-plutonic province also moved from Hida-Ryongnam area in the Jurassic to the Gyeonsang-Chugoku belt in the Cretaceous. In this sense, the middle to late Jurassic crustal movement of the Daebo orgeny seems to have been very significant in geographical and tectonic controls in both Southwest Japan and South Korea.

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Locality Names in Japan

Akiyoshi	秋 吉	Chichibu	秩 父	Chugoku	中 国
Funatsu	船 津	Furudani	古 谷	Gamo	蒲 生
Hida	飛 驒	Higashinagano	東長野	Higuchi	樋 口
Honshu	本 州	Iga-Aburahi	伊賀-油日	Ishimachi	石 町
Itoigawa-Shizuoka	糸魚川-静岡	Kamiogi	上仰木	Kanoashigochi	鹿足河内
Katata	堅 田	Kobiwako	古琵琶湖	Kuruma	来 馬
Kwanmon	関 門	Kyomiyama	京見山	Maizuru	舞 鶴
Minamisho	南 庄	Mine	美 禰	Nishinakayama	西中山
Nishisonogi	西彼杵	Ogoto	雄 琴	Okayama	岡 山
Osakabe	刑 部	Osayama	大佐山	Otsu	大 津

Ryoke	領 家	Ryuge	龍 華	Sambagawa	三波川
Sambosan	三宝山	Sangun	三 郡	Sayama	佐 山
Shiga	滋 賀	Shimagawara	島ヶ原	Shimane	島 根
Shimanto	四万十	Shimonoseki	下 関	Sogahara	惣ケ原
Tabe	田 部	Takashima	高 島	Tamba-Mino	丹波-美濃
Tetori	手 取	Toyohigashi	豊 東	Toyonishi	豊 西
Toyora	豊 浦	Utano	歌 野	Wakino	脇 野
Wani	和 邇	Yamaguchi	山 口	Yamaoku	山 奥
Yokaichi	八日市				

Locality Names in South Korea

Bansong	盤 松	Bolim	宝 林	Bongmyeongri	鳳鳴里
Bongmyeongsan	鳳鳴山	Bulkuksa	佛国寺	Buunryeong	富雲嶺
Chareong	車 嶺	Daebo	大 宝	Daecheon	大 川
Daedong	大 同	Dangi	檀 紀	Dangog	檀 谷
Danyang	丹 陽	Eunseong	恩 城	Gobangsan	高坊山
Geyonggi	京 畿	Gyeongsang	慶 尚	Hanaeri	下乃里
Hongjeom	紅 店	Jangsan	壮 山	Jangseong	長 省
Jeju	済 州	Jeongseun	旌 善	Joseon	朝 鮮
Kanghwa	江 華	Kimpo	金 浦	Maseong	麻 城
Mungyeong	聞 慶	Nakdong	洛 東	Nampo	濫 浦
Nogam	緑 岩	Ogcheon	沃 川	Pyeongan	平 安
Sadong	寺 洞	Sapyeongri	沙坪里	Silla	新 羅
Sobaek	小 白	Songrim	松 林	Yeoncheon	漣 川
Yoengnam	嶺 南	Yeongweol	寧 越		

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*: in Japanese, **: in Korean; these are mostly with English abstract.

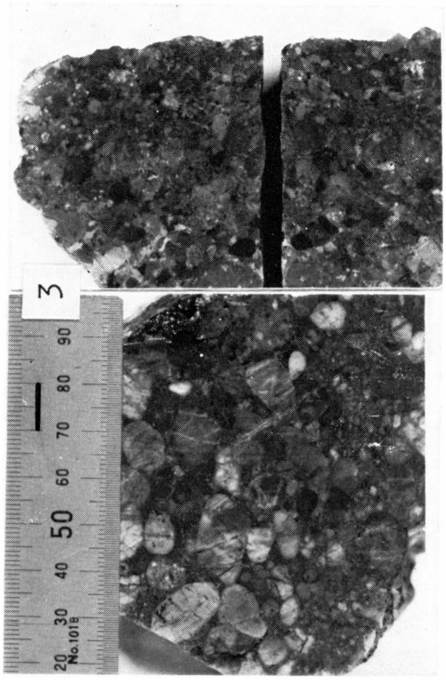
Explanation of Plate 1

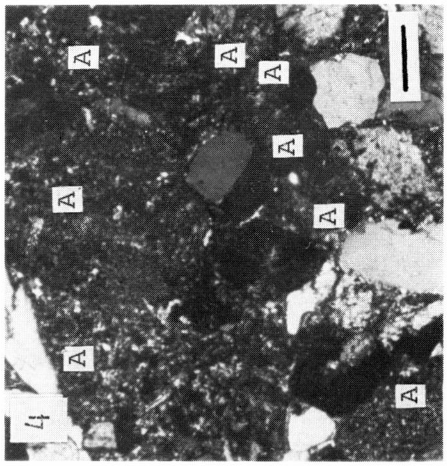
Fig. 1. Fossil-bearing muddy sandstone bed, upper part of Member "a" of the Yamaoku Formation. f: casts of bivalve shells.

Fig. 2. Sandstone-rich alternation of sandstone and shale, Member "c" of the Yamaoku Formation.

Fig. 3. Polished surface of conglomerate of the Yamaoku Formation. Scale bar: 1 cm.

Fig. 4. Photomicrograph of sandstone of the Yamaoku Formation, showing abundant grains of acidic volcanic rocks (A). Scale bar: 0.24 mm.





YU: Sedimentological Study on the Early Jurassic Marine Facies

Explanation of Plate 2

Fig. 1. Scanning electron micrograph of shale of Member "b", Yamaoku Formation, showing strongly preferred orientation of clay fabric. Scale bar: 1 micron

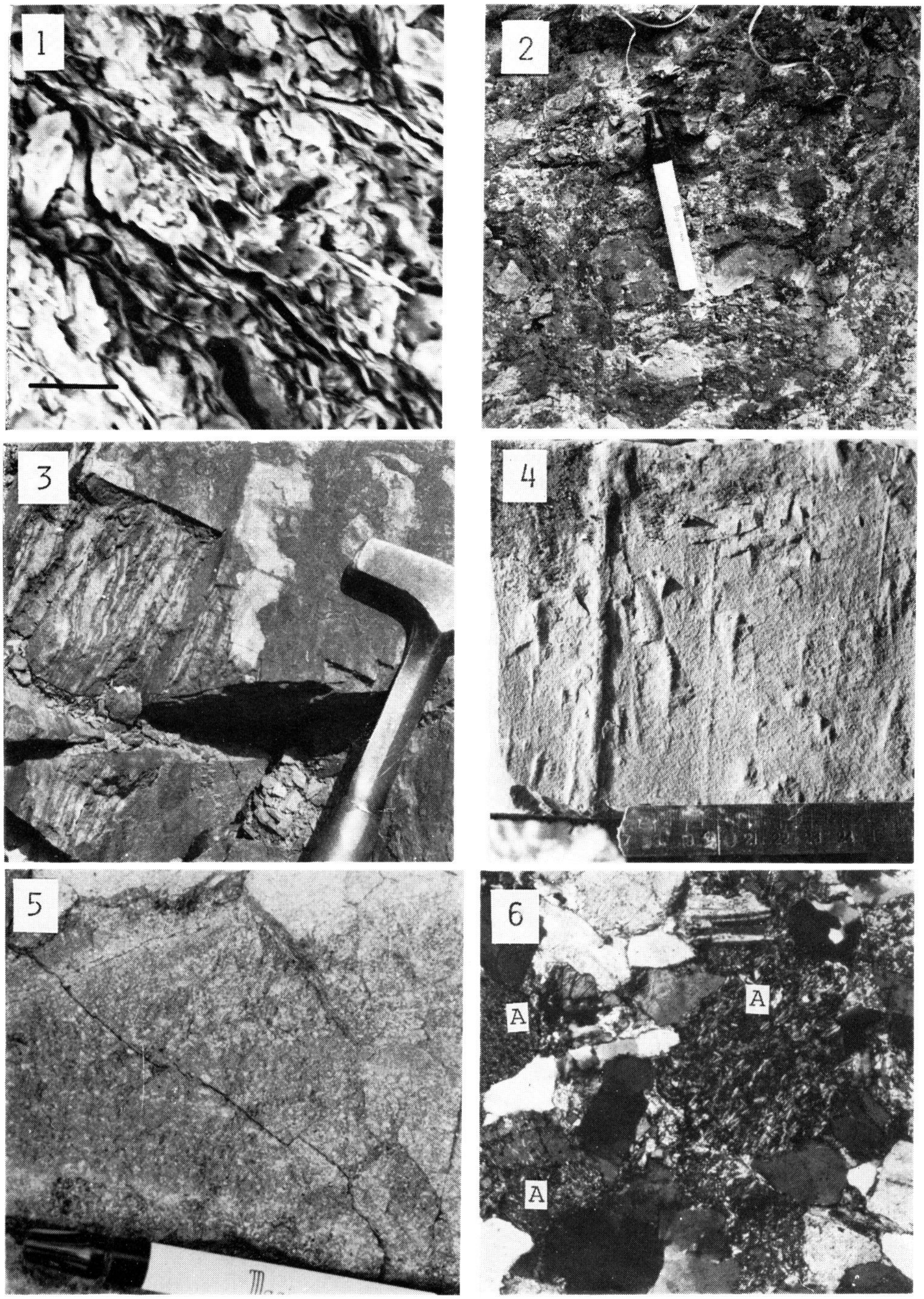
Fig. 2. Exposure of the basal conglomerate of the Toyora Group, containing baundant schist clasts.

Fig. 3. Thinly laminated shale of the Nishinakayama Formation, Toyora Group.

Fig. 4. Sole marks (prod and groove) of the Utano Formation, Toyora Group.

Fig. 5. Graded and corss bedded conglomerate of fine pebble and granule, Higuchi Group.

Fig. 6. Photomicrograph of sandstone of the Toyora Group. A: clasts of acidic volcanic rocks. Scale bar: 0.24 mm.



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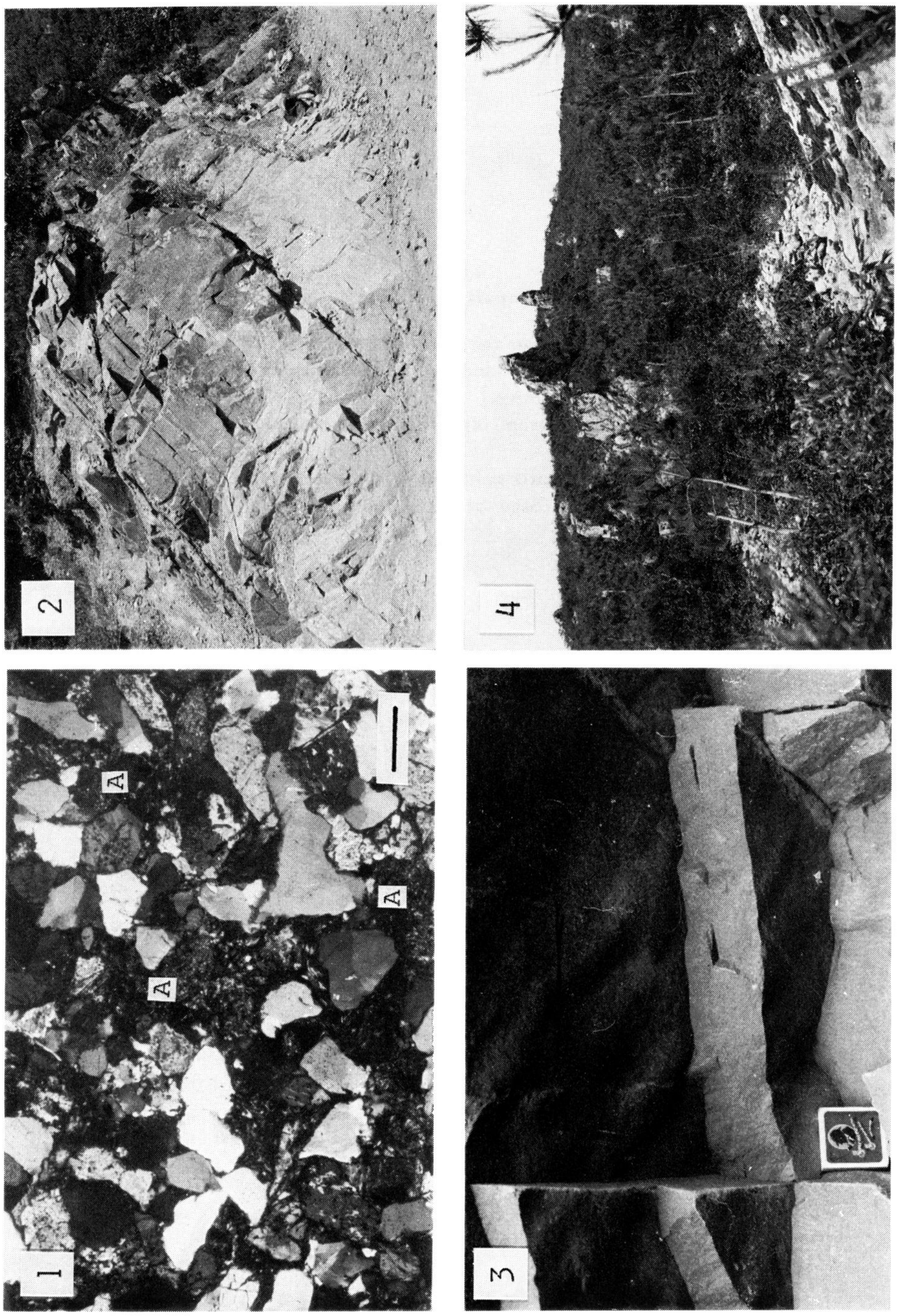
Explanation of Plate 3

Fig. 1. photomicrograph of sandstone of the Higuchi Group. A: clasts of acidic volcanic rocks. Scale bar: 0.24 mm.

Fig. 2. Exposure of upward fining sequence from coarse-grained sandstone (lower right) to sandy shale (upper left) through fine-grained sandstone (middle). Daedong Supergroup, Mungyeong area.

Fig. 3. RipPle mark of the Daedong Supergroup, Mungyeong area.

Fig. 4. Outcrop of quartz sandstone of the Daedong Supergroup making a resistant ridge, Mungyeong area.



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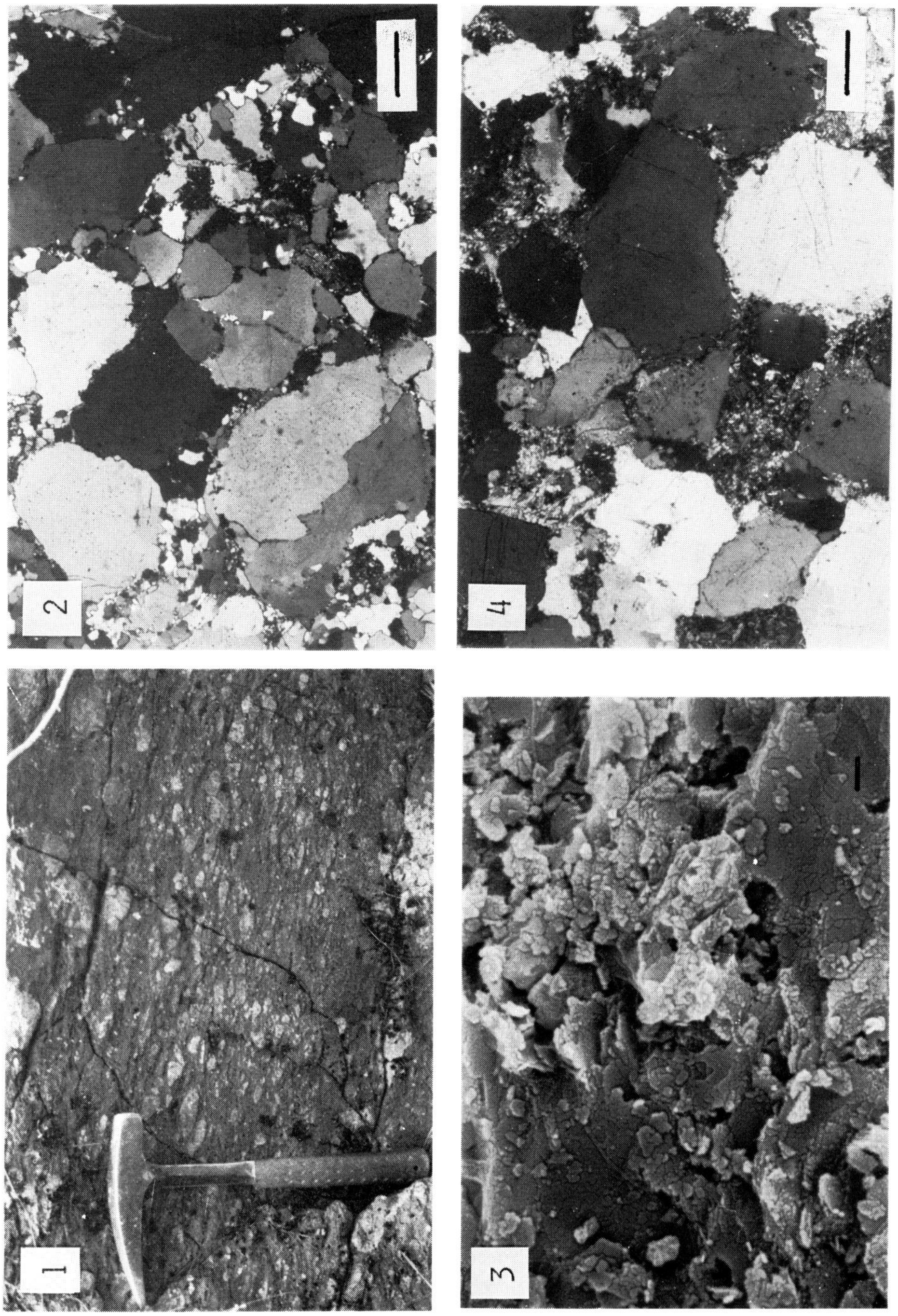
Explanation of Plate 4

Fig. 1. Conglomerate of "a" zone of the Daedong Supergroup, Mungyeong area.
Fig. 2. Photomicrograph of quartz sandstone of the Daedong Supergroup, showing sand grain with dust ring. Scale bar: 0.24 mm.
Fig. 3. Scanning electron micrograph of shale of the Daedong Supergroup, Daecheon area. Scale bar: 5 micron.
Fig. 4. Photomicrograph of quartz sandstone of the Pyeongan Supergroup, showing sand grain with dust ring. Scale bar: 0.24 mm.



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