Memoirs of the Faculty of Science, Kyoto University, Series of Geol. & Mineral.
Vol. XXXIV, No. 1, pp. 35–74, pl. 3.

The Shimanto Terrain in the Kii Peninsula, Southwest Japan

—with Special Reference to its Geologic Development Viewed from Coarser Clastic Sediments—

By

Takao Tokuoka

(Received Sept. 9, 1967)

Abstract

The Shimanto Supergroup in the Kii Peninsula is divided into two groups, i.e. the Hidakagawa Group in the northern part and the Muro Group in the southern part. The former is mainly Cretaceous and the latter is early Cenozoic. In this paper conglomerates and sandstones of the two groups are treated with, and several considerations on the geologic development of the Shimanto Terrain are given.

In the Cretaceous the Shimanto Terrain was in a eugeosynclinal condition, while in the early Cenozoic it changed to be in a miogeosynclinal condition. The change of environment is shown in the differences of megascopic characters of clastic sediments and properties of sandstones. The provenances of the Shimanto Terrain can be generally sought to the north of the geosyncline, that is, the so-called Meso-Volcanics in the Inner Zone, various rocks in the Ryoke Metamorphic Belt, the Paleozoics in the Chichibu Terrain and the so-called Torinosu Group.

After the close of the Shimanto geosyncline a marine transgression occurred again at the Middle Miocene, and formed the Kumano and Tanabe Groups. Their basins were smaller and more local in comparison with the Shimanto geosyncline. Clastic materials were supplied mainly from the Sambagawa Metamorphic Belt and the Muro Group.

Orthoquartzite gravels were commonly found from the conglomerates in the southernmost district of the Muro Group. They are supermature orthoquartzites with excellent sorting and rounding. These rocks cannot be seen in the present Japanese Islands and furthermore the paleocurrent data of this district show apparently from south to north direction. Such being the case, it may be reasonably concluded that a missing land once existed to the south of the Shimanto geosyncline where nowadays is the Pacific Ocean.

Introduction

The Shimanto Terrain occupies a vast area about 1000 km long and 100 km wide in the Outer Zone of Southwest Japan, and has been considered a part of the so-called Alpine Orogenic Belts in Japan. In "The Geologic Development of the Japanese Islands" (Minato et al., 1965) the subcontinental stage of the Honshu Major Belt and the Mesozoic geosynclines of the Outer Side have been discriminated in the Japanese Islands from the Triassic to the Paleogene. The Shimanto Supergroup of the Shimanto Terrain, which is the main part of the above-mentioned Mesozoic geosynclines, is composed of thick geosynclinal sediments.

The Shimanto Supergroup in the Kii Peninsula is divided into two groups, i.e. the Hidakagawa Group in the northern part and the Muro Group in the southern part. The former is Mesozoic (mainly Cretaceous) and the latter is early Cenozoic. They have complicated folding and faulting structures. The study of the Shimanto Terrain has been made by several geologists in the last decade, and its geologic age and geologic structure have been clarified in some degree. The properties of the sedimentary rocks, however, have seldom been reported on so far.

In this paper the writer wishes to treat with the properties of the sedimentary

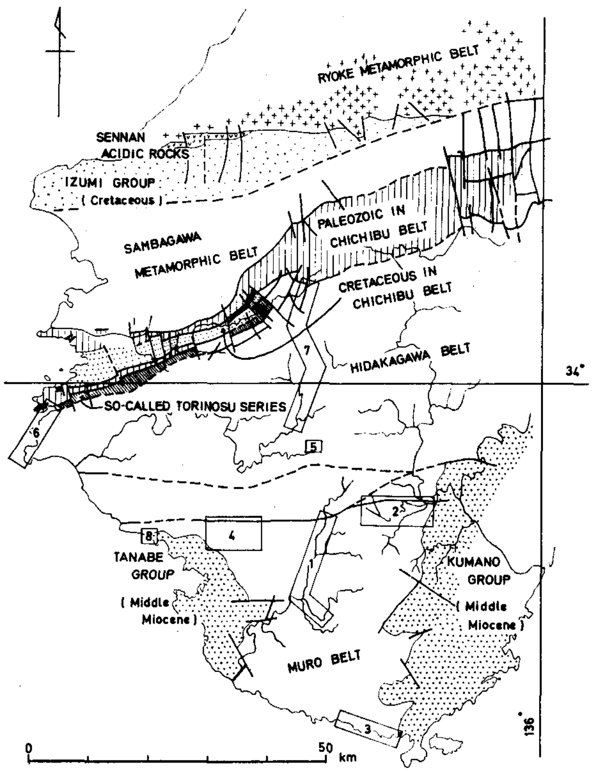


Fig. 1. Index Map (The studied areas are shown by quadrangles with numbers.)

rocks, mainly of the conglomerates and sandstones in the Shimanto Terrain in the Kii Peninsula, and several considerations will be given on the geologic development of the Shimanto Terrain in the Japanese Islands. The studied areas are shown in Figure 1.

The writer is indebted to Prof. K. NAKAZAWA for his valuable advices and encouragement. The writer is also indebted to Dr. S. ISHIDA, Dr. T. SHIKI and Dr. D. SHIMIZU for their kind encouragements and advices. Dr. T. HARATA, Mr. H. SUZUKI and Mr. H. TERASHIMA collaborated with the writer in field work and kindly joined in discussion. The writer wishes to express his sincere thanks to them.

PART 1. THE CONGLOMERATES AND SANDSTONES OF THE HIDAKAGAWA GROUP

I. General Remarks

The Hidakagawa Group is a part of the so-called Unknown Mesozoic of the Outer Zone of Southwest Japan, and has long attracted no attention. There has been made no detailed report on the Hidakagawa Group whose geologic age is only referred to as Mesozoic conceptionally. The Group is composed of flysch type alternations of sandstone and shale, frequently intercalated by siliceous or cherty rocks and basic volcanic rocks, and rarely by conglomerates. Several sole markings, many of which are deformed secondarily, biohieroglyphs and graded beddings can be observed. It can be assigned roughly to "normal flysch". The strata have very complicated folding and faulting structures, and the stratigraphy and geologic structure have not been clarified yet. The group may attain to more than 10,000 m in total thickness.

The present writer will treat with conglomerates and massive sandstones as a whole in order to clarify the source area and sedimentary environments of the Hidakagawa Group.

II. The Conglomerates of the Hidakagawa Group

1. *Localities Investigated and Their Geologic Setting*

The conglomerates were studied in the following two districts.

(a) The Kashoguchi district along the upper reaches of the Nyunokawa in Ryujin-mura (Loc. 5 in Fig. 1; Fig. 2)

(b) The Gobo district along the western coast of the Kii Peninsula (Loc. 6 in Fig. 1; Fig. 3)

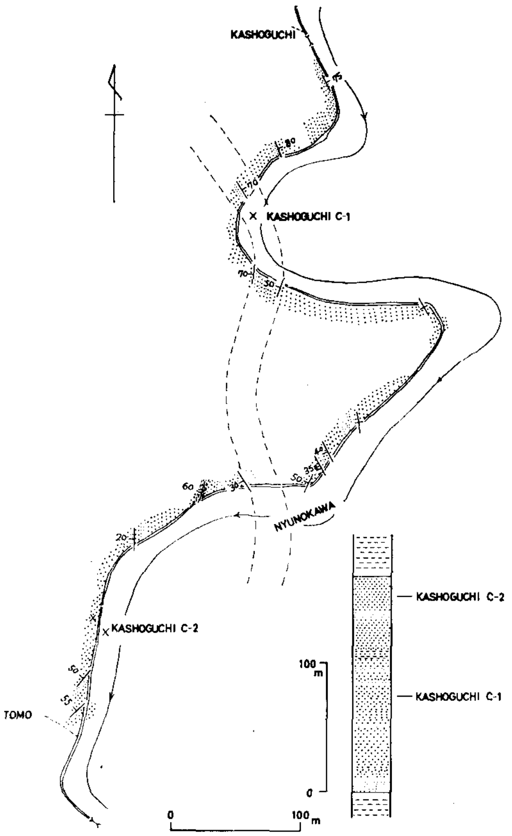


Fig. 2. Route map and columnar section of the Nyunokawa Formation of the Hidakagawa Group along the upper reaches of the Nyunokawa (heavy dotted: conglomerate, dotted: sandstone, broken lines: alternations of sandstone and shale)

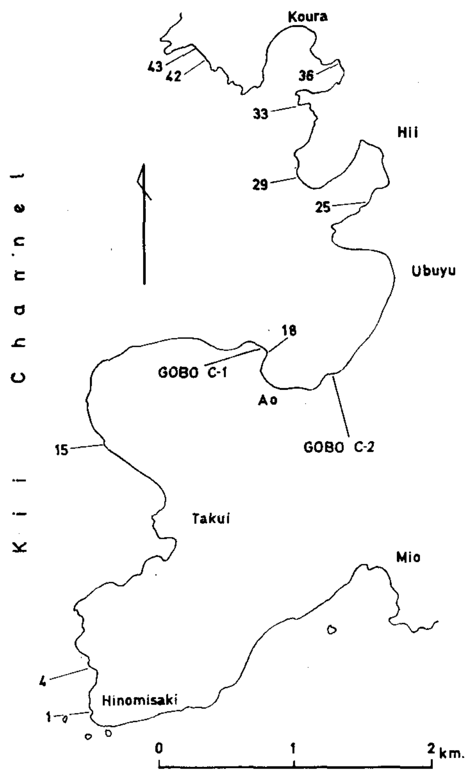


Fig. 3. Investigated localities of conglomerate and sampling localities of sandstone in the Gobo district (Gobo C-1 and C-2 show the localities of conglomerate. Numbers show the sampling localities of sandstone.)

(a) The Kashoguchi district (The Kashoguchi Conglomerates)

The lithology of the Hidakagawa Group in this district is as follows (Wakayama Pref., 1966). The Hidakagawa Group in Ryujin-mura is divided into the Nyunokawa Formation and the Ryujin Formation in ascending order. The former is composed of alternations of sandstone and shale, and in its uppermost part there are several layers of conglomerate. The latter formation is also composed of shales and shale-rich alternations, and is intercalated by small quantities of siliceous or cherty rocks and basic tuffs. The Hidakagawa Group generally takes E-W trend, and dips northward at about 50–90 degrees with monoclinal structure seemingly. But macroscopically, it has been considered to take complicate folding and faulting structures. Main part of the group is considered to be of the Cretaceous, more particularly, the Upper Cretaceous, although reliable fossil-evidences are not discovered.

At Kashoguchi along the upper reaches of the Nyunokawa there can be seen several layers of conglomerate representing the uppermost part of the Nyunokawa Formation. They are collectively called the Kashoguchi conglomerates. The route map and columnar section are shown in Fig. 2. The Kashoguchi conglomerates intercalating several layers of sandstone and alternations of sandstone and shale in them attain to about 160 m in thickness. The conglomerates conformably overlie the lower alternation rich in shale, and are overlaid by the Ryujin Formation. Conglomerates at two localities (Kashoguchi C-1 and C-2) were investigated.

(b) The Gobo district

According to HASHIMOTO (1967) the Hidakagawa Group in this district can be tentatively divided into "A" and "B" Formations in ascending order. "A" Formation may attain to more than 700 m in thickness and "B" Formation to more than 800 m. They are composed mainly of sandstones, shales, and alternations of sandstone and shale. They are intercalated by conglomerates, cherts, acidic tuffs, basic lavas and muddy limestones. The Hidakagawa Group has a general strike of N 70°–80° E and takes isoclinal folded structure. It is considered to be the Upper Cretaceous from some fossil evidences.

The writer examined the properties of conglomerates at two localities (Gobo C-1 and C-2) shown in Fig. 3. They are contained in the lowest part of "B" Formation.

2. *The Properties of the Conglomerates of the Hidakagawa Group*

(a) Size*

Size distributions at four localities are shown in Fig. 4. At Kashoguchi C-1, C-2 and Gobo C-2 they show similar unimodal patterns having the peak at 2–4 cm. (Strictly speaking they correspond with secondary maximums in coarse admixtures by UDDEN (1914) judging from the matrix of conglomerates.) That of Gobo C-1, however, is somewhat different. According to the grade scales of WENTWORTH (1922), it can be said that they are composed mainly of pebble gravels containing many cobbles and fewer boulder gravels. At Kashoguchi C-2 there is a well rounded boulder gravel of sandstone whose size is 250×190 cm on the exposure surface.

* Size of gravels in this paper indicates the length of the longest axis on the exposure surface. Size frequency distribution at each locality is determined by counting 200 gravels at random. They are practically divided into 1–2, 2–4, 4–8, 8–16 and 16–32 cm size grades.

(b) Composition

The method illustrating the composition of conglomerate is shown in the previous paper (TOKUOKA, 1966b). In each locality 100 to 300 gravels and in the case of the Hidakagawa Group 200 gravels, larger than 1 cm in diameter, were examined. They were classified in the field into such elements as sandstone, shale, chert, limestone, granitic rocks, acidic volcanic and dyke rocks*, and others by unaided eye.

The Kashoguchi District

1. Cherts are most abundant and occupy almost a quarter of the total.

2. Sandstone, shale, and acidic volcanic and dyke rocks occupy about 15 to 25%.

3. Granitic rocks (mainly granites and granite porphyries) take up 12% at each locality.

4. Limestone takes up 5% at Kashoguchi C-1, and 1% at Kashoguchi C-2. (Because of the bad condition of exposure at C-2 the ratio may increase to some degree.)

5. Gravels larger than 10 cm in diameter, whose quantities are shown by small circle in Fig. 4, are composed of acidic volcanic and dyke rocks, sandstone, granite, and shale.

The Gobo District

1. Limestones are very abundant in each locality.

2. Sandstone, acidic volcanic and dyke rocks, granitic rocks, and chert are smaller in quantity than those of the Kashoguchi conglomerates, although commonly seen.

3. At Gobo C-2 there are many unclassified gravels which contain schists and greenish igneous rocks.

4. Gravels larger than 10 cm are abundant in Gobo C-1 and smaller in quantity in Gobo C-2. In the former, limestone is predominant, and the other elements such as sandstone, shale and granite are subordinate. In the latter the gravels are almost exclusively composed of sandstone and limestone.

(c) Roundness

Roundness of gravels was examined by means of the roundness chert of DMITRIEVA et al. (1962), which exhibits roundness of material in 19 figures. After determining roundness by the above figures, the writer classed the roundness of gravels in eight grades by the difference of value of about 0.1. In this case observation error is almost negligible.

---

* In the element of acidic volcanic and dyke rocks, rhyolite tuff and dacite tuff are included.

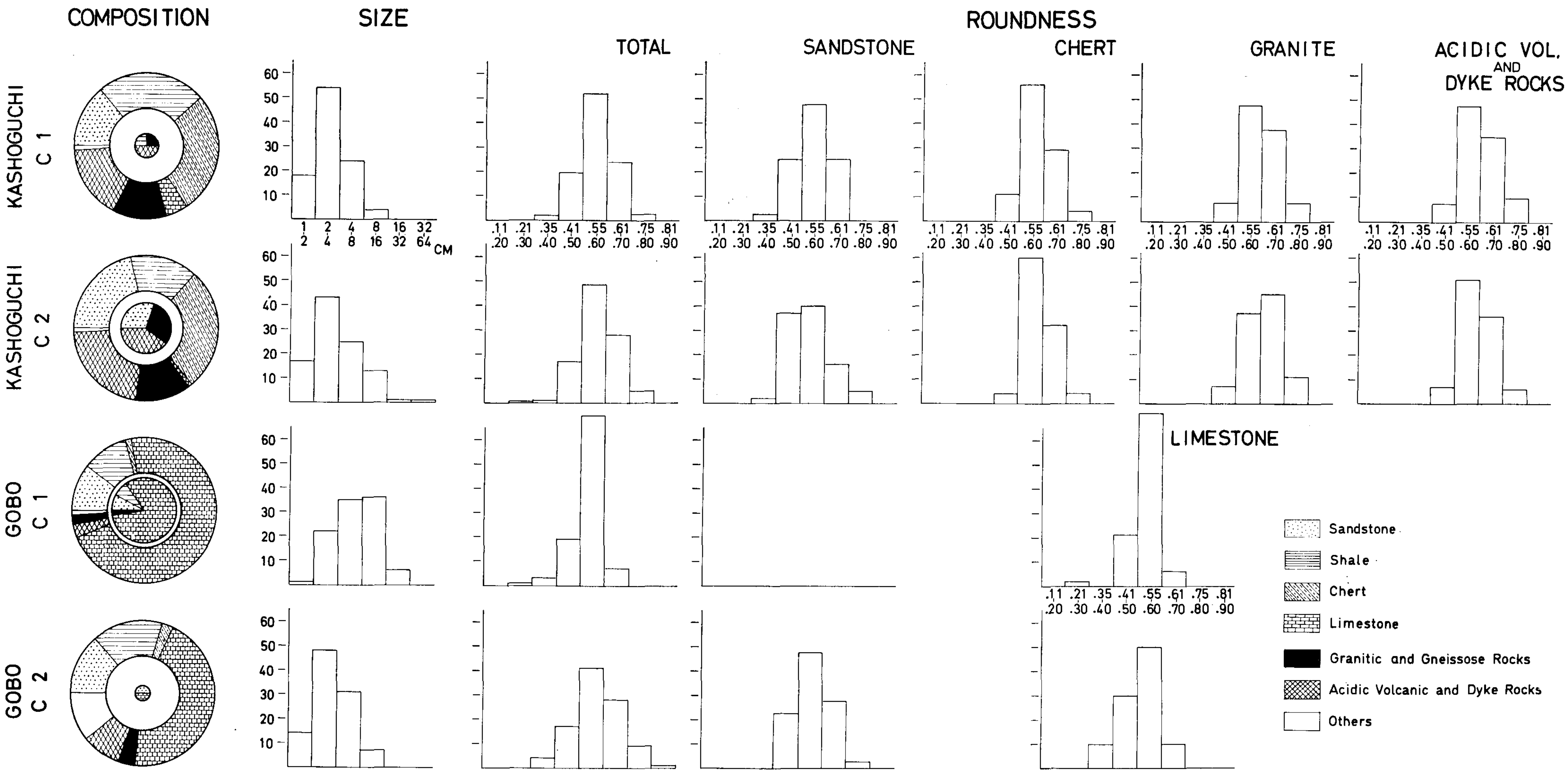


Fig. 4. Properties of the conglomerates of the Hidakagawa Group (The inner circles at the left show the composition of gravels larger than 10 cm in diameter. The sizes of the inner circles are proportional to their total volume in gravels larger than 1 cm. For instance the inner circles of Kashoguchi C-1 and C-2 show 2% and 10% respectively.)

The writer measured the roundness of gravels larger than 1 cm in diameter on the exposure surface. For roundness frequency distribution of the total gravels, 100 or 200 gravels (200 gravels in the Hidakagawa Group) were measured at random at each locality, and then for individual roundness frequency distribution of sandstone, chert, limestone, acidic volcanic and dyke rocks, and granitic rocks, more than 40 gravels were measured.

Total and individual roundness distributions are shown in Fig. 4. The following facts can be pointed out.

1. Total roundness distribution at each locality shows unimodal pattern having the peak at 0.55–0.60, and extends mainly from 0.35–0.40 to 0.75–0.80 and sometimes from 0.21–0.30 to 0.81–0.90.

2. In the Kashoguchi district individual roundness of sandstone, chert, granite (granitic rocks), and acidic volcanic and dyke rocks were measured. Roundness patterns are slightly different between sedimentary rocks and igneous rocks. Granite and acidic volcanic and dyke rocks are rich in more rounded gravels in comparison with sandstone.

3. In the Gobo district roundness of sandstone and limestone could be measured. They take similar distribution patterns having the peak at 0.55 – 0.60, but sandstone is slightly more rounded than limestone.

(d) Lithology

Lithologic characters and occurrences of the main constituents of gravels will be shown briefly in the following.

1. Granite: Granites are commonly contained in each locality. They are composed of biotite granite and two-mica granite. Many of them show porphyritic or graphic texture, and there are no typical plutonic granites.

2. Hypabyssal Rocks: There are granite porphyry, granophyre, quartz porphyry, dacite and porphyrite. Granite porphyry, granophyre and quartz porphyry are commonly found in all localities, while dacite is found in some degree. In the Gobo district porphyrites are found in addition to acidic hypabyssal rocks.

3. Rhyolite Tuff: Rhyolite tuffs are commonly found in all localities. About a half of the rhyolite Tuffs in the Gobo district and about one-tenth in the Kashoguchi district are welded tuffs. As xenolithes there are distinguished sandstone (graywacke type), chert and mudstone.

4. Limestone: Limestone gravels are divided into two types, muddy fine-grained limestone and pure grey limestone. In the Kashoguchi district they are represented by only muddy fine-grained limestones, while in the Gobo district there are many pure gray limestones and a smaller number of the first type.

5. Sandstone: There are three types of sandstone, i.e. (a) graywacke containing no rock fragments of chert, schist and schistose hornfels, (b) graywacke

containing above-mentioned rock fragments and (c) quartzose to arkose sandstone with calcite cement and containing above-mentioned rock fragments. In the Kashoguchi district there are abundant (b) type and many (c) type sandstones, and (a) type sandstones are rarely included. In the Gobo district there are abundant (c) type and many (b) type sandstones.

6. Schist: Schists are seldom seen at Gobo C-1 and C-2, which are composed of green schists and quartz schists. At the other localities no schist gravel has been discovered.

7. Other Rocks: There are schistose hornfels, hornfelses of sandstone, shale, chert, etc. However, their quantities are very small.

(e) Maturity

This will be discussed in connection with three indices such as roundness, lithology and degree of sorting.

1. Roundness: As already mentioned, the chief ingredient of roundness at each locality is in the class of 0.55–0.60. Roundness distribution stretches mostly from 0.35–0.40 to 0.75–0.80, and sometimes from 0.21–0.30 to 0.81–0.90. Individual roundness of sandstone, chert, limestone, granite, and acidic volcanic and dyke rocks is also shown in Fig. 4. The chief ingredient is in the class of 0.55–0.60 in all cases. The roundness of the conglomerates of the Hidakagawa Group is considered to be of comparatively high grade.

2. Lithology: Many sorts of gravels are contained in the conglomerates of the Hidakagawa Group, which can be regarded as polymictic conglomerates. There are many undurable rocks, such as limestone, green schist, granitic rocks, calcareous sandstone and graywacke sandstone. Furthermore it is characteristic that many limestone gravels are contained in the Gobo district. Durable rocks such as chert and acidic hypabyssal rocks occupy a comparatively small part of the total composition.

3. Degree of sorting: Size distributions of gravels larger than 1 cm, each of which takes a unimodal pattern, are shown in Fig. 4. The conglomerates of the Hidakagawa Group are composed mainly of pebble gravels, and contain many cobbles and a smaller number of boulder gravels. The chief ingredient at all localities is in the size grade of 2–4 cm. Matrices of conglomerates are composed of ill-sorted coarse sandstone.

The characters of the conglomerates of the Hidakagawa Group can be summarized as follows. Judging from roundness distribution, the conglomerates are in comparatively mature stage. From the viewpoints of lithology and sorting, however, they are in immature stage.

III. The Sandstones of the Hidakagawa Group

The Hidakagawa Group is mainly composed of flysch-like alternations of sandstone and shale frequently intercalating comparatively thick sandstones. Thick sandstones are usually massive, sometimes slightly graded, and contain some quantities of shale patches. They are marked by high induration and dark or light gray color. The writer examined massive sandstones thicker than 1 m of two districts in thin sections.

1. *Sampling Localities*

(a) The Ryujin-Hanazono district along the road between Ryujin-mura and

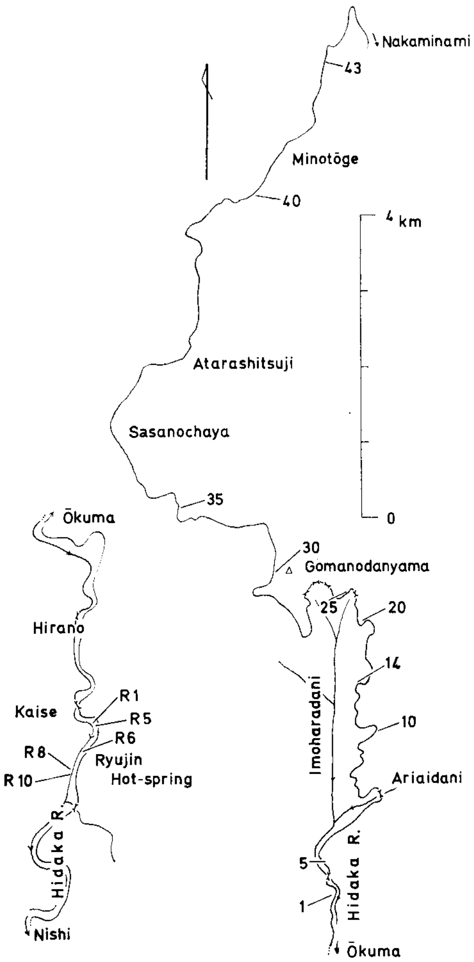


Fig. 5. Sampling localities of sandstone in the Ryujin-Hanazono district (Numbers show the sampling localities.)

Hanazono-mura (Loc. 7 in Fig. 1; Fig. 5)

Fifteen samples were examined in thin slices.

(b) The Gobo-Yura district along the western coast from Gobo to Yura (Loc. 6 in Fig. 1; Fig. 3)

Ten samples were examined.

2. *The Properties of Massive Sandstones of the Hidakagawa Group*

(a) Grain-size distribution

The sandstones of the above districts are characterized by polymodal or

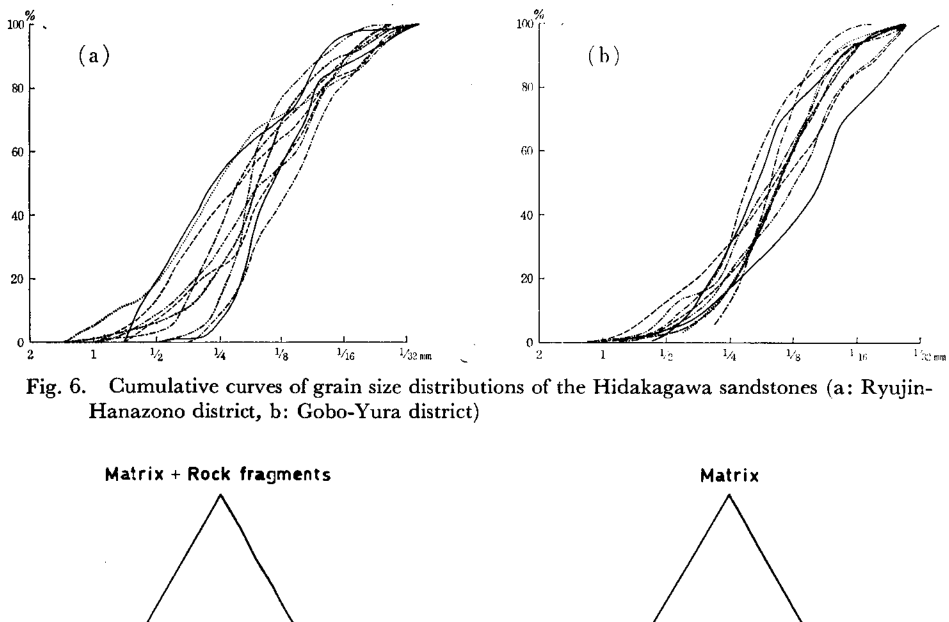


Fig. 6. Cumulative curves of grain size distributions of the Hidakagawa sandstones (a: Ryujin-Hanazono district, b: Gobo-Yura district)

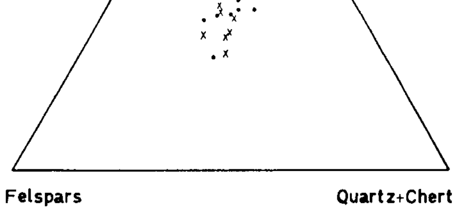


Fig. 7. Compositional diagram of the Hidakagawa sandstones (dotted: Ryujin-Hanazono district, crossed: Gobo-Yura district)

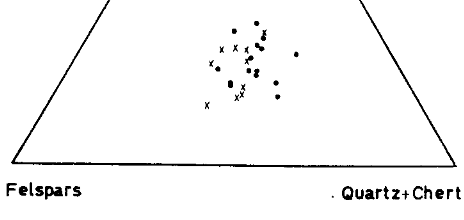


Fig. 8. Compositonal diagram of the Hidakagawa sandstones (dotted: Ryujin-Hanazono district, crossed: Gobo-Yura district)

Table 1. Textural properties of the Hidakagawa sandstones.

Ryujin-Hanazono District

Sample	Md	Q_3	Q_1	So	Sk	R
1	0.167	0.271	0.083	1.81	−0.10	0.20 (0.1–0.8)
5	0.260	0.427	0.099	2.08	−0.21	0.20 (0.1–0.5)
10	0.214	0.398	0.088	2.13	−0.12	0.21 (0.1–0.6)
14	0.177	0.214	0.130	1.29	−0.04	0.21 (0.1–0.5)
20	0.161	0.235	0.110	1.46	0.00	0.21 (0.1–0.6)
25	0.146	0.228	0.083	1.66	−0.04	0.18 (0.1–0.5)
30	0.206	0.302	0.103	1.71	−0.13	0.21 (0.1–0.6)
35	0.141	0.184	0.088	1.45	−0.10	0.21 (0.1–0.5)
40	0.110	0.177	0.075	1.54	0.03	0.19 (0.1–0.5)
43	0.260	0.442	0.107	2.03	−0.16	0.23 (0.1–0.6)
R-1	0.192	0.271	0.151	1.34	0.04	0.25 (0.1–0.6)
R-5	0.214	0.383	0.151	1.59	0.10	0.22 (0.1–0.6)
R-6	0.177	0.302	0.125	1.56	0.09	0.25 (0.1–0.5)
R-8	0.172	0.243	0.125	1.39	0.00	0.22 (0.1–0.7)
R-10	0.155	0.323	0.114	1.68	0.19	0.22 (0.1–0.5)
Average	0.183	0.293	0.109	1.65	−0.03	0.21 (0.1–0.8)

Gobo -Yura District

Sample	Md	Q_3	Q_1	So	Sk	R
1	0.099	0.177	0.062	1.69	0.04	0.21 (0.1–0.5)
4	0.192	0.281	0.125	1.50	−0.02	0.20 (0.1–0.6)
15	0.214	0.281	0.141	1.41	−0.06	0.18 (0.1–0.5)
18	0.161	0.199	0.125	1.26	−0.02	0.21 (0.1–0.4)
25	0.151	0.214	0.105	1.43	−0.02	0.20 (0.1–0.5)
29	0.151	0.214	0.099	1.47	−0.04	0.20 (0.1–0.4)
33	0.146	0.228	0.083	1.66	−0.04	0.22 (0.1–0.5)
36	0.167	0.260	0.105	1.58	−0.02	0.20 (0.1–0.5)
42	0.121	0.235	0.085	1.66	0.12	0.22 (0.1–0.5)
43	0.161	0.312	0.095	1.81	0.06	0.19 (0.1–0.5)
Average	0.156	0.240	0.103	1.55	0.00	0.20 (0.1–0.6)

bimodal, and rarely unimodal distributions of grain size. The cumulative curves are shown in Fig. 6. Textural properties of each sample are shown in Table 1.

(b) Roundness

Roundness of sand grains is mainly in the classes from angular to subrounded, in which subangular class occupies the majority. Occasionally there are included rounded sand grains. Roundness of quartz grains in each sample is shown in Table 1. In each section fifty quartz-grains having the apparent maximum length between 0.2 and 0.5 mm under the microscope are examined.

(c) Mineral composition

Seven components were regarded as major constituents under the microscope; namely, quartz, chert, feldspar, rock fragments of acidic igneous rocks, rock fragments of the other igneous rocks, rock fragments of sedimentary rocks, and matrix. Composition of sandstones is shown in Fig. 7 and 8. Several characteristics are enumerated as follows.

1. Quartz is one of the most important constituents of sandstones. It occupies about 20 to 30% of the total components. The majority of quartz grains is igneous. Metamorphic quartz and vein quartz are much smaller in quantity.

2. Cherts are very rare. They generally occupy no more than 1% of quartz grains.

3. Feldspar grains are composed of plagioclase and K-feldspar. The former is more abundant than the latter. Among sand grains there are often discovered very fresh and angular shaped K-feldspars which may have been derived directly from granitic source area.

4. There are rock fragments of acidic igneous rocks, andesitic to basaltic rocks, sedimentary rocks and metamorphic rocks. The first takes up the largest part, and the others are small in quantity. The majority of acidic rocks is rhyolite. Andesitic to basaltic rocks, which are not clearly identified, are characterized by lath-shaped plagioclase in groundmass. Sedimentary rocks are shale, siliceous shale and fine-grained sandstone. Metamorphic rocks are quartz schist, schistose hornfels, and hornfelses of shale and sandstone.

5. Matrices are fine detrital materials and clay minerals. Calcite cement is commonly included. Their quantities are variable among individual samples. In some cases they attain to about 10% of the total composition.

PART 2. THE CONGLOMERATES AND SANDSTONES OF THE MURO GROUP

I. General Remarks

The stratigraphy and geologic structure of the Muro Group were reported by HARATA, TOKUOKA and MATSUMOTO (1963), HARATA (1964), TOKUOKA (1966a, b), and HARATA et al. (1967). Sedimentary structures and paleocurrent directions of the Muro Group were also reported by HARATA (1965). The Muro Group is composed of alternations of sandstone and shale frequently intercalated by conglomerates, and can be assigned to "coarse-grained sandy flysch". Its geologic age is thought to be from the Upper Oligocene to the Lowest Miocene by molluscan fossil evidences (HARATA et al., 1963; MATSUMOTO, 1966).

It attains to about 10,000 m in total thickness, and sole markings such as flute cast, groove cast, load cast, etc., and biohieroglyphs can frequently be seen. Furthermore sedimentary structures such as graded bedding, current ripples, small-scale cross-stratification, etc. can be seen.

As the Muro Group occupies a vast area of the southern Kii Peninsula, and has complicated folded structures, and moreover contains no reliable key beds, the areal correlation and subdivisions of strata have not been accomplished yet. However, in several districts detailed geologic survey had been carried out, and stratigraphy and geologic structure have been made clear in some degree.

In the Muro Group there are comparatively many conglomerate beds whose thickness is from several meters to about 10 m and sometimes attains to 50 m. They contain pebble to boulder gravels composed of various igneous, sedimentary and metamorphic rocks. As to sandstones, which are the main constituent of the Muro Group, there are two types. One is sandstone 5 to 10 cm thick, alternating with shale. In this case, grading, parallel lamination and cross lamination are frequently seen. The other, which is more abundant and widely distributed, is massive sandstone of 1 to 10 m in thickness occasionally attaining to 30 m. In this type of sandstone the above sedimentary structures are very rarely found.

II. The Conglomerates of the Muro Group

1. *Localities Investigated and Their Geologic Setting*

The following four districts were studied in detail, whose geographic locations are shown in Fig. 1.

(a) The Hikigawa district in the upper reaches of the Hiki River (Loc. 1 in Fig. 1; Fig. 9)

The general geology and properties of conglomerates and sandstones of this district have been already reported by the writer (Tokuoka, 1966a). This district is located in the center of the Muro belt. The Muro Group has a strike of about E-W trend and isoclinally folded structures. It is composed of alternations of sandstone and shale rich in sandstone, frequently intercalated by conglomerates. Many sorts of sole markings, graded bedding, cross lamination and ripple marks can be frequently seen.

Representative conglomerate beds of 17 layers, each of which is several meters thick or more, were examined. They are extracted from various horizons of about 3,000 m in thickness, and are shown in Fig. 9 by signs, such as C-1, 2, and so on.

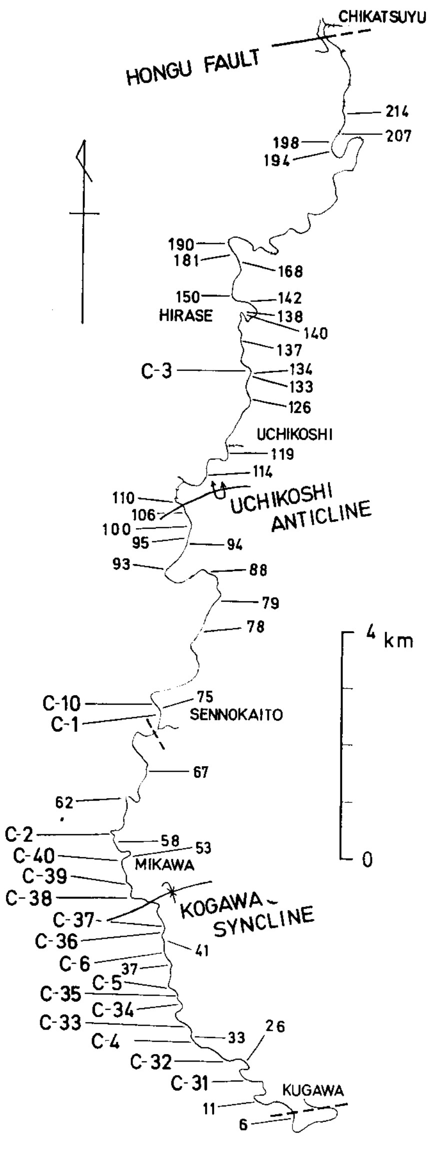


Fig. 9. Investigated localities of conglomerates and sampling localities of massive sandstones in the Hikigawa district (C-1, 2, ··· show the localities of conglomerate. Numbers show the sampling localities of sandstone.)

(b) The Kawayu district in Hongu-cho (Loc. 2 in Fig. 1; Fig. 10)

A synthetic study of the stratigraphy, geologic structure, properties of sedimentary rocks, sedimentary structure and so on in this district was carried out by the Kishu Shimanto Research Group (HARATA et al., 1967). The area of Hongu-cho is the type locality of the Muro Group, and the group is divided into the Yomurakawa-Muro and the Ukekawa-Muro Subgroup in ascending order along

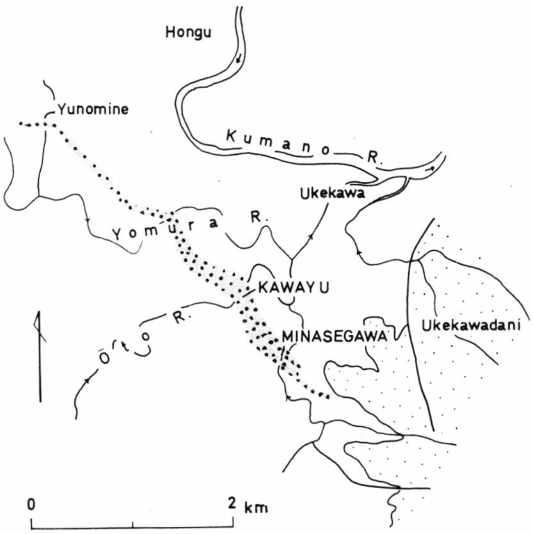


Fig. 10. Investigated localities of conglomerates in the Hongu district (Heavy dotted area shows the distribution of conglomerate. Dotted area in the right is the Kumano Group of the Middle Miocene.)

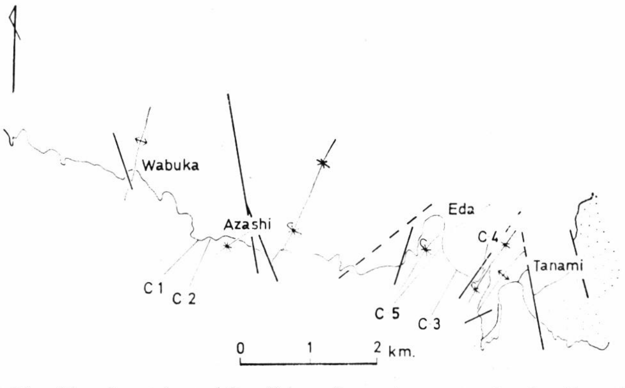


Fig. 11. Investigated localities of conglomerates in the Esumi district (Heavy lines show the main faults in the district. Dotted area in the right is the Kumano Group of the Middle Miocene.)

the Oto River. The Muro Group has NW-SE trend and isoclinal folded structures accompanied by several strike faults. At the base of the Ukekawa-Muro Subgroup there is one conglomerate bed of about 50 m in thickness, which is well exposed at Minasegawa and Kawayu. The bed decreases in thickness toward NW direction.

The properties of conglomerates at Kawayu (Loc. Kawayu) and Minasegawa (Loc. Minasegawa) were examined precisely. These localities are shown in Fig. 10.

(c) The Esumi district in Susami-cho (Loc. 3 in Fig. 1; Fig. 11)

The geology of this district was studied by HARATA et al. (1963), and MIZUNO and IMAI (1964). The Muro Group in this district has a general strike of NEE-SWW trend and isoclinally folded structures. It can be divided into two formations, that is, the Lower and the Upper Formation which may be correlated to the Yomurakawa-Muro and the Ukekawa-Muro Subgroup, respectively. The conglomerate beds were examined at five localities which are shown in Fig. 11. C-1 and C-2 belong to the Upper Formation, and C-3, 4 and 5 to the Lower Formation by HARATA et al. (1963).

(d) The Kizekkyo district in Tanabe City (Loc. 4 in Fig. 1; Fig. 12)

This district has already been reported by the writer (TOKUOKA, 1966b). The Muro Group of this district represents the uppermost part of the Muro Group. The conglomerates were examined in detail at nine localities shown in Fig. 12.

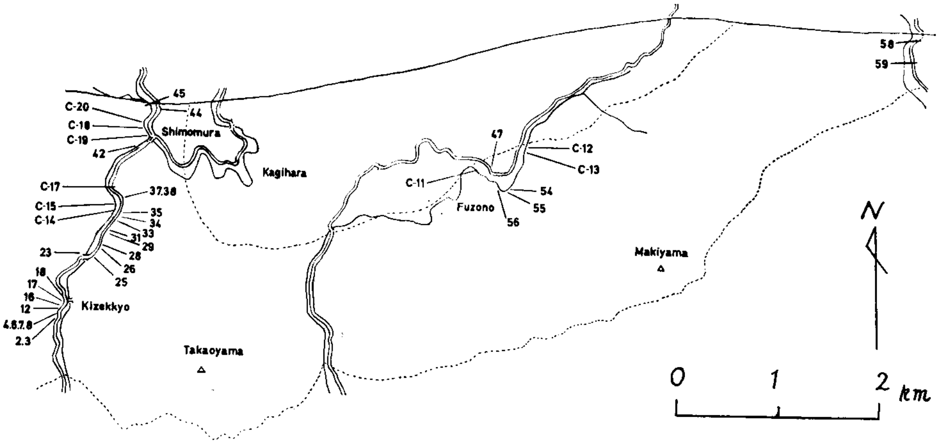


Fig. 12. Investigated localities of conglomerates and sampling localities of massive sandstones in the Kizekkyo district (C-11, 12, ··· show the localities of conglomerate. Numbers show the sampling localities of sandstone. The area between two broken lines shows the distribution of the Kizekkyo Sandstone and Conglomerate. The heavy line is the main fault in this district.)

2. *The Properties of the Conglomerates of the Muro Group*

(a) Size

(a-1) Size frequency distribution at two localities selected as representatives

Size distribution at two localities (Loc. C-3 of Hikigawa district and Loc. C-14 of Kizekkyo district) has been studied in detail, and is shown in Fig. 13.

The results are summarized below.

1. Size distributions exhibit unimodal patterns in each case in the same sense as mentioned in Part 1-II.

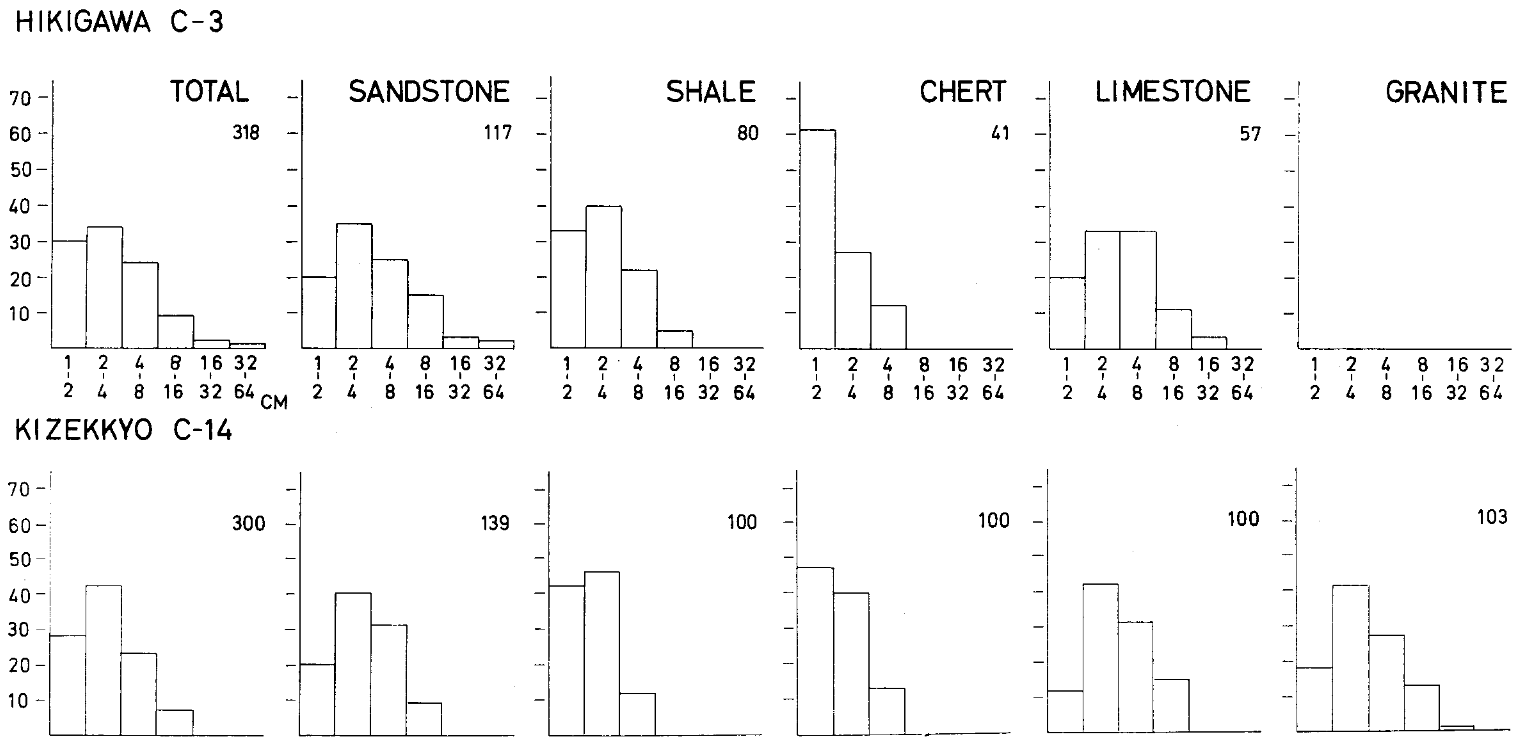


Fig. 13. Size distribution of total gravels and respective ones at the representative localities in the Muro Group (The numbers at the above right in each section show the numeral of gravels counted.)

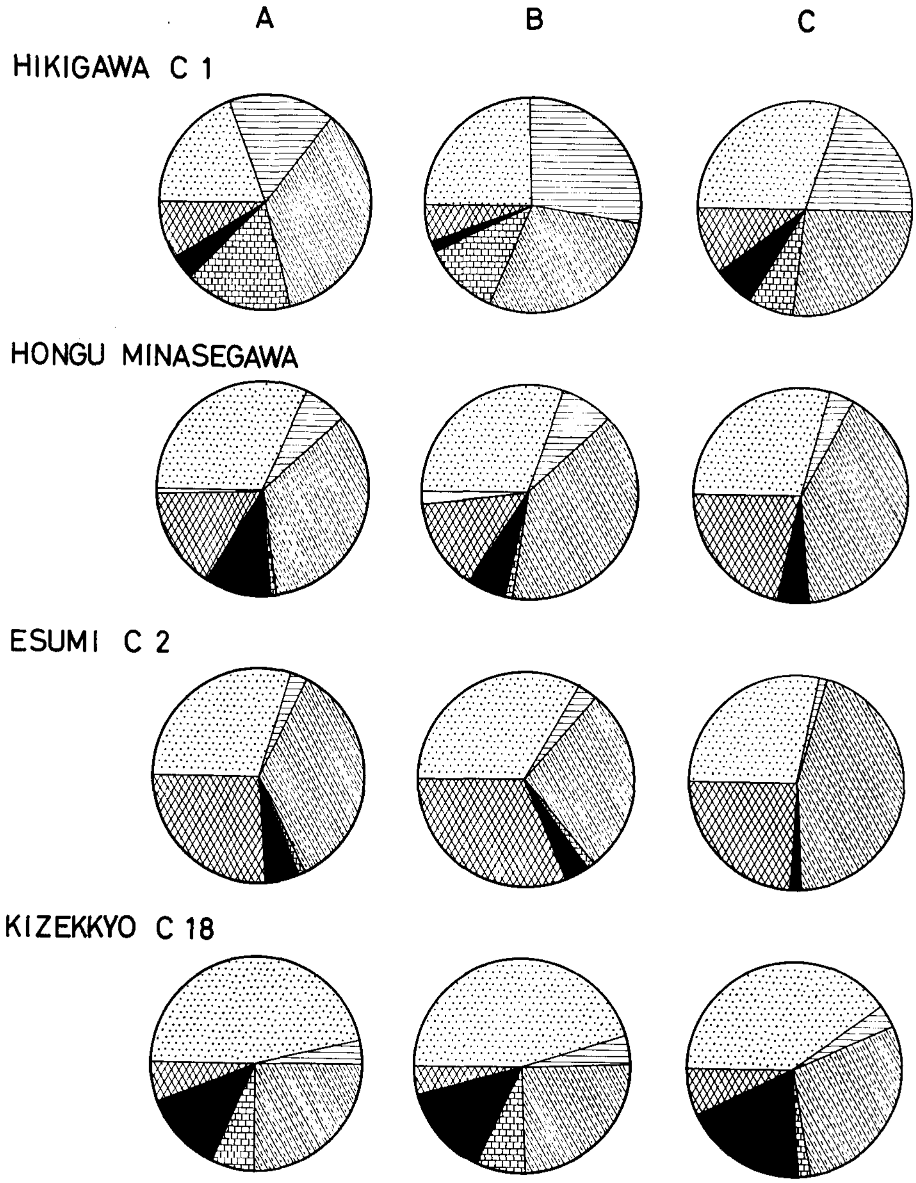


Fig. 16. The difference in composition according to the number of gravels counted at the representative localities (A, B and C represent composition of 100 gravels by random counting at three places in one exposure. The explanation is the same as in Figure 4.)

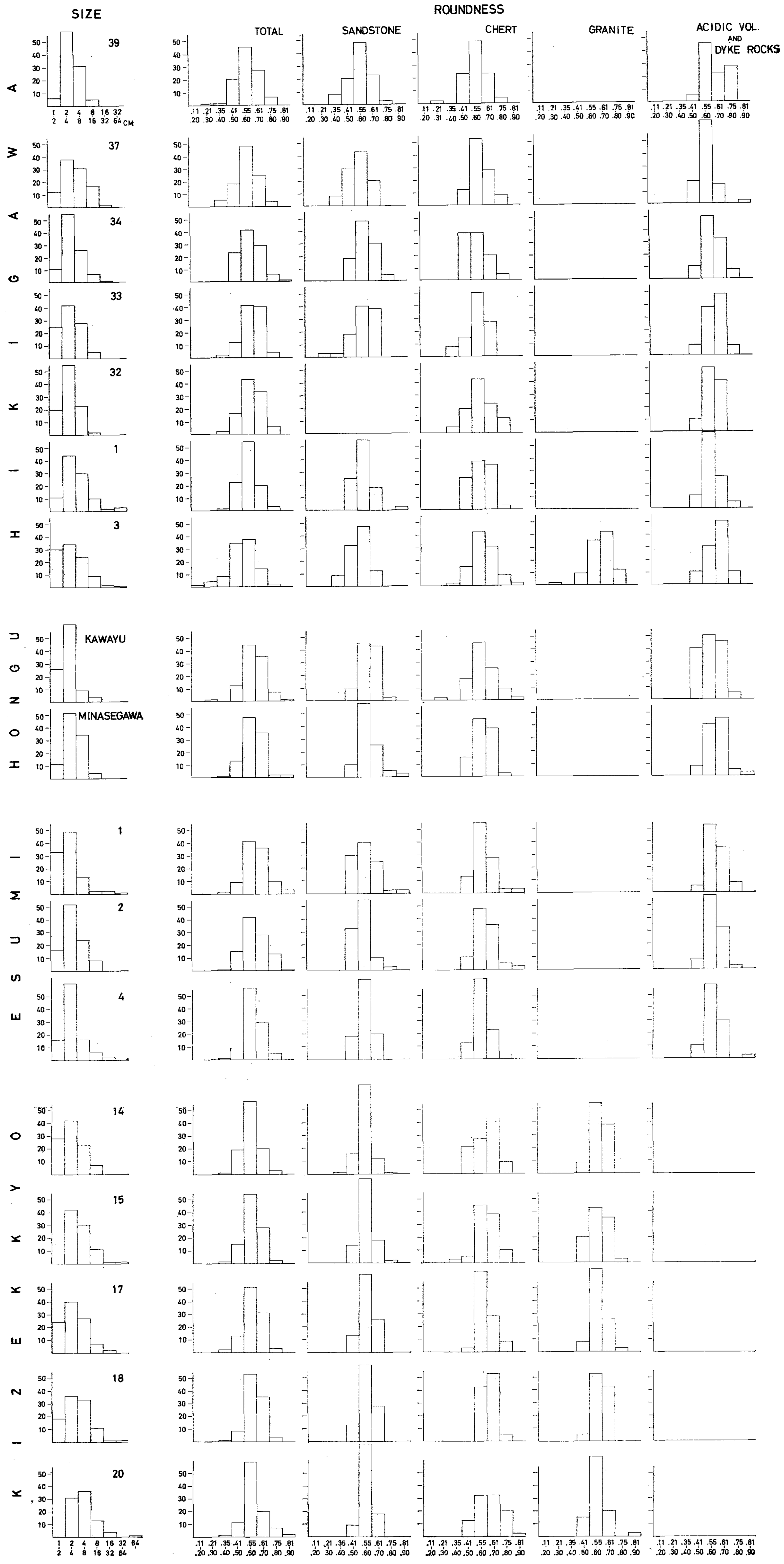


Fig. 14. Frequency distribution of size and roundness of the conglomerates of the Muro Group at each locality

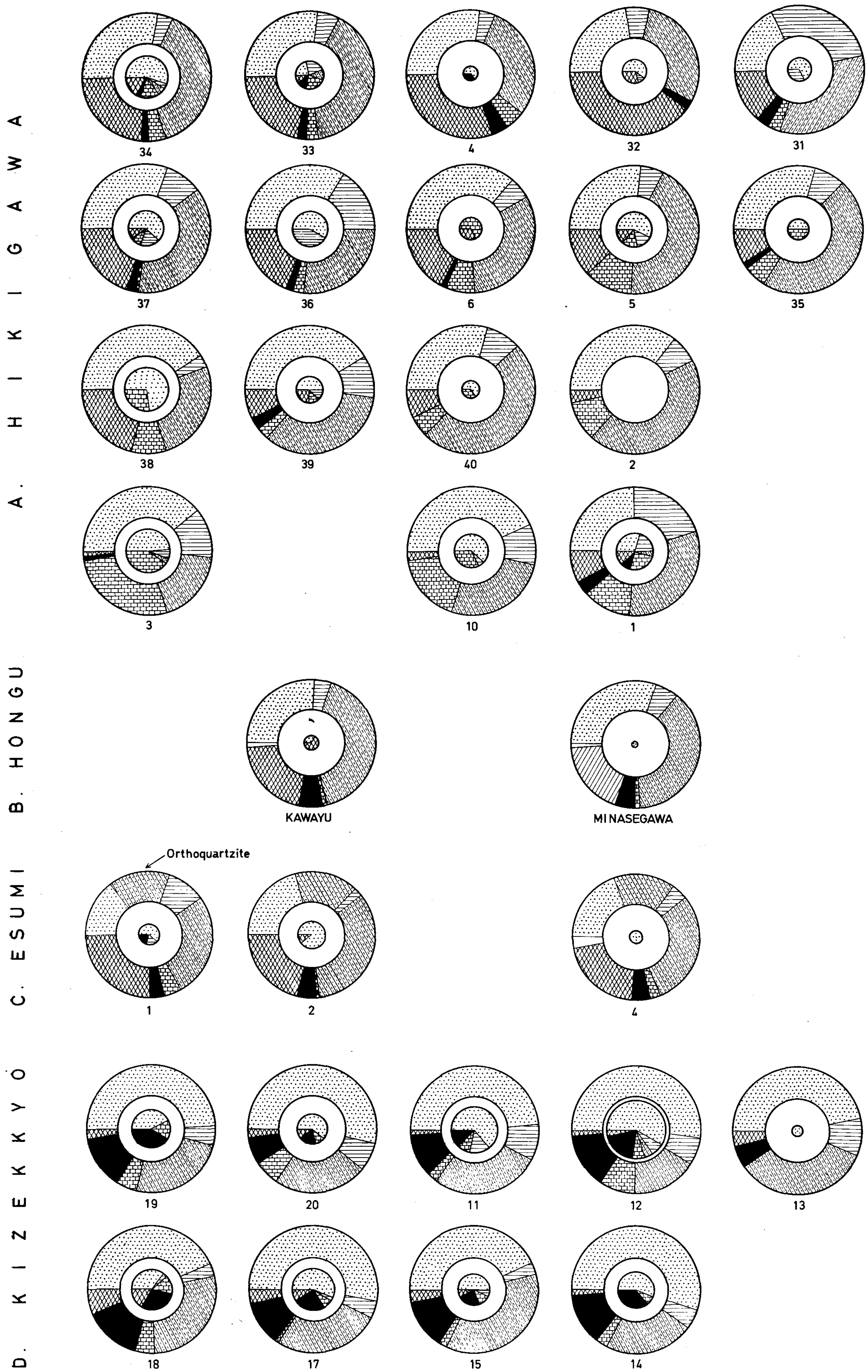


Fig. 15. Composition of the conglomerates of the Muro Group at each locality (The explanation is the same as in Figure 4. The inner circles show the quantities of gravels larger than 10 cm in diameter. The inner circles of C-12 and C-13 in the Kizekkyo district show 16% and 1%, respectively.)

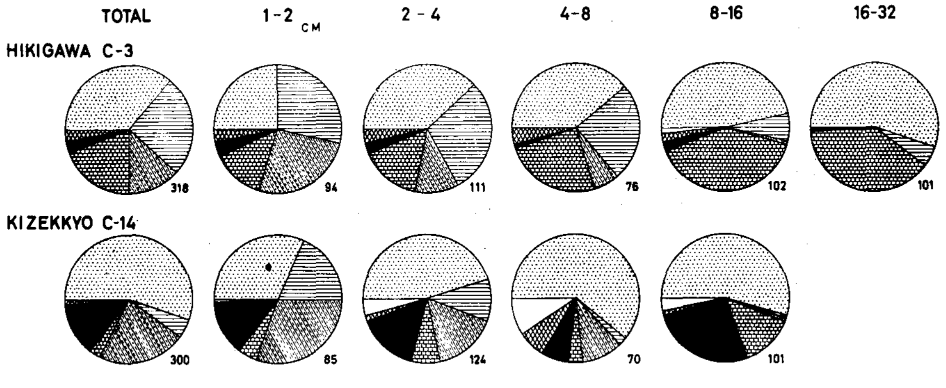


Fig. 17. The difference of composition due to gravel size at the two localities (The explanation is the same as in Figure 4. The numbers at the lower right are the numeral of gravels examined.)

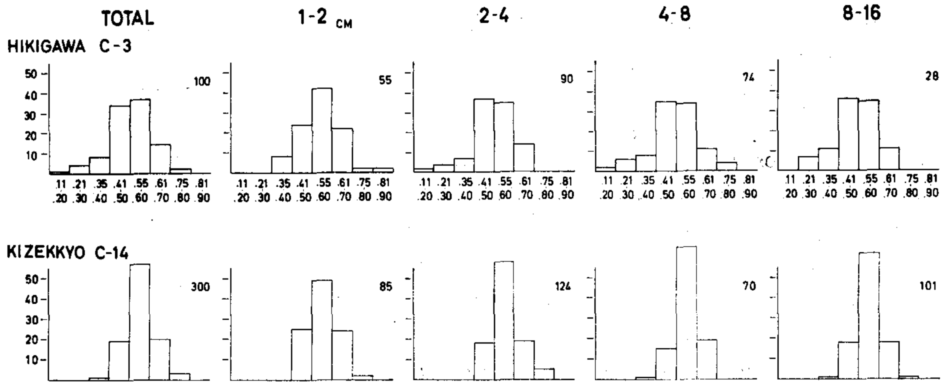


Fig. 18. Roundness of gravels according to size grade at the two localities (The numbers at the above right in each section show the numeral of gravels examined.)

2. Generally speaking, conglomerates are composed mostly of pebble size gravels accompanied with small quantities of cobble gravels, and seldom with boulder gravels.

3. Size distributions of sandstone, shale, limestone, and granite gravels exhibit almost similar patterns. It is different, however, in the case of chert gravel. Chert gravels are very abundant in 1 to 2 cm size grade, decrease suddenly in number in larger size grades, and there is no chert gravel larger than 8 cm in diameter.

4. In larger gravels sandstone and limestone are relatively more abundant than the other rocks.

5. The proportion of gravels larger than 10 cm in diameter is illustrated by small circles in Fig. 15, whose sizes are proportional to their quantities. It is noteworthy that larger gravels of sandstone, limestone, acidic volcanic and dyke rocks, granite, etc. are distributed commonly in many localities.

(a-2) Size distribution at each locality

Size distribution at each locality is shown in the left end of Fig. 14. In many cases it extends from 1-2 cm grade to 8-16 cm grade, occasionally to 16-32 cm grade, rarely to 32-64 cm grade, and shows unimodal patterns. The chief ingredient in each locality is in 2-4 cm grade. Loc. C-1 and C-3 of the Hikigawa district, Esumi C-1, and C-15, C-18, C-20 of the Kizekkyo district are somewhat different from the other localities, and all of which have boulder gravels larger than 32 cm in diameter.

(b) *Composition*

Before referring to the composition of conglomerates in each district, attention must be paid to the following two problems, that is, the difference in composition according to the number of gravels counted and the difference in composition due to gravel size.

(b-1) The difference in composition according to the number of gravels counted

Fig. 16 shows the composition examined at several localities. A, B and C represent composition of 100 gravels by random counting at three parts of one exposure. They indicate nearly equal composition. To show the general composition of conglomerate, 300 gravels were counted, and in particular cases where exposure of conglomerates were in bad condition, 100 or 200 gravels were counted. In this method the difference in composition according to the number of gravels counted may be negligible.

(b-2) The difference of composition due to gravel size

This was examined at Loc. C-3 of the Hikigawa district and Loc. C-14 of the Kizekkyo district, and the results are shown in Fig. 17. The followings can be pointed out.

1. The proportion of chert decreases gradually according to increasing of size. In the case of shale a similar tendency is recognized. On the other hand the proportion of sandstone and limestone increases. This inclination has already been suggested in the above section (see also Fig. 13).

2. Granitic rocks and acidic volcanic and dyke rocks show no regular changes in quantity.

3. It may be suggested that composition of conglomerates illustrated by counting gravels larger than 1 cm is essentially very similar to composition shown by counting gravels 2 to 4 cm size grade.

(b-3) Composition in each district

Composition of the conglomerates in each district is shown in Fig. 15. Several characteristics are listed as follows.

a. *The Hikigawa district*

1. Chert, sandstone, and acidic volcanic and dyke rocks are very abundant.

2. Granitic rocks are commonly contained in almost all localities despite their small quantities.

3. There are abundant acidic volcanic and dyke rocks, in particular, in the southern area. At some localities they attain to about 45% of the total. Almost 90% of them belong to rhyolite tuff, of which about a half have welded textures.

4. There are many muddy fine-grained limestones. Most of them commonly contain sand grains. Small foraminifers, all of which are destroyed and crystallized secondarily, are frequently discovered in them.

5. Sandstones, which are contained in large quantities in each locality, can be divided into three types (a, b, c-type) according to their rock fragments and matrices.

(a-type) Graywacke containing no rock fragments of chert, schist and schistose hornfels.

(b-type) Graywacke containing above-mentioned rock fragments.

(c-type) Quartzose to arkose sandstone containing above-mentioned rock fragments and wholly or partly cemented by calcite.

In this district c-type and b-type are abundant, and a-type is of small quantity.

b. *The Kawayu district*

1. There are abundant chert, sandstone, acidic volcanic and dyke rocks.

2. There are many metamorphic rocks, among which hornfelses occupy the majority.

3. Granitic rocks exist commonly.

4. Limestones are rare.

5. Half of the acidic volcanic and dyke rocks are volcanic and the other half hypabyssal. Furthermore the former rocks are mostly rhyolite tuffs, which sometimes have welded texture.

6. There are many hornfelses. These can be hardly distinguished from nonmetamorphic sandstone and shale by unaided eye, but under the microscope it is clear that about a half of the sandstones and two-thirds of the shales suffered thermal metamorphism.

7. Sandstones occupy 25 to 30% of the total, of which a-type occupies about a half, and b-type and c-type take up a quarter, respectively.

c. *The Esumi district*

1. Small gravels of 1 cm or so in diameter are comparatively rich in this district.

2. Cherts are very abundant and take up about 40% of the total. Sandstones and acidic volcanic and dyke rocks occupy 25 to 30%.

3. Granitic rocks are small in quantity, but are commonly found.

4. Limestones are rare.

5. Three-fifths of the acidic volcanic and dyke rocks, are volcanic and the others are hypabyssal. The former are mostly rhyolite tuffs, in which welded tuffs are often found.

6. Of the three types of sandstone, b-type is abundant and c-type is scarce. Furthermore it is noteworthy that d-type sandstone (orthoquartzite by PETTIJOHN) is commonly contained (about 10 to 15% of the total). This will be mentioned later in detail.

d. *The Kizekkyo district*

1. This district is rich in coarser materials than the other districts, and there are many boulder gravels.

2. Sandstone, chert, and granitic and gneissose rocks are dominant.

3. Limestones are commonly contained at each locality.

4. Acidic volcanic and dyke rocks are relatively small in quantity. Of these one-sixth are volcanic, and the rest are hypabyssal. All the volcanic rocks are rhyolite tuffs in reality, none of which is welded.

Of the three types of sandstone, c-type is very abundant, b-type is common, and a-type is rare.

(c) Roundness

(c-1) Roundness of gravels at two representative localities

Before discussing the roundness of gravels at each locality, it is neccessary to verify the difference of roundness according to size grade. This was examined at Loc. C-3 of the Hikigawa district and Loc. C-14 of the Kizekkyo district for 1–2, 2-4, 4-8 and 8-16 cm size grades (Fig. 18). It has been clarified that no essential difference of roundness value according to size grade can be seen. In conclusion, there is no room for consideration of the problem of difference in roundness according to size.

(c-2) Roundness at each locality

The total roundness distribution and individual roundness distributions of sandstone, chert, granite, and acidic volcanic and dyke rocks are shown in Fig. 14 collectively. The total roundness distribution shows unimodal patterns with a peak in 0.55–0.60 class in all localities. It ranges mainly from 0.21–0.30 to 0.75–

0.80. Occasionally it ranges from 0.11–0.20 to 0.81–0.90. As for the individual roundness distributions there are apparent differences between sedimentary rocks (sandstone and chert) and igneous rocks (granite, and acidic volcanic and dyke rocks). The latter group has many more rounded gravels than the former, and often has a chief ingredient value of 0.61–0.70. This difference is made much clearer when the roundness of sandstone is compared with that of acidic volcanic and dyke rocks.

(d) Lithology

1. Granitic and Gneissose Rocks: Biotite granite, muscovite granite and two-mica granite are present, of which biotite granite is most abundant, two-mica granite is common, and muscovite granite rarely exists. Granodiorite is seen in (a) and (d) districts. Garnet is commonly contained as accessory mineral. Gneissose granites are common in all districts, and in (d) they are abundant. Gneiss is also seen everywhere, but the quantity is very small in comparison with gneissose granites. Few crushed granites are also found in (c).

2. Hypabyssal Rocks: There are graphic granite, microgranite, granite porphyry, granophyre, aplite, quartz porphyry, dacite and porphyrite. Notwithstanding their small quantities, hypabyssal rocks exist commonly in all districts. They are comparatively abundant in (d), common in (b) and (c), but rare in (a).

3. Rhyolite Tuff: This is commonly contained in all districts. There are abundant rhyolite tuffs in (a), (b) and (c). Rhyolite tuffs are divided microscopically into two groups, welded and non-welded groups. Welded rhyolite tuffs are abundant in (a), common in (b) and (c), and not existed in (d). As xenolithes in rhyolite tuffs there are distinguished sandstone (graywacke type), chert, siliceous shale, mudstone, andesitic rock, etc., of which chert and siliceous shale contain radioralian fossils occasionally.

4. Limestone: Limestone gravels can be divided into three types, (1) Muddy fine-grained limestone, (2) Oolitic limestone and (3) Pure gray limestone.

(1) Muddy fine-grained limestone—This is commonly contained in all districts, being comparatively abundant in (a) and (d). It is blackish gray in color and becomes white gray after weathering. The gravels are pebble to boulder in size, and boulder gravels are commonly seen. Sand grains are frequently included in these. It is noticeable that some quartz schist fragments are found as sand grains. Small foraminifers are usually contained. Although these muddy fine-grained limestone gravels look like calcareous nodules, they are not so, as will be discussed later.

(2) Oolitic limestone—This is seen only in (d). It is somewhat similar to the so-called Torinosu Limestones, and some fossils characteristic of the so-called Torinosu fauna have been discovered. The details were reported by the writer

(TOKUOKA, 1966b).

(3) Pure gray limestone—This is seen commonly in (d) and seldom in (a). It is also like the so-called Torinosu Limestone, and some fossils characteristic of the so-called Torinosu fauna have been discovered. The details were reported by the writer (TOKUOKA, 1966b).

5. Cherts: These are white, gray, white and gray banded, black, and rarely red in color. Radiolarian remains are contained frequently.

6. Siliceous Rock: This is scarcely found in (a) and (b). It can not be distinguished from chert by unaided eye. Under the microscope it shows glassy or cryptocrystalline texture in groundmass, and few plagioclase crystals exist sporadically.

7. Sandstone: This can be divided into four types as already mentioned.

(1) Graywacke containing no rock fragments of chert, schist and schistose hornfels (a-type)—This type of sandstone was discovered in (a), (b) and (d). They are small in quantity, and if present they are usually found in weathered state. Moreover it is characteristic that they have very scarce rock fragments.

(2) Graywacke containing above-mentioned rock fragment (b-type)—Sometimes this type also includes fragments of andesitic and basaltic rocks. They are commonly seen in all districts.

(3) Quartzose to arkose sandstone containing above-mentioned rock fragments and wholly or partly cemented by calcite (Calcareous sandstone) (c-type)—These sandstones contain grains of quartz-schist commonly. In some specimens matrices are completely composed of calcite, while in others matrices are composed of many muddy materials and less calcite. The former type changes gradually into a part of the muddy fine-grained limestone as already mentioned. They must have had a close relationship with each other in source areas. Calcareous sandstones are very abundant in (a) and (d), and are common in (b) and (c).

(4) Quartzose sandstone (Orthoquartzite) (d-type)—More than 95% of grains are composed of well rounded quartz. Well-rounded tourmaline grains can be seen occasionally. Secondary overgrowth of quartz is very remarkable. All of orthoquartzite gravels belong to "first cycle quartzite" by KRYNINE (1941). They are common in (c). In the other districts they can rarely be seen.

8. Schist: This exists rarely in (b) and (c). In (a) and (d) it has not been discovered yet*. There are quartz schist, green schist, pelitic schist and psammitic schist.

---

* In the Muro Group along the coast of Kirimezaki of the western coast of the Kii Peninsula there have been frequently discovered pebble gravels of quartz schist and green schist. The Muro Group of this district may be correlated to the uppermost part. Quartz schist pebble has also been discovered at the south of Chikatsuyu in Nakaheji-cho in the Muro Group.

9. Schistose Hornfels: Although small in quantity it is commonly seen in all districts. Biotite, muscovite, garnet, cordierite, etc. are seen as secondary minerals.

10. Mylonitic Rocks: Mylonitic sandstone and sandy shale exist in (b) district. Mylonitic granite (crushed granite) has been discovered in (c) district.

(e) Maturity

1. Roundness: Roundness at each locality is shown in Fig. 14. There is no essential difference in roundness among all localities. The chief ingredient of roundness is always in 0.55–0.60 class. Roundness distribution extends generally from 0.21–0.30 to 0.75–0.80, seldom stretches from 0.11–0.20 to 0.81–0.90. Individual roundness of sandstone, chert, granite, and acidic volcanic and dyke rocks is also shown in Fig. 14. In many cases they have chief ingredient values of 0.55–0.60, and sometimes 0.61–0.70. The roundness of the conglomerates of the Muro Group is in comparatively higher stage.

2. Lithology: Various sorts of gravels are contained. The conglomerates of the Muro Group can be regarded as polymictic conglomerates. Unstable or undurable rocks such as limestone, granitic and gneissose rocks, calcareous sandstones and graywacke sandstones are commonly found.

3. Degree of sorting: Size distribution of conglomerates and properties of matrices must be considered. Size distribution of gravels larger than 1 cm at each locality is shown in Fig. 14. They exhibit unimodal patterns. The conglomerates are composed mainly of pebble gravels, and contain many cobble gravels, and sometimes a smaller number of boulder gravels. The chief ingredient is in the size of 2–4 cm in most cases. Matrices of conglomerates are composed of ill-sorted coarse sandstone.

In conclusion, judging from the roundness it may be suggested that the conglomerates of the Muro Group are in comparatively mature stage. On the contrary, lithology and degree of sorting suggest their immature stage.

III. The Sandstones of the Muro Group

The writer examined massive sandstones of the Muro Group in two districts. Massive sandstones thicker than 1 m were examined in thin sections. They are marked by moderate induration and white or light gray color.

1. *Sampling Localities*

(a) The Hikigawa district (Loc. 1 in Fig. 1; Fig. 9)

The geology of this area was reported by Tokuoka (1966a). Sampling points are shown in Fig. 9. Thirty-two samples were examined.

(b) The Kizekkyo district (Loc. 4 in Fig. 1; Fig. 12)

Details of sedimentary rocks of this district were reported by TOKUOKA (1966b). There are abundant massive sandstones in this district. They are very coarse and rich in shale patches. Sampling points are shown in Fig. 12. Thirty-two samples were examined.

2. *The Properties of Massive Sandstones of the Muro Group*

(a) Grain-size distribution

In the Hikigawa district there are unimodal, bimodal and polymodal types in almost equal quantity. There are only polymodal types in the Kizekkyo district.

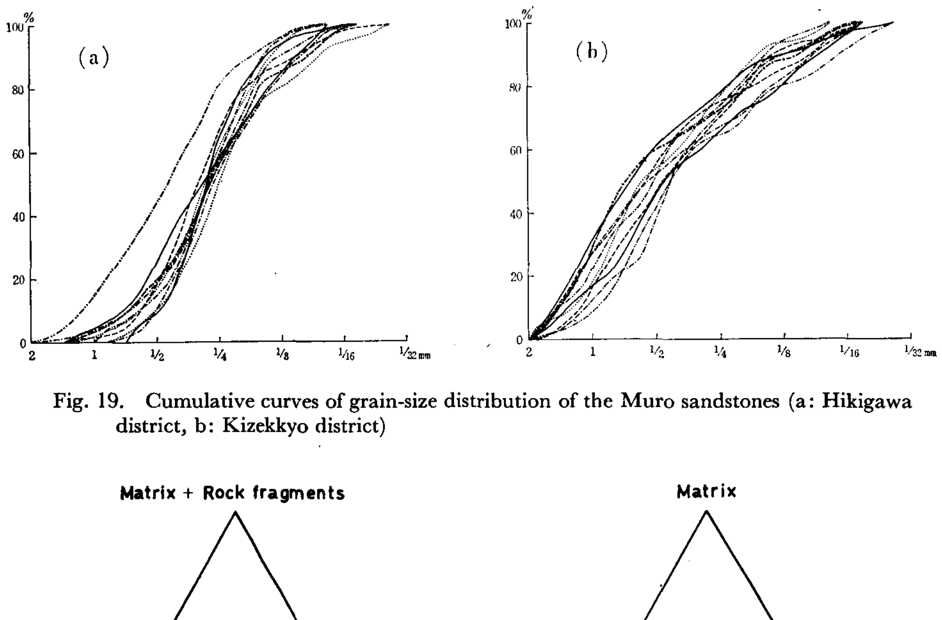


Fig. 19. Cumulative curves of grain-size distribution of the Muro sandstones (a: Hikigawa district, b: Kizekkyo district)

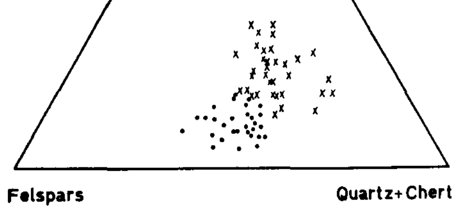


Fig. 20. Compositional diagram of the Muro sandstones (crossed: Hikigawa district, dotted: Kizekkyo district)

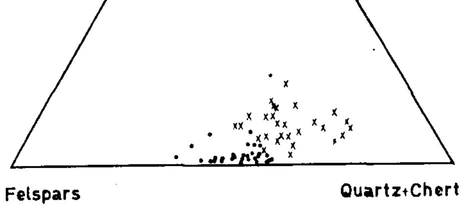


Fig. 21. Compositional diagram of the Muro sandstones (crossed: Hikigawa district, dotted: Kizekkyo district)

The cumulative curves are shown in Fig. 19. Textural properties are shown in Table 2.

Table 2. Textural properties of the Muro sandstones.

Hikigawa District

Sample	Md	Q_3	Q_1	So	Sk	R
6	0.302	0.500	0.161	1.76	−0.05	0.27 (0.1–0.6)
11	0.281	0.383	0.192	1.41	−0.03	0.30 (0.1–0.6)
12	0.323	0.456	0.221	1.44	−0.01	0.24 (0.1–0.4)
33	0.281	0.406	0.172	1.54	−0.05	0.28 (0.1–0.5)
58	0.456	0.766	0.292	1.62	0.03	0.31 (0.1–0.5)
95	0.292	0.369	0.214	1.31	−0.03	0.28 (0.1–0.5)
97	0.250	0.354	0.161	1.48	−0.04	0.28 (0.1–0.5)
110	0.271	0.383	0.161	1.54	−0.07	0.29 (0.1–0.5)
198	0.302	0.427	0.199	1.47	−0.03	0.24 (0.1–0.5)
209	0.271	0.442	0.206	1.47	0.10	0.26 (0.1–0.5)
Average	0.303	0.449	0.208	1.50	−0.02	0.28 (0.1–0.6)

Kizekkyo District

Sample	Md	Q_3	Q_1	So	Sk	R
2	0.707	1.082	0.271	2.00	−0.23	0.21 (0.1–0.4)
7	0.562	1.082	0.177	1.97	−0.22	0.20 (0.1–0.4)
12	0.442	0.604	0.228	1.63	−0.15	
17	0.500	0.941	0.250	1.94	−0.03	0.18 (0.1–0.5)
23	0.523	0.897	0.297	1.74	−0.01	0.20 (0.1–0.4)
25	0.583	1.082	0.281	1.96	−0.05	0.14 (0.1–0.3)
28	0.471	0.854	0.214	2.00	−0.08	0.17 (0.1–0.4)
31	0.686	1.164	0.292	2.00	−0.14	0.15 (0.1–0.4)
33	0.471	0.766	0.177	2.08	−0.21	0.16 (0.1–0.3)
42	0.442	0.686	0.172	2.00	−0.22	0.15 (0.1–0.3)
Average	0.539	0.916	0.236	1.93	−0.13	0.17 (0.1–0.5)

(b) Roundness

Roundness of sand grains in the Hikigawa district is in the classes from angular to rounded, in which subangular and subrounded classes occupy the majority. Occasionally rounded sand grains are included. That of the Kizekkyo district is mainly in angular and subangular classes. Subrounded grains, and rarely rounded ones, are included. Roundness of quartz grains is shown in Table 2 by the same method as the Hidakagawa Group.

(c) Mineral composition

Composition of sandstones is shown in Fig. 20 and 21. Several characteristics are as follows.

1. Quartz is the chief constituent of sandstones. It occupies about 35 to 65% of the total components. Quartz grains are mostly of igneous origin, and sometimes of metamorphic origin.
2. Cherts are very rarely included.
3. Feldspar grains occupy about 15 to 50% of the total components. Very fresh and angular-shaped K-feldspars (mainly microcline) are frequently discovered.
4. Rock fragments are composed of acidic igneous rocks, andesitic to basaltic rocks, sedimentary rocks and metamorphic rocks. Acidic igneous rocks, which are mostly composed of rhyolite tuff, take up the largest part. Andesitic to basaltic rocks are very rare. Sedimentary rocks are composed of shale, sandstone and others. Metamorphic rocks, whose quantities are very small, are quartz schist, schistose hornfels, and hornfelses of shale and sandstone. Quartz schists are common but small in quantity in sandstones of the Kizekkyo district, and rather rare in the Hikigawa district.
5. Matrices are made of fine detrital materials and clay minerals, whose quantities are very small. Calcite cements are very rarely included.

PART 3. THE GEOLOGIC DEVELOPMENT OF THE SHIMANTO TERRAIN IN THE KII PENINSULA DEDUCED FROM THE ANALYSIS OF COARSER CLASTIC SEDIMENTS

I. General Remarks

According to MINATO et al. (1965), the geologic development of the Japanese Islands is divided into the following four stages.

1. Pre-geosynclinal stage—Pre-Silurian
2. Geosynclinal stage—Silurian to Permian
3. Subcontinental stage of the Honshu Major Belt and the Mesozoic geosynclines of the Outer Side—Triassic to Paleogene
4. Island arc stage—Neogene

The geologic history of the Shimanto Major Belt, which occupies the main part of the "Mesozoic geosynclines", is briefly summarized as follows.—Since a certain age of the early Mesozoic, the major belt was an area where subsidence and sedimentation prevailed. Towards the end of the Paleogene, and again in the early Miocene, this geosyncline underwent folding and faulting movements as well as metamorphism and magmatism. These movements are often called the Shimanto orogeny as a whole (YAMASHITA, 1961).

The geologic development of the Shimanto Terrain in the Kii Peninsula will be considered from the data given in Part 1 and 2. Moreover, the Kumano and Tanabe Groups of the Middle Miocene which represent the post-orogenic stage of the Shimanto Major Belt will be referred to.

II. The Geologic Ages and Geologic Structures of the Hidakagawa and Muro Groups

According to MINATO et al. (1965), the oldest sediments evidenced paleontologically in the Shimanto Terrain are those of the Upper Jurassic, but the presence of the older sediments which include at least those of the Lower Jurassic and the upper half of the Triassic is probable. The Hidakagawa Group has been considered to be the Cretaceous (Wakayama Pref., 1966). HASHIMOTO (1967) reported several molluscan fossils such as *Acila* (*Truncacila*) n. sp., *Nanonavis* (*Nanonavis*) sp. cf. *N* (*N.*) *sachalinensis*, *Inoceramus* sp. aff. *I. labiatus*, etc. from south of Konose, Hirokawa-cho, and suggested that these fossils might be of the Upper Cretaceous. In the light of those, and furthermore from structural and lithologic data, the writer is of the opinion that the Hidakagawa Group, at least its greater part, may be assigned to the Upper Cretaceous. The Muro Group has been considered to be Upper Oligocene to Lowermost Miocene from molluscan fossils such as *Venericardia tokunagai*, *Costacallista* cf. *shikokuensis*, *Portlandia watasei*, etc. (HARATA et al., 1963; MATSUMOTO, 1966). Unquestionable sediments of the Eocene and the Lower Oligocene have not been discovered, but a part of the Muro Group or the Hidakagawa Group is expected to include these strata. In conclusion, the Shimanto Terrain in the Kii Peninsula may have been in a continuous geosynclinal environment at least from the Cretaceous to the Lowermost Miocene.

As to the geologic structures, the Hidakagawa Group has been considered to have isoclinal folded and faulted structures (Wakayama Pref., 1966; HASHIMOTO, 1967; HIRAYAMA and TANAKA, 1955). The Muro Group, on the contrary, has somewhat intermediate geologic structures between isoclinal and basin-like structures (HARATA et al., 1963; HARATA, 1965; TOKUOKA, 1966a, b; HARATA et al., 1967).

III. The Lithologic Characteristics of the Hidakagawa and Muro Groups

1. *Megascopic Characters*: Roughly speaking the Hidakagawa Group is composed of flysch-type alternations of sandstone and shale, rich in the latter and frequently intercalating massive sandstones, siliceous or cherty rocks, basic volcanic rocks, and rarely conglomerates. The Muro Group is also composed of flysch-type (more precisely coarse grained sandy flysch-type) alternations of sandstone and

shale intercalating many massive sandstone layers, and sometimes conglomerates. The above differences will suggest a change in depositional environments within a continuous geosyncline.

2. *Properties of Massive Sandstones*: Compositional difference between the two groups described in the foregoing parts is conceptionally shown in Fig. 22. Textural variations are also shown in Table 3. Massive sandstones of the Hidakagawa Group are mainly fine sandstones and belong to typical graywacke, and those of the Muro Group are medium to coarse sandstones and belong mainly to arkosite and sometimes to graywacke and feldspathic quartzite. The above

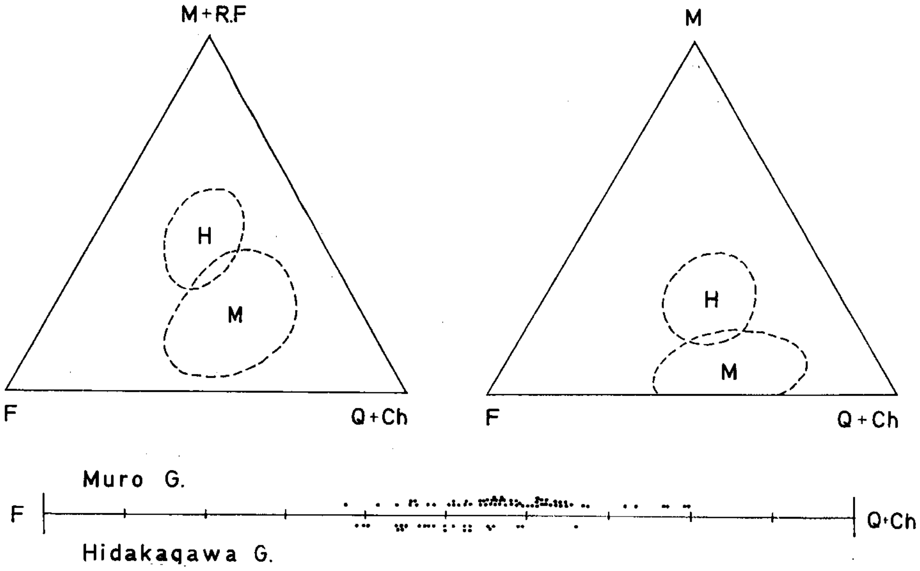


Fig. 22. Properties of massive sandstones of the Hidakagawa and Muro Groups conceptionally shown (H: Hidakagawa Group, M: Muro Group; M: Matrix, R.F.: Rock Fragments, F: Feldspars, Q: Quartz, Ch: Chert)

Table 3. Textural variations of massive sandstones of the Hidakagawa and Muro Groups.

	Locality	Median (mm)			Coef. of Sorting			Coef. of Skewness			Roundness		
		Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Muro Group	Hikigawa	0.456	0.250	0.303	1.76	1.31	1.50	0.10	−0.07	−0.02	0.6	0.1	0.28
	Kizekkyo	0.707	0.442	0.539	2.08	1.63	1.93	−0.01	−0.23	−0.13	0.5	0.1	0.17
Hidakagawa Group	Ryujin-Hanazono	0.260	0.110	0.183	2.13	1.29	1.65	0.10	−0.21	−0.03	0.8	0.1	0.21
	Gobo-Yura	0.214	0.099	0.156	1.81	1.26	1.55	0.12	−0.06	0.00	0.6	0.1	0.20

facts may suggest the differences in depositional environments between the Hidakagawa and the Muro Group.

IV. The Problem of Provenances of the Hidakagawa and Muro Groups

The properties of conglomerates have already been described. Strict correlation will need further examination, but the following correlation may be given (Table 4). Almost all sorts of rocks found in conglomerates can be seen in the Inner Zone and the Chichibu Terrain, which are situated to the north of the Shimanto Terrain. As for the roundness frequency distribution, as already mentioned, the gravels of igneous rocks (granitic rocks, and acidic volcanic and dyke rocks) contain more rounded ones than those of sedimentary rocks (sandstone and chert, and partly limestone). This fact may suggest a longer distance or a longer transportation of igneous rocks from source areas than those of the sedimentary rocks.

Table 4. Provenances of the Hidakagawa and Muro Groups estimated from the study of conglomerates.

Sorts of Gravels	The Correlative Region or Group	Hidakagawa Group	Muro Group
Granitic and Gneissose rocks	The Ryoke granitic rocks	○	◎
Acidic hypabyssal rocks	The Inner Zone of Southwest Japan	◎	○
Intermediate hypabyssal rocks	The Inner Zone of Southwest Japan	□	△
Rhyolite tuff	So-called Meso-Volcanics in the Inner Zone of Southwest Japan (including the Sennan Acidic Rocks)	○	◎
Limestone	So-called Torinosu Group	◎	◎
Chert	The Paleozoics in the Chichibu Belt	◎	◎
Sandstone-1 (a-type)	The Paleozoics in the Chichibu Belt	○	○
Sandstone-2 (b-type)	So-called Torinosu Group or, in the case of the Muro Group, partly the Hidakagawa Group	○	○
Sandstone-3 (c-type)	So-called Torinosu Group	◎	◎
Sandstone-4 (d-type)	(unknown)	×	□
Schist	The Sambagawa Metamorphic Belt	△	△
Hornfels and schistose hornfels	The southern marginal zone of the Ryoke Metamorphic Belt	□	△

◎: abundant ○: common □: rare △: very rare ×: none

Several facts concerning limestone, calcareous sandstone (Sandstone-3) and orthoquartzite (Sandstone-4) are worthy of mention. Limestone and calcareous sandstone, which are abundant in the Hidakagawa and Muro Groups are considered to have been derived from the so-called Torinosu Group. The so-called Torinosu Group which can be seen at present has narrow distribution and comparatively poor calcareous materials. But judging from a lot of its gravels the group must have been distributed much more widely at that time and supplied abundant materials to the Shimanto geosyncline.

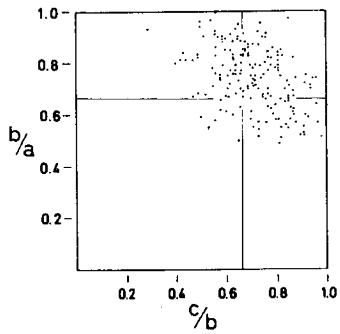


Fig. 23. Shapes of orthoquartzite gravels in the Esumi district according to Zingg's classification

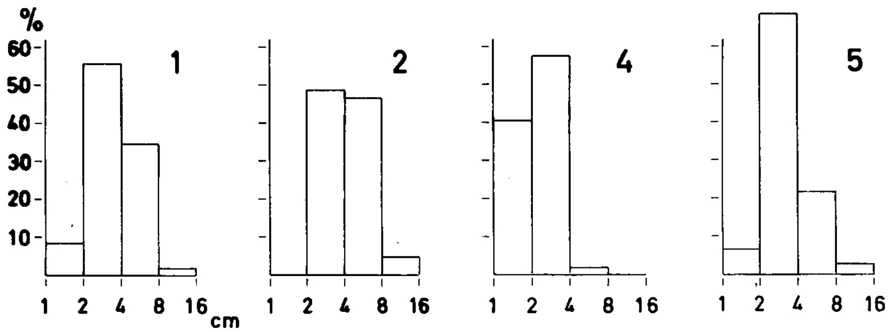


Fig. 24. Size distribution (a-axis) of orthoquartzite gravels (Numbers at the upper right show localities in the Esumi district)

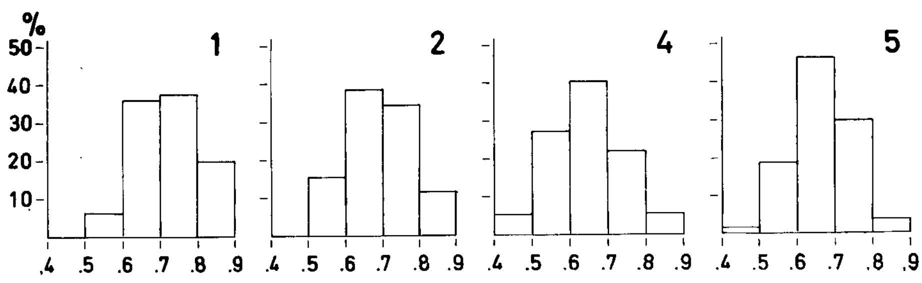


Fig. 25. Roundness distribution of orthoquartzite gravels

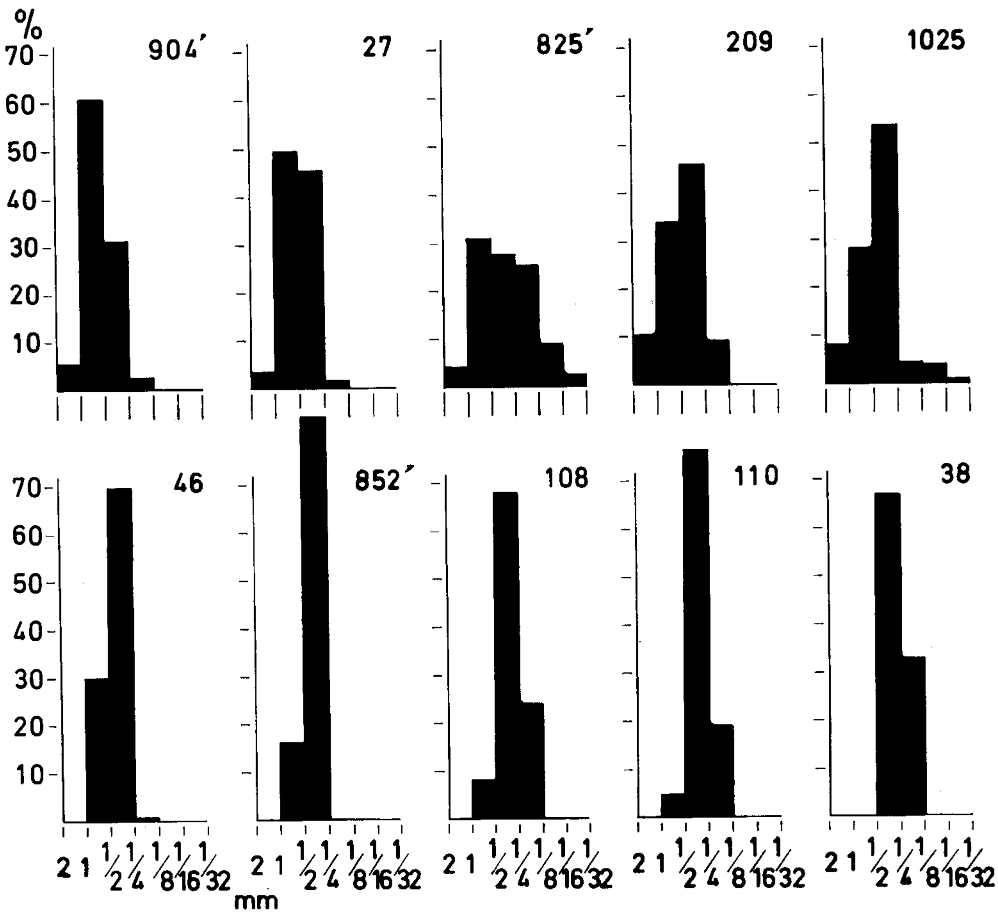


Fig. 26. Mechanical composition of orthoquartzites.

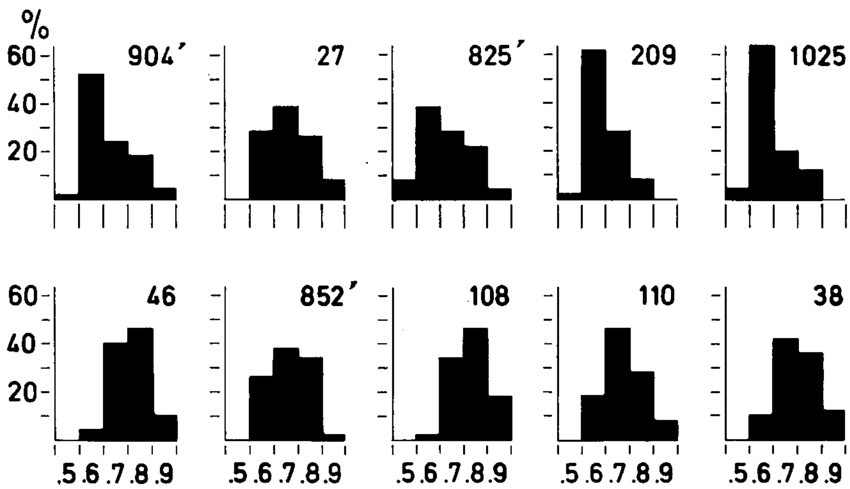


Fig. 27. Roundness distribution of sand grains in orthoquartzites.

Table 5. Compositional and textural properties of orthoquartzites

Loc.	Sample	Detrital Quartz	Secondary Quartz	Felspar	Chert	Clay	Median (mm)	Coef. of Sorting	Coef. of Skewness	Roundness
C-2	904′	77.8	21.9	tr.	tr.	0.3	0.69	1.3	−0.05	0.67 (0.5–0.9)
C-1	27	7.15	23.0	4.7	0	0.8	0.62	1.2	0.02	0.71 (0.6–0.9)
C-1	825′	86.9	6.1	0	1.4	5.6	0.41	1.8	0.00	0.68 (0.5–0.9)
C-5	209	78.9	20.5	0	0	0.6	0.56	1.5	−0.02	0.64 (0.5–0.9)
C-4	1025	77.8	18.2	0	tr.	4.0	0.49	1.5	0.06	0.64 (0.5–0.8)
C-1	46	75.8	23.9	0	tr.	0.3	0.54	1.2	0.00	0.76 (0.6–0.9)
C-1	852′	77.4	21.9	0	0.2	0.6	0.47	1.2	−0.01	0.71 (0.6–0.9)
C-2	108	83.5	15.9	0	0	0.6	0.40	1.3	0.11	0.78 (0.6–0.9)
C-2	110	79.2	20.2	0	tr.	0.5	0.40	1.2	−0.02	0.73 (0.6–0.9)
C-1	38	77.0	22.7	0	tr.	0.3	0.33	1.1	0.02	0.75 (0.6–0.9)

The Discovery of Orthoquartzites and its Significance: As to the origin of the orthoquartzite gravels, they are obtained only from the Muro Group, in the Esumi district commonly and in the Hikigawa district rarely. The properties of the orthoquartzite gravels are illustrated in Fig. 23–27 and Table 5 preliminarily. They belong to the supermature orthoquartzite with excellent sorting and rounding. Orthoquartzite (first cycle quartzite) is generally considered to have been formed after prolonged and intense chemical decay in peneplaned regions as described by KRYNINE (1941). Almost all of the discovered orthoquartzites are well rounded gravels, and furthermore, the general sense of the paleocurrent direction in the Esumi district is from SE to NW (HARATA, 1965). From the above properties and evidences, no suitable source area can be found in the present Japanese Islands, and it can be safely said that orthoquartzite gravels have been introduced from the south of the Shimanto geosyncline. If this is true, it is very important to consider the paleogeography and the nature of basement rocks of the Shimanto geosyncline. The details will be reported in another paper.

V. The Kumano and Tanabe Groups of the Middle Miocene

The Kumano and Tanabe Groups gently and monoclinally overlie the Muro Group with remarkable clino-unconformity. Their geologic ages are determined to be the Middle Miocene by many molluscan fossil evidences. It is neccessary to refer to these groups in order to clarify the geologic development of the Shimanto Terrain.

1. *Conglomerates*: The properties of conglomerates were examined at the following six localities, and are shown in Fig. 28.

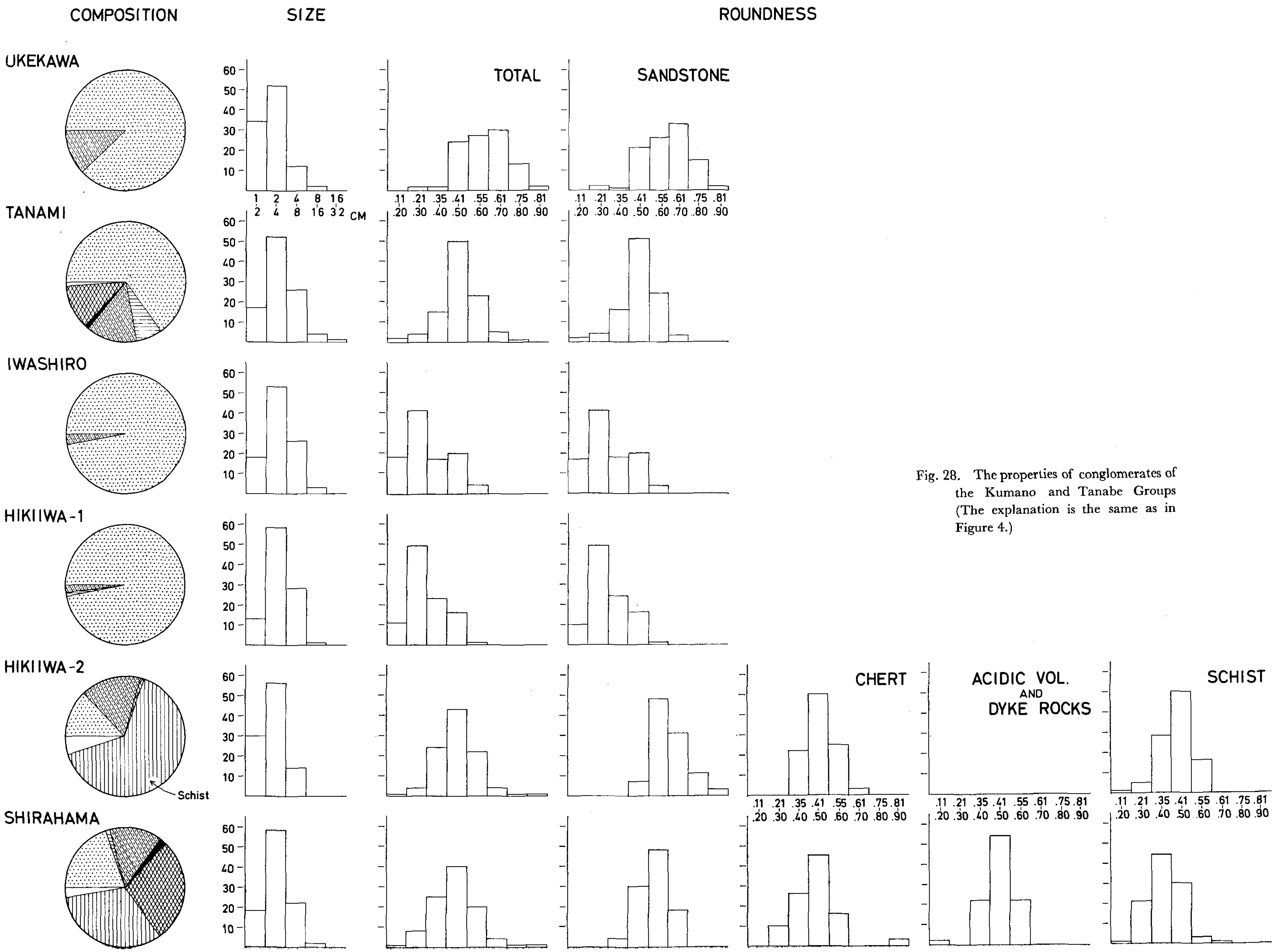


Fig. 28. The properties of conglomerates of the Kumano and Tanabe Groups (The explanation is the same as in Figure 4.)

1.	Ukekawa:	Upper part of the basal conglomerate of the Kumano Group at Ukekawa-dani, Hongu-cho (Loc. 2 of Fig. 1)
2.	Tanami:	The basal conglomerate of the Kumano Group at Tanami, Kushimoto-cho (Loc. 3 of Fig. 1)
3.	Iwashiro:	The basal conglomerate of the Tanabe Group at Iwashiro, Tanabe City (Loc. 8 of Fig. 1)
4.	Hikiiwa-1:	The basal conglomerate of the Tanabe Group at Hikiiwa, Tanabe City (Loc. 4 of Fig. 1)
5.	Hikiiwa-2:	About 10 m above the horizon of Hikiiwa-1 (Loc. 4 of Fig. 1)
6.	Shirahama:	Approximately middle horizon of the Tanabe Group at the northwest of Shirahama coast, Shirahama-cho.

There are remarkable differences in composition and roundness between basal conglomerates and other conglomerates. The basal conglomerates are composed mostly of sandstones derived from the Muro Group. Furthermore, gravels such as chert, acidic igneous rocks of the basal conglomerates are also considered to have been derived secondarily from conglomerates of the Muro Group.

On the other hand, conglomerates at Hikiiwa-2 and Shirahama are typically polymictic, and are rich in more rounded gravels than in the basal parts. Several characters are as follows. They are composed mainly of sandstone, chert, acidic volcanic and dyke rocks, and schist. Sandstone gravels are undoubtedly derived from the Muro Group. Schist gravels (mainly quartz-schist and sometimes green schist and graphite schist), whose quantities occupy 32 to 65% of the total, must have been derived from the Sambagawa Metamorphic Belt. Roundness distributions of chert, and acidic volcanic and dyke rocks show less roundness than those of the Hidakagawa and Muro Groups. This fact suggests no possibility of secondary derivation from the conglomerates of the Hidakagawa and Muro Groups. They may have been derived from the Paleozoics of the Chichibu Terrain and the so-called Meso-Volcanics, respectively. Orthoquartzite pebbles are rarely found at Shirahama, although detailed study has not been made.

2. *Sandstones*: Sandstones of the Tanabe Group are characterized by white color and slight to intermediate induration and some porosity. Sandstones are examined preliminarily from boring core (about 500 m in depth) at Shirahama, Shirahama-cho. Generally speaking, they are finer in grain size and richer in clay matrices than the sandstones of the Muro Group. K-felspars are comparatively rich among constituent minerals, and schist fragments are very richly included.

VI. The Geologic Development of the Shimanto Terrain in the Kii Peninsula

The geologic developments of the Japanese Islands since the Mesozoic to the Cenozoic stated by YAMASHITA (1961) and MINATO et al. (1965) are believed to be correct fundamentally. The writer will examine the geologic development of the Shimanto Terrain on the basis of the data already mentioned.

In the Kii Peninsula, the beginning of the Shimanto geosyncline is not clear because the Triassic and definite Jurassic rocks have not been confirmed yet. However, the Cretaceous period was undoubtedly in a strong eugeosynclinal condition accompanying basic submarine volcanisms and deposition of cherts. Remarkable subsidence and deposition had continued to the Tertiary (up to the Lowermost Miocene). But in the Tertiary the environment changed to miogeosynclinal condition characterized by alternations of sandstone and shale without submarine volcanism. The change of environment is shown in differences of megascopic characters of clastic sediments, and also in differences of massive sandstones of the two groups. Massive sandstones of the Hidakagawa Group are typical graywackes. On the other hand those of the Muro Group have somewhat intermediate properties. The difference in geologic structure between the Hidakagawa and the Muro Group suggests the occurrence of the tectonic movement. It corresponds to the change of the Shimanto Terrain from eugeosynclinal to miogeosynclinal condition. The most intense crustal movement took place at the close of the Lowermost Miocene, by which the Shimanto geosyncline disappeared and the basic geologic structures of the Shimanto Terrain were accomplished. This is clearly shown by the clinounconformity between the Muro Group and the Kumano-Tanabe Group and furthermore by different natures of coarse clastic rocks of the two. It was also presumed by HASHIMOTO (1962) that the late Cretaceous to the early Tertiary tectonic mobility was remarkable and the most intense deformation occurred in the early Miocene time in the Shimanto Terrain in Kyushu. Accordingly very similar geologic developments of the Shimanto Terrain in Kyushu and the Kii Peninsula can be deduced.

There must be a close connection between the process from birth to disappearance of the Shimanto geosyncline in the Outer Zone and the acidic igneous activity (Hiroshima Movement by YAMASHITA) in the Inner Zone of Southwest Japan. Furthermore, the process may be in relation with the so-called Yenshan Movements and the associated igneous activities in the East Asiatic continent. The igneous activity in the Inner Zone of Southwest Japan began with the intermediate volcanism of the Early Cretaceous, and was followed by the violent acidic volcanisms and plutonism of the Middle to Late Cretaceous, and continued up to the

Paleogene. In further study it is nesessary to search for a causal relation between the geosynclinal development in the outer side and the igneous activities in the inner side of the Japanese Islands.

The provenances of the materials in the Shimanto geosyncline can be generally sought to the north of the geosyncline, that is, the so-called Meso-Volcanics in the Inner Zone, various rocks in the Ryoke Metamorphic Belt, the Paleozoics in the Chichibu Terrain, the so-called Torinosu Group and its correlatives. The so-called Torinosu Group and its correlatives, which have narrow distribution at recent times, must have been widely distributed and provided abundant materials to the geosyncline. The Meso-Volcanics and their correlatives must have also distributed very widely in the Inner Zone. These source areas had been in a tendency of continuous upheaval movement from the Cretaceous to early Tertiary, and had suffered progressive erosional actions. In conglomerates of the Hidakagawa Group, there are abundant acidic hypabyssal rocks and granites having somewhat porphyritic and granophyric textures. In the Muro Group there are abundant gravels of granite of typical plutonic texture and gneissose granite. These facts suggest the continuous upheaval and erosion of the Ryoke granitic rocks. The Sambagawa Metamorphic Belt, which is situated between the Ryoke Metamorphic Belt and the Chichibu Terrain, and whose metamorphic rocks had already been accomplished prior to the deposition of the Cretaceous geosynclinal sediments in the Shimanto Terrain, had scarcely supplied materials to the geosyncline or only in small quantities. Accordingly the Sambagawa Metamorphic Belt was in comparatively low land at the time of the Shimanto geosyncline. It became a main source area during the Neogene.

After the close of the Shimanto geosyncline, marine transgression occurred again at the Middle Miocene, and formed the Kumano and Tanabe Groups. But their basins were smaller and more local than the Shimanto geosyncline. The source areas changed remarkably in comparison with those of the Shimanto geosyncline. Clastic materials were supplied mainly from the Sambagawa Metamorphic Belt and the Muro Group, and in small quantities from the so-called Meso-Volcanics and the Chichibu Terrain.

The Shimanto Terrain occupies a vast area about 1000 km long and 100 km wide in the Outer Zone of Southwest Japan facing the Pacific Ocean. The following problem is to be mentioned in connection with the developments of the Pacific Ocean. This is the existence of orthoquartzite gravels in the conglomerates of the Muro Group. They are supermature orthoquartzites with excellent sorting and rounding. As the orthoquartzite cannot be seen in the present Japanese Islands, the source of the orthoquartzite gravels must be sought in some other area. Moreover, orthoquartzite gravels are mostly discovered in the southernmost district (Esumi district, Loc. 3 of Fig. 1) of the Shimanto Terrain, where they attain to about 10 to 15% of the composition of the conglomerates and have been scarcely discovered in the other districts. Accordingly it is apparent that they were not supplied from the north. On the other hand, paleocurrent directions in the Esumi district are clearly from south to north as the general sense. Almost all gravels of orthoquartzites in the Esumi district are well rounded. Such being the case, they must have been transported over long distance from a "certain" southern source area. Orthoquartzite gravels have also been discovered in the Tanabe Group, although detailed study has not been made. From the above-mentioned facts, it may be reasonably concluded that a missing land once existed in the Pacific Ocean during the Tertiary age.

References

CAROZZI, A.V. (1960): Microscopic Sedimentary Petrography. *John Wiley & Sons, Inc. Publishers.*

DMITRIEVA, E.V. et al. (1962): Atlas of Textures and Structures of Sedimentary Rocks, Part 1. (in Russian)

DZULYNSKI, S. and E.K. WALTON (1965): Sedimentary Features of Flysch and Greywackes. *Elsevier Publishing Company.*

FOLK, R.L. (1951): Stages of Textural Maturity in Sedimentary Rocks. *Jour. Sed. Petrol.*, Vol. 21, No. 3, pp. 127–130.

GREENMAN, N.N. (1951): The Mechanical Analysis of Sediments from Thin-Section Data. *Jour. Geol.* Vol. 59, pp. 447–462.

HARATA, T., T. TOKUOKA and E. MATSUMOTO (1963): Some Important New Facts from the Muro Group in the South Part of the Kii Peninsula—The New Occurrence of Fossils from the Upper Part of the Muro Group. *Earth Science*, 69, pp. 20–24. (in Japanese with English abstract)

HARATA, T. (1964): The Muro Group in the Kii Peninsula, Southwest Japan. *Mem. Coll. Sci., Univ. Kyoto, Ser.* B, Vol. 31, no. 2, pp. 71–94.

HARATA, T. (1965): Some Directional Structures in the Flysch-like Beds of the Shimanto Terrain in the Kii Peninsula, Southwest Japan. *Mem. Coll. Sci., Univ. Kyoto, Ser.* B, Vol. 32, no. 2, pp. 103–176.

HARATA, T., H. SUZUKI, H. TERASHIMA and T. TOKUOKA (1967): The Research of the Shimanto Terrain in the Kii Peninsula, Japan—The Muro Group in Hongu-cho and Nakaheji-cho District. *Earth Science*, Vol. 21, No. 6, pp. 1–9. (in Japanese with English abstract)

HASHIMOTO, I. (1962): The Sedimentary Complex of Uncertain Ages in South Kyushu. *Dep. General Education, Kyushu Univ.*, No. 9, pp. 13–69. (in Japanese with English abstract)

HASHIMOTO, I. (1967): The Unknown Mesozoics in Yura and Gobo Districts, Wakayama Prefecture. *Jour. Geol. Soc. Japan*, Vol. 73, No. 2, p. 136. (abstract)

HIRAYAMA, K. and K. TANAKA (1956): Explanatory Text of the Geological Map of Japan, (scale 1:50,000) "Todorogi". *Geological Survey of Japan.*

KANO, H. (1961): The Conglomerates from Otani and Sawando in the Hida Mountainlands as viewed from the Conception of Maturity—Studies on the Granite-bearing Conglomerates in Japan, No. 10. *Jour. Geol. Soc. Japan*, Vol. 67, no. 789, pp. 350–359. (in Japanese with English abstract)

KANO, H., K. NAKAZAWA and T. SHIKI (1961): Considerations on the Permian Back Grounds of the Maizuru Districts judging from the Conglomerates. *Jour. Geol. Soc. Japan*, Vol. 67, no. 791, pp. 463–475. (in Japanese with English abstract)

KRUMBEIN, W.C. (1941): Measurement and Geological Significance of Shape and Roundness of Sedimentary Particles. *Jour. Sed. Petrol.* Vol. 11, No. 2, pp. 64–72.

KRYNINE, P.D. (1941): Paleogeographic and Tectonic Significance of Sedimentary Quartzite. *Geol. Soc. Amer. Bull.*, Vol. 52, pp. 1915–1916.

KUENEN, PH.H. (1956): Experimental Abraision of Pebbles. 2. Rolling by Current. *Jour. Geol.* Vol. 64, no. 4, pp. 336–368.

MATSUMOTO, E. (1966): Molluscan Fossils from the Muro Group in the Southern Part of the Kii Peninsula, Central Japan, Part 1. *Mem. Coll. Sci., Univ. Kyoto, Ser.* B, Vol. 32, No. 4, pp. 369–378.

MATSUSHITA, S. (1953): The Regional Geology of Japan, "Kinki District". *Asakura Shoten, Tokyo.* (in Japanese)

MINATO, M., M. GORAI and M. HUNAHASHI (1965): The Geologic Development of the Japanese Islands. *Tsukiji Shokan , Tokyo.*

MIZUNO, A. (1957): Explanatory Text of the Geological Map of Japan, (Scale 1:50,000) "Nachi". *Geological Survey of Japan.*

MIZUNO, A. and I. IMAI (1964): Explanatory Text of the Geological Map of Japan, (Scale 1:50,000) "Tanami". *Geological Survey of Japan.*

PETTIJOHN, F.J. (1956): Sedimentary Rocks, 2nd ed. *Harper & Brothers, New York.*

PLUMLEY, W.J. (1948): Black Hills Terrace Gravels—A Study in Sediment Transport. *Jour. Geol.*, Vol. 56, pp. 526-577.

POTTER, P.E. (1955): The Petrology and Origin of the Lafayette Gravel. Part 1, Mineralogy and Petrology, *Jour. Geol.* Vol. 63, no. 1, pp. 1–38.

POTTER, P.E. and F.J. PETTIJOHN (1963): Paleocurrents and Basin Analysis. *Springer-Verlag.*

SCHLEE, J. (1957): Upland Gravels of Southern Maryland. *Bull. Geol. Soc. Amer.*, Vol. 68, pp. 1371–1410.

SHIKI, T. (1959): On Some Compositional and Textural Properties of Sandstones in the Maizuru Zone, Southwest Japan, with Special Reference to their Maturity. *Earth Science*, 42, pp. 5–17. (in Japanese with English abstract)

TOKUOKA, T. (1966a): The Muro Group along the Upper Reaches of the Hiki River in Wakayama Prefecture, Japan. *Jour. Geol. Soc. Japan*, Vol. 72, no. 2, pp. 53-61. (in Japanese with English Abstract)

TOKUOKA, T. (1966b): Kizekkyo Sandstone and Conglomerate of the Paleogene Muro Group in the Kii Peninsula, Japan. *Mem. Coll. Sci., Univ. Kyoto., Ser.* B, Vol. 32, no. 4, pp. 335–349.

UDDEN, J.A. (1914): Mechanical Composition of Clastic Sediments. *Geol. Soc. Amer. Bull.* Vol. 25, pp. 655–744.

WAKAYAMA PREFECTURE (1966): Geological Report on the Ryujin Hotspring in Ryujin-mura, Wakayama Prefecture. (in Japanese) (Mimeoprint)

WENTWORTH, C.K. (1922): A Scale of Grade and Class Terms for Clastic Sediments. *Jour. Geol.* Vol. 30, pp. 377–392.

YAMADA, N. (1966): Nature of the Late Mesozoic Igneous Activities in and around Southwest Japan. *Earth Science*, 85·86, pp. 53–58. (in Japanese with English abstract)

YAMASHITA, N. (1961): Alpine Orogeny in Japan and Problems of the Green Tuff Age. *Earth Science*, 50·51, pp. 9–21. (in Japanese with English abstract)

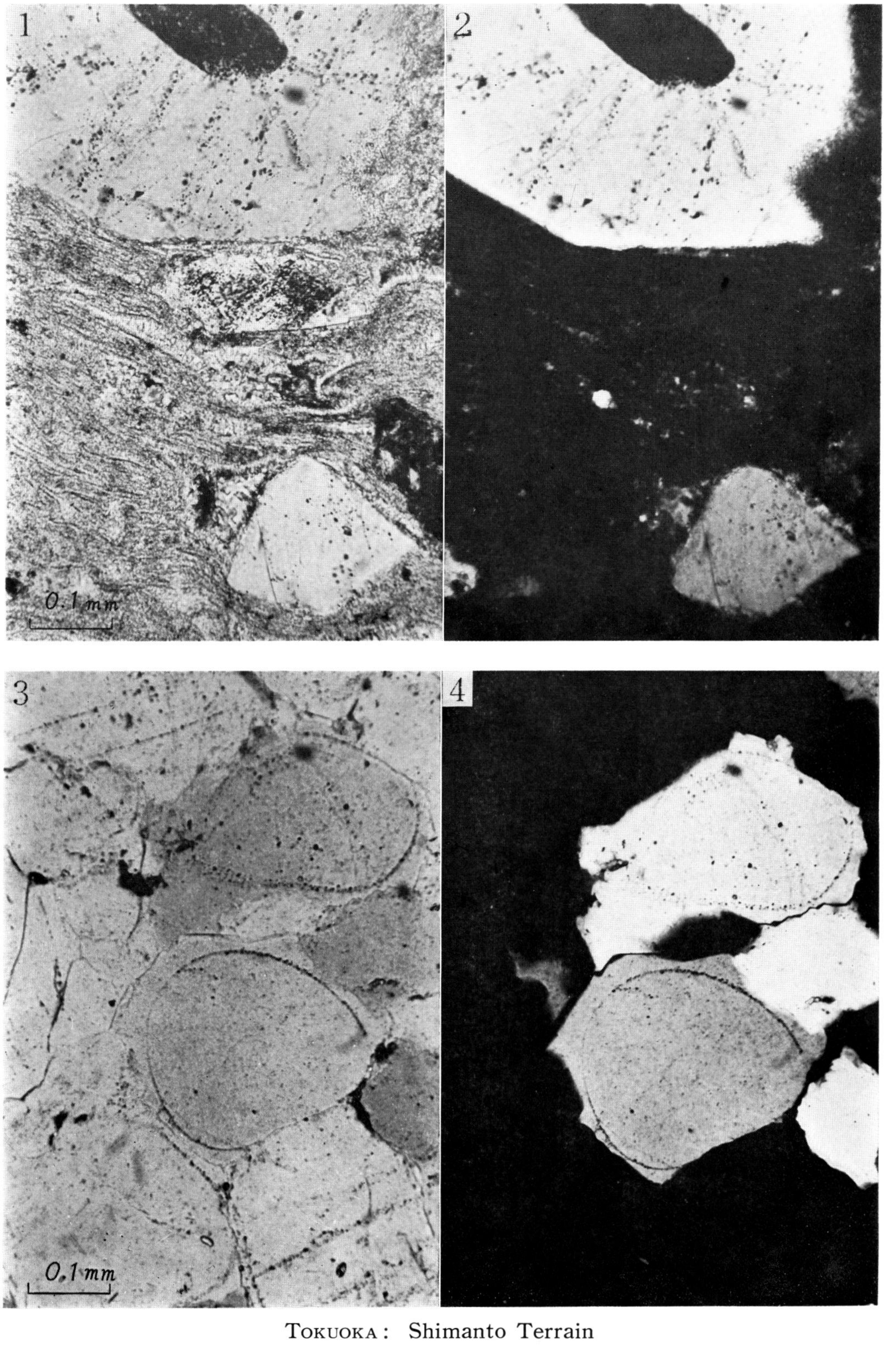
Explanation of Plate 3

Fig. 1. Rhyolite tuff in the conglomerates of the Muro Group (Loc. C-3 in the Hikigawa district). The quartz crystals are partly corroded. The black particle at the lower right is a fragment of shale. Flow and welding structures are clearly visible. Ordinary light, ×160.

Fig. 2. Same as Fig. 1. Crossed nicols, ×160.

Fig. 3. Orthoquartzite in the conglomerates of the Muro Group (Loc. C-2 in the Esumi district). The specimen is wholly composed of quartz. Original well rounding quartz grains can be determined by dust rings. Secondary quartz overgrowths are very remarkable. Ordinary light, ×160.

Fig. 4. Same as Fig. 3, showing interlocking and slightly pressolved textures of mosaic quartz. Secondary quartz overgrowths are seen in optical continuity to detrital cores. Crossed nicols, ×160.



TOKUOKA: Shimanto Terrain