# Lower Cretaceous Sandstones of the Katsuuragawa Valley, Shikoku

By

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*with 12 Tables and 13 Figures*

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ABSTRACT: The sandstone petrography is herein treated in detail from various points of view as one of the effectual means to elucidate the Lower Cretaceous sedimentation in the Katsuuragawa valley of eastern Shikoku, where the Lower Cretaceous System is divided into the Tatsukawa, Hanoura, Hoji and Fujikawa Formations in ascending order on the basis of a major cycle of sedimentation. A special attention has been given on the variation in the sandstone properties to make clear the change of the sedimentation through the above four cycles.

It is inferred that the clastic rocks were predominantly derived from older sedimentary, basic volcanic and granitic terrains, with a smaller contribution from a metamorphic terrain. Although these rocks contributed throughout to the Lower Cretaceous deposits of the whole sequence as the source rocks, the vicissitude of them is manifested by the statistically significant difference in the mineral composition of sandstones. The most remarkable compositional difference is recognized statistically between the sandstones of the Hanoura and Hoji Formations, and this suggests that a considerably intense crustal movement took place to expose granitic rocks extensively in the interval between the two formations. While, no or a little compositional change between those of other formations suggests that intense movements did not occur too seriously to bring out the vicissitude of the provenance.

Most of the Lower Cretaceous sandstones are characterized by the wacke type with more than 15 percent matrix content, being texturally closely similar to "greywacke". Some others belong to the arenite type with much mature texture. Judging from the gross litho- and bio-facies, they are reasonably referred to a variety of the arenite-wacke associations.

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## I. INTRODUCTION

The Cretaceous System in the Chichibu terrain of the Outer Zone of Southwest Japan is narrowly distributed in many scattered areas, forming synclinoria or structural basins. It has been considered that its deposits were formed in an unstable shelf of the Paleozoic Chichibu terrain and in a transitional zone of the Shimanto geosynclinal trough. Detailed investigations into it have played an important role as a key to elucidate the geologic development of the Japanese Islands, as represented by the theory of the "Sakawa orogenic cycle" of KOBAYASHI (1941, 1954).

One of such basins is the Katsuuragawa valley in Tokushima Prefecture, eastern Shikoku. There are a number of works on the Cretaceous stratigraphy in this valley by able geologists, namely, YEHARA (1924), NAGAO (in YABE, 1927), TSUKANO (1931), MATSUZAWA (1931), SUZUKI (1941), YAMASHITA (1947, 1949; in HIRAYAMA and others, 1956, 1958), NUMANO and NAKANO (1965) and others.

In addition to them, I examined critically the Cretaceous stratigraphy under the supervision of Professor Tatsuro MATSUMOTO of Kyushu University when I was a student of the same university. Thus, a detailed stratigraphy has been already established (NAKAI, 1968), being reinforced with paleontological studies (HAYAMI and NAKAI, 1965; NAKAI and MATSUMOTO, 1968).

On the basis of the stratigraphical study, moreover, I have engaged in the petrographical study on the Cretaceous sandstones in this area to make clear the geologic history of the Cretaceous sedimentation in the Chichibu terrain. As far as the sedimentological study on the Cretaceous System in the Chichibu terrain is concerned, there has been nothing but FUJII's (1956) work in the Yatsushiro district, Kyushu.

The primary purpose of this study is to investigate the properties of sandstones from the Lower Cretaceous formations in detail, and to clarify the mode of changes in the sandstone properties through several cycles of sedimentation. Some comments on the mode of sedimentation and the relation between sedimentation and tectonics are given on the basis of the sandstone petrography in addition to the gross litho- and bio-facies. Comparative remarks between the Katsuuragawa and Yatsushiro basins are also described.

Before going further, I would like to express my sincerest gratitude to Professor Tatsuro MATSUMOTO of Kyushu University for his invaluable suggestion and criticism during the course of this study. Special thanks are due to Associate Professor Hakuyu OKADA of Kagoshima University for his stimulating discussion of sedimentological problems which arose during this work and his critical reading of this manuscript. I am indebted to Professor Akira HASE of Hiroshima University and Associate Professor Kametoshi KANMERA of Kyushu University, who kindly provided me with constant encouragement and many facilities for this study. Thanks are also due to Dr. Itaru HAYAMI of Kyushu University for his valuable discussion on statistical problems, to Associate Professor Mitsuo NAKANO and Dr. Yuji OKIMURA of Hiroshima University for their continued encouragement to my efforts, and to Mr. Hideo TAKAHASHI of

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## II. NOTES ON THE LOWER CRETACEOUS STRATIGRAPHY

The Cretaceous strata of the Katsuuragawa valley are fairly well exposed along the River Katsuura, forming a synclinorium which is superimposed on the highly folded structure of the Upper Paleozoic Chichibu Supergroup. The stratigraphical sequences, sedimentary environments and geologic ages of the strata have been discussed in some detail in my another paper (NAKAI, 1968). The compiled geological map and the generalized stratigraphical columnar section are shown in Figs. 1 and 2, respectively.

As to the Lower Cretaceous System concerned in this paper, four major cycles of sedimentation are recognized. They are represented by the Tatsukawa, Hanoura, Hoji and Fujikawa Formations in ascending order. The stratigraphy is concisely described below.

### 1) Tatsukawa Formation

The first cycle of the Cretaceous sedimentation in this valley is represented by the Tatsukawa Formation, which is referable to the Ryoseki Group, a more comprehensive formational name generally used in the Chichibu terrain. This formation, about 500 m in thickness, overlies the Upper Paleozoic (Permian) Chichibu Supergroup with a remarkable unconformity, though demarcated from the Paleozoic rocks by high angle thrusts in many places in the present situation.

It consists of conglomerate, sandstone and shale or mudstone, and is characterized by a fairly large amount of coarser clastics. As intercalated beds of conglomerate occur irregularly at several horizons, the lithofacies is very changeable in lateral and vertical directions. Conglomerate at the basal part is characterized by red color and consists of poorly sorted, subangular to subrounded pebbles of chert, altered basic volcanics and mudstone (or clayslate?), whereas those at other parts generally show bluish color and are composed of somewhat well-sorted and subangular pebbles mainly of chert and subordinately of altered basic volcanics, sandstone, mudstone and limestone. Sandstone is medium- to coarse-grained, and shows pale bluish- to greenish-grey color. At the basal part, near Yokosetazukawa, sandstone as well as conglomerate is ill-sorted and reddish in color. Mudstone or shale is dark grey or black in color.

Sandstone and shale commonly yield fresh- to blackish-water mollusks and many terrestrial plants which are considered to indicate a climate of subtropical and moisture monsoon zone (KOBAYASHI, 1942). The identified species are listed as follows:

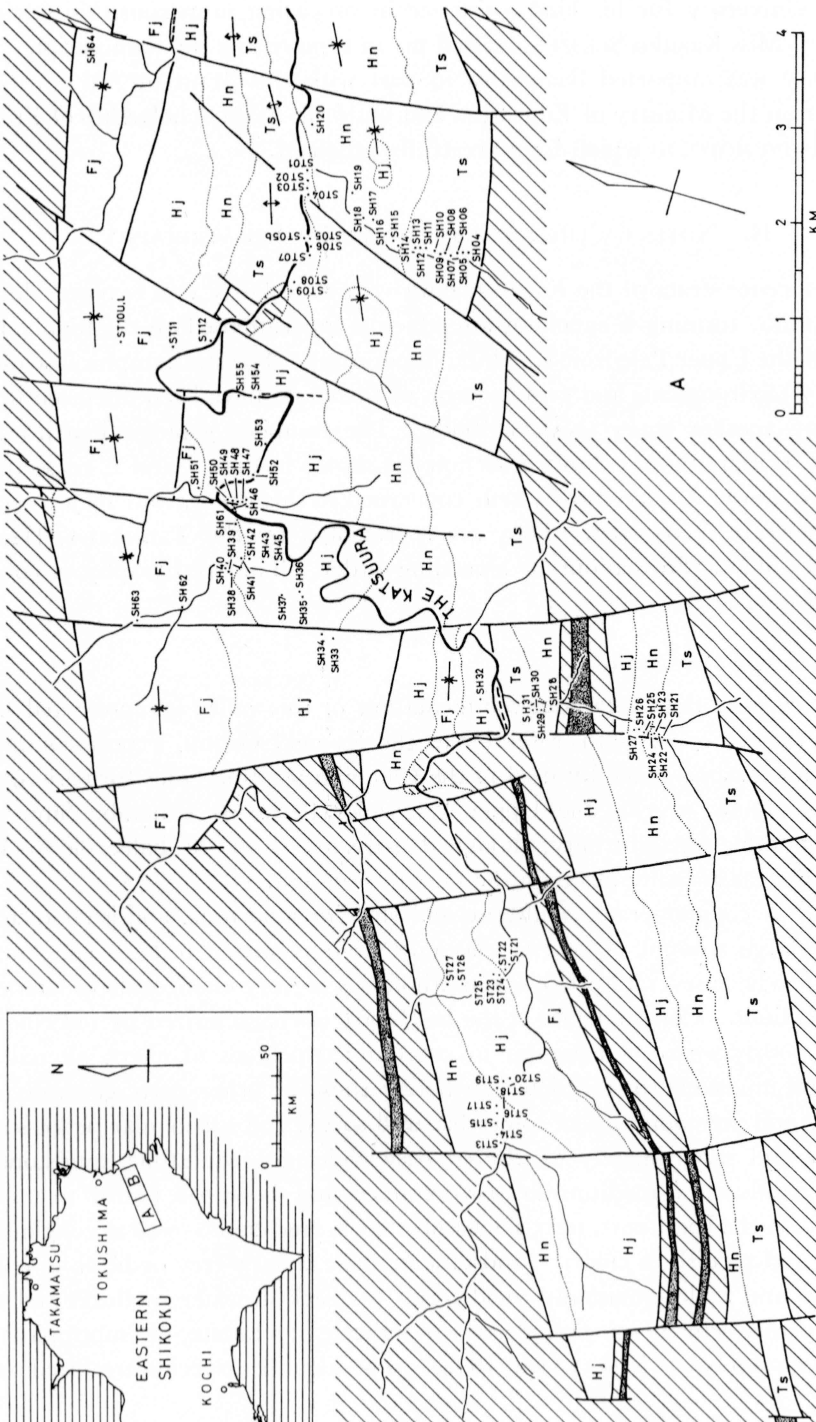


FIG. 1. Geological outline map of the Katsuuragawa valley, showing the localities of the sandstone samples.
A: The western part of the surveyed area.

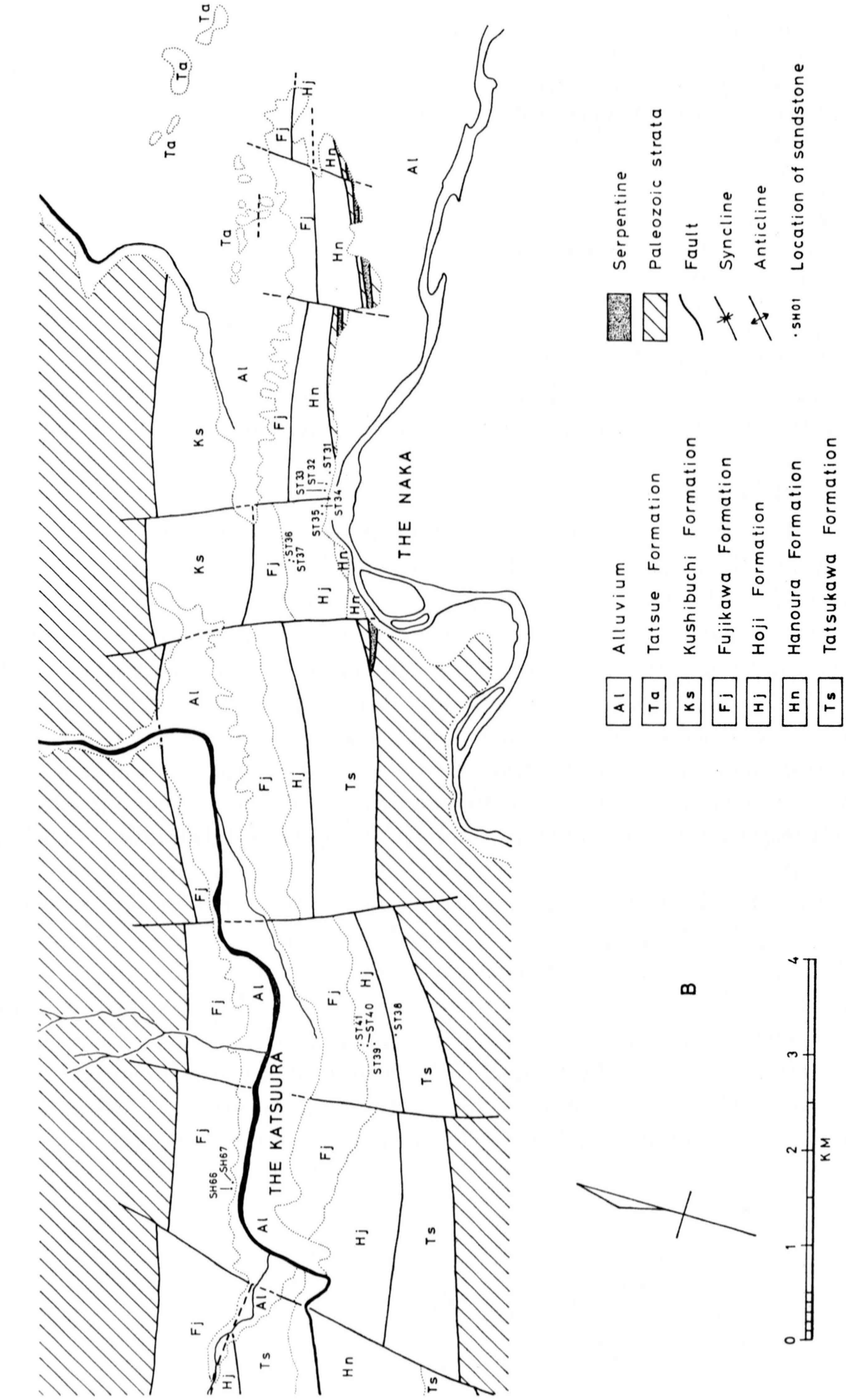


Fig. 1. (Continued). B: The eastern part of the surveyed area.

Mollusks:
- *Liostrea* sp.
- *Protocardia* sp. cf. *P. hillana* (SOWERBY)
- *Neomiodon otsukai* (YABE and NAGAO)
- *Eomiodon sakawanus* (KOBAYASHI and SUZUKI)
- *Protocyprina naumanni* (NEUMAYR)
- "*Glauconia*" *neumayri* (NAGAO)

Plants:
- *Cladophlebis* sp.
- *Podozamites lanceolatus* (LINDLEY and HUTTON)
- *Nilssonia schaumburgensis* (DUNKER)
- *Nilssonia orientalis* HEER
- *Ptilophyllum* sp.
- *Onychiopsis elongata* (GEYLER)

Although no reliable index fossil as age-indicator has been obtained, this formation may be tentatively correlated with Lower Neocomian on stratigraphical grounds.

2) Hanoura Formation

The second cycle of the Cretaceous sedimentation in this valley is called the Honoura Formation, representing a phase of marine inundation and being referable to the Lower Monobegawa Group which is comprehensively used in the Chichibu terrain. This formation, about 300 m in thickness, covers the Tatsukawa Formation conformably, and in some places abuts against the Paleozoic rocks with a remarkable unconformity. Its basal part begins with well-sorted conglomerate which generally contains rounded pebbles mainly of chert and limestone and subordinately of sandstone, mudstone and altered basic volcanics. Conglomerate near Itchu, which is considered to have covered originally the Paleozoic rocks with a remarkable unconformity despite the present fault relationship, is characterized by reddish coloration, consisting of subrounded and ill-sorted pebbles of chert, altered basic volcanics and sandstone. This is succeeded by beds of dark to bluish grey, medium- to fine-grained sandstone, and then black shale with lenticular limestone or limy shale beds becomes predominant upwards. Convolute lamination is sometimes observed in siltstone or very fine-grained sandstone. The lithological sequence, which is little diversified in lateral direction, represents a hemicyclic sedimentation from shallower non-marine to deeper marine environments in ascending order. The fossil evidence also supports this fact.

Marine pelecypods and ammonites occur commonly in the main part, whereas non-marine mollusks are found at a few localities in the sandstone near the basal part. The identified species are listed bellow.

Mollusks:
- *Mesosaccella* sp.
- *Nuculana sanchuensis* YABE and NAGAO
- *Nuculopsis* (*Palaeonucula*) *ishidoensis* (YABE and NAGAO)
- *Nanonavis* (*Nanonavis*) *yokoyamai* (YABE and NAGAO)
- *Pterinella shinoharai* HAYAMI
- *Gervillia* (*Gervillia*) *forbesiana* D'ORBIGNY
- *Neithea* sp. cf. *N. atava* (RÖMER)

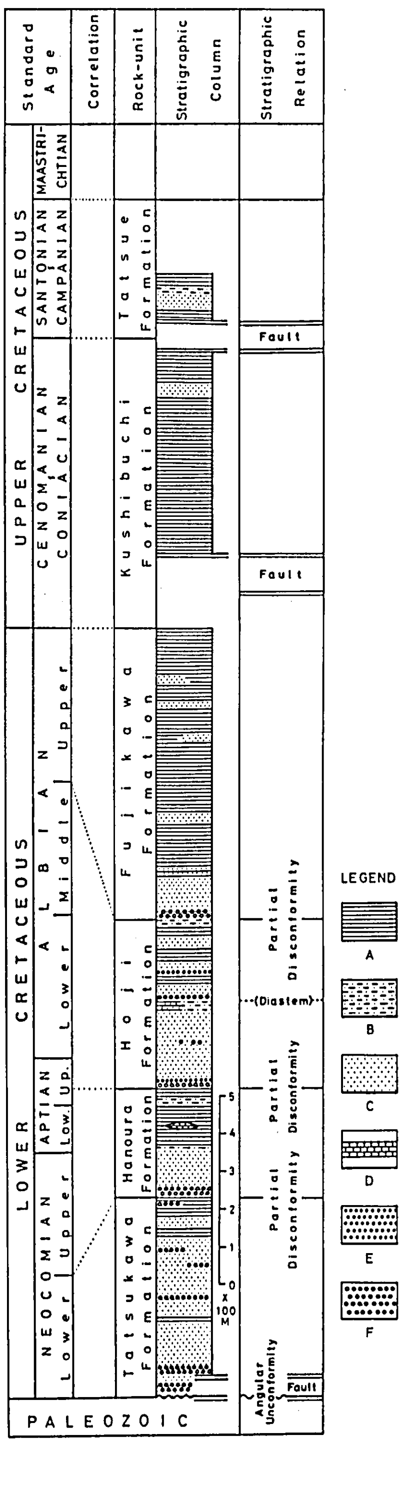


FIG. 2. Generalized stratigraphical columnar section of the Cretaceous strata in the Katsuuragawa valley. A: Shale, B: Siltstone to very fine-grained sandstone, C: Medium-grained sandstone, D: Limestone, E: Coarse-grained sandstone, F: Conglomerate.

*Neithea* sp.
*Variamussium kimurai* HAYAMI
*Lopha* (*Arctostrea*) *carinata* (LAMARCK)
*Exogyra* sp.
*Pterotrigonia pocilliformis* (YOKOYAMA)
*Pterotrigonia yokoyamai* (YEHARA)
*Astarte* (*Astarte*) *subsenecta* YABE and NAGAO
"*Cardium*" sp.
*Protocardia* sp.
*Scittila japonica* HAYAMI
*Eomiodon sakawanus* (KOBAYASHI and SUZUKI)
*Paracorbicula* sp.
*Panopea* sp. cf. *P. plicata* (SOWERBY)
*Plectomya aritagawana* HAYAMI
*Phyllopachyceras* sp. cf. *P. infundibulum* (D'ORBIGNY)
*Tropaeum* sp. cf. *T. drewi* CASEY
*Colchidites* (*Imerites*) sp.
*Uhligella* ? sp.
*Cheloniceras* (*Epicheloniceras*) sp. cf. *C.* (*E.*) *martinoides* CASEY

This formation is correlated with Upper Neocomian to lower Upper Aptian on the basis of the above listed ammonites.

### 3) Hoji Formation

The Hoji Formation represents the third cycle of the Cretaceous sedimentation in this area, which displays a regressive facies in comparison with the Hanoura Formation and is correlated with the lower part of the Upper Monobegawa Group generally called in the Chichibu terrain. This formation is about 500 m in thickness and covers the Hanoura Formation conformably.

It consists mainly of massive, medium-grained and light grey to bluish grey sandstone with fairly well-sorted conglomerate in the basal and middle parts. Conglomerate is composed of fairly rounded pebbles of chert, sandstone, altered basic volcanics and granitic rocks. Thin beds of shale, coaly shale and coal are also intercalated frequently. Cross-lamination and ripple marks are observed in some sandstone beds, though their direction cannot be ruled by observation.

Abundant trigonian fossils are found from sandstone, making sometimes fossil-beds about 10 cm thick. The following fossils are obtained from this formation.

Mollusks:

*Gervillia (Gervillia) forbesiana* D'ORBIGNY
"*Ostrea*" sp.
*Pterotrigonia pocilliformis* (YOKOYAMA)
*Nipponitrigonia kikuchiana* (YOKOYAMA)
*Fimbria* ? sp.
*Isocyprina aliquantula* (AMANO)

Plants:

*Cladophlebis* sp. cf. *C. denticulata* (BRONGNIART)
*Zamiophyllum* sp.
*Podozamites* sp. cf. *P. lanceolatus* (LINDLEY and HUTTON)
*Sphenopteris* sp.
*Ptilophyllum pecten* (PHILLIPS)

This formation seems to have been formed under deltaic to littoral environments, as judged from the litho- and bio-facies. On stratigraphical grounds, this is probably correlated with upper Upper Aptian to Middle Albian, though no fossil as precise age-indicator has been obtained yet.

4) Fujikawa Formation

The fourth cycle of the Cretaceous sedimentation in this valley is represented by the Fujikawa Formation, which is assigned to the upper part of the Upper Monobegawa Group and shows a phase of marine inundation. It is about 600 m thick and forms a synclinal structure. This formation covers the Paleozoic rocks with a remarkable unconformity on the north though the present relationship between the two is in fault contact in many places, whereas it overlies the Hoji Formation conformably on the south.

Its basal part begins with conglomerate or very coarse-grained sandstone, which, in turn, graduates upwards into medium-grained, massive sandstone. Conglomerate overlying the Paleozoic rocks in the north of Fujikawa is tilloid, which is composed of much rounded pebbles of chert with a great amount of muddy matrix. The succeeding part is made up of thick, monotonous, black shale with a few intercalations of medium- to fine-grained sandstone. The lower half of the shale is occupied by rhythmites which are composed of about 5 cm thick bands showing grading from siltstone to mudstone.

The sandstone of the basal part contains abundant trigonian fossils, whereas the shale and the intercalated sandstone of the main part yield ammonites. The following fossils are obtained.

Mollusks:

*Pterotrigonia pocilliformis* (YOKOYAMA)

*Hypophylloceras yeharai* NAKAI and MATSUMOTO
*Mariella* sp. aff. *M. cantabrigiensis* (JUKES-BROWNE)
*Desmoceras* (*Pseudouhligella*) *dawsoni shikokuense* (YABE and SHIMIZU)

From the fossil evidence this formation is correlated with Upper Albian in terms of international scale (see NAKAI and MATSUMOTO, 1968).

## III. PETROGRAPHY OF SANDSTONES

### A. METHOD OF STUDY

The specimens of sandstone from the Lower Cretaceous formations in the Katsuuragawa valley were collected according to a predetermined plan to secure adequate stratigraphical coverage as effectively as possible throughout this area. The localities and stratigraphical positions where the examined specimens were collected are shown in Figs. 1 and 3, respectively. Thus collected sandstone specimens have been petrographically investigated with regard to grain-size, major and accessory mineral compositions.

The size analysis is made microscopically from thin-sections. They are as a rule prepared in parallel to bedding plane, but specimens from massive sandstone without perceptible stratification are cut at random direction. More than 250 quartz grains per thin-section are counted as to the maximum length. The reason why the measurement is restricted to quartz grains is that they are the most common one among major minerals of sandstone. However, no attempt is carried out to measure grains smaller than 6 $\phi$ (about 0.016 mm) because the smaller grains are hardly identified mineralogically at reasonable speed.

To determine the quantitative mineralogical composition of sandstones and to provide data for sedimentological studies, a number of workers have followed the point-counting method which CHAYES (1949) has introduced in the modal analysis of igneous rocks. In the present paper this method is also carried out with a Swift point counter. The relative amounts of the major constituents, which are feldspar (orthoclase, plagioclase and microcline), quartz (non-undulose quartz and undulose quartz), rock fragments (chert and others) and matrix (clay matrix and carbonate cement), are estimated through the same thin-sections as used in the size analysis. The point counting is made on more than 1000 framework elements except for cementing substances, following a linear grid system.

The heavy mineral analysis is one of the routine works on the sandstone petrography. The analytical procedure is followed basically according to the standard method of MILNER (1962a). The examined specimens consist almost of the remainders of the same ones as used in the modal analyses. The bulk sample of about 200 grams is crushed into fractions which are passable through a sieve of 80 mesh (opening in 0.175 mm). The fractionized sample is reduced in weight of about 20 grams, heated to a boil in 6N HCl solution, washed with water to remove out the clay sized frac-

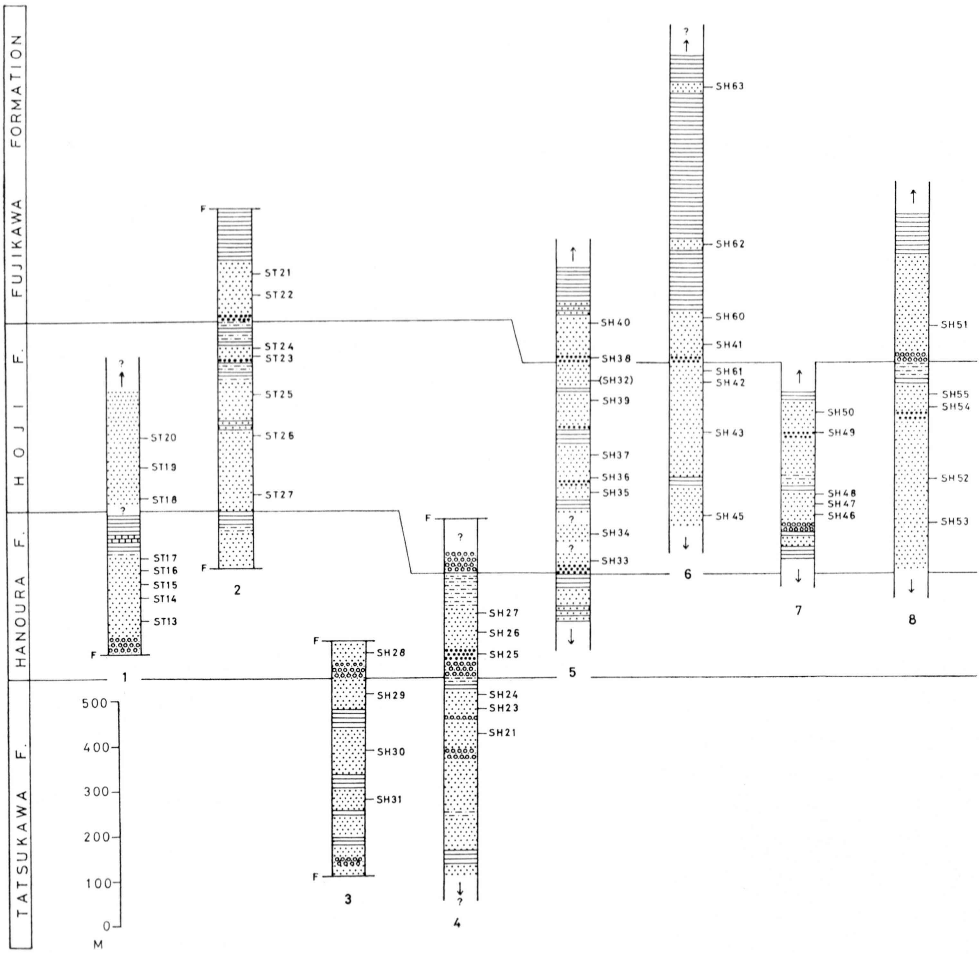


FIG. 3. Stratigraphical columnar section showing the sampling points of the examined sandstones. 1: Asahi, 2: Tanono, 3: North of Shokuda, 4: South of Shokuda, 5: North of Hiura, 6: North of Kageki, 7: North of Yanagidani, 8: South of Fujikawa.

tions, and dried. And then, by using heavy liquid of THOULET's solution (S.G.=about 2.9), heavy residuals are extracted. They are mounted on slide glass with Canada balsam, and more than 200 grains of non-opaque minerals are counted to estimate heavy mineral composition.

### B. GRAIN-SIZE ANALYSIS

1. *Size pattern*

After the millimeter scale, in which quartz grains are measured through eye-piece, is converted to the phi-scale ($\phi$), which is adopted by KRUMBEIN (1934, 1936), by using PAGE's (1955) conversion table, frequency curve and cumulative frequency

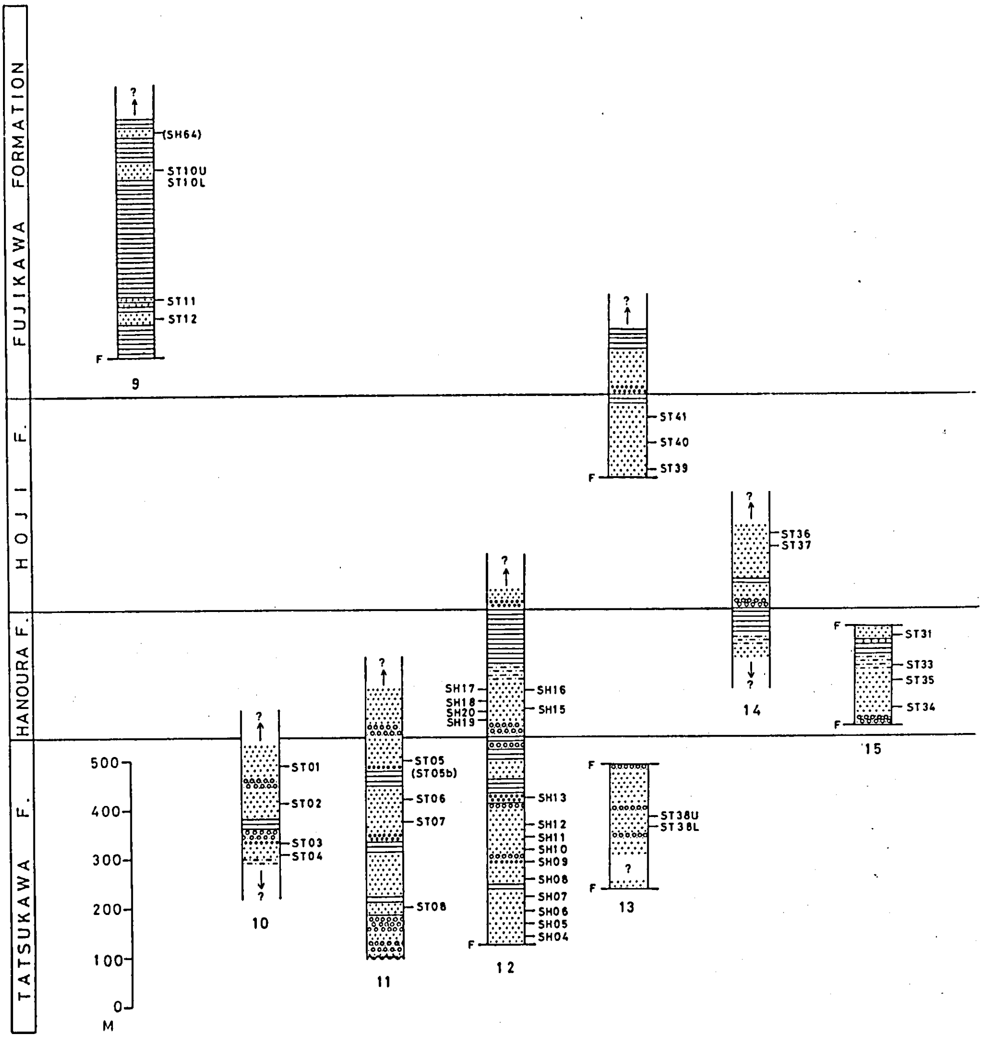


FIG. 3. (Continued). 9: Fukukawa, 10: Southeast of Yokosetazukawa, 11: Yokosetazukawa, 12: Tatsukawa, 13: Ikuna, 14: Mochii, 15: Komo.

curve are drawn to analyse some statistical parameters without taking the clay matrix into consideration.

Most of the examined specimens show the polymodality in frequency curve, and its chief ingredient or maximum is dated as the mode ($M_o$) in Table 1. Besides, cumulative frequency curve is drawn in the special graph paper which has been devised by FRIEDMAN (1958) to equate closely the result by grain-counting method to that by sieving method. FRIEDMAN demonstrated a clear linear relationship between the two results, though ROSENFELD and others (1953) doubted the validity of a correction factor by which the result from thin-section is adequately converted to that

TABLE 1. SIZE PARAMETERS AND THEIR EVALUATIONS OF SANDSTONES

| Formation | Specimen | Mode in phi ($M_o$) | Mean in phi ($M_z$) | Sorting Index in phi ($\sigma_I$) | Skewness ($Sk_I$) | Kurtosis ($K_G$) |
|---|---|---|---|---|---|---|
| Tatsukawa Formation | SH04 | 3.19 | 2.98 | 0.69 (M) | −0.03 (S) | 1.02 (M) |
| | SH05 | 2.80 | 2.57 | 0.90 (M) | 0.20 (P) | 1.05 (M) |
| | SH06 | 3.65 | 2.77 | 0.97 (M) | −0.07 (S) | 1.07 (M) |
| | SH08 | 2.94 | 3.00 | 0.69 (M) | 0.19 (P) | 0.94 (M) |
| | SH10 | 3.19 | 3.13 | 0.68 (M) | 0.18 (P) | 1.10 (M) |
| | SH11 | 3.83 | 3.92 | 0.78 (M) | 0.12 (P) | 0.90 (P) |
| | SH13 | 3.47 | 3.18 | 0.79 (M) | 0.04 (S) | 0.99 (M) |
| | SH21 | 3.47 | 3.10 | 0.78 (M) | 0.24 (P) | 1.09 (M) |
| | SH23 | 3.47 | 2.94 | 0.77 (M) | 0.23 (P) | 0.79 (M) |
| | SH24 | 2.64 | 2.97 | 0.65 (M) | 0.30 (P) | 0.91 (M) |
| | SH29 | 2.47 | 2.86 | 0.71 (M) | 0.40 (P) | 1.23 (L) |
| | SH30 | 2.29 | 2.66 | 0.90 (M) | 0.29 (P) | 1.11 (M) |
| | ST01 | 2.78 | 2.86 | 0.60 (M) | 0.23 (P) | 1.36 (L) |
| | ST02 | 2.05 | 2.58 | 0.93 (M) | 0.33 (P) | 0.97 (M) |
| | ST03 | 3.63 | 2.67 | 0.93 (M) | 0.05 (S) | 0.93 (M) |
| | ST04 | 4.37 | 3.63 | 0.68 (M) | 0.06 (S) | 1.43 (L) |
| | ST05 | 4.37 | 2.76 | 0.98 (M) | 0.10 (S) | 0.77 (P) |
| | ST05b | 1.87 | 2.53 | 0.62 (M) | 0.49 (P) | 0.55 (P) |
| | ST06 | 4.37 | 3.42 | 0.50 (M) | 0.21 (P) | 2.14 (L) |
| | ST07 | 4.37 | 2.88 | 0.84 (M) | 0.06 (S) | 0.97 (M) |
| | ST08 | 4.37 | 3.69 | 0.60 (M) | 0.16 (P) | 1.02 (M) |
| | ST38L | 3.63 | 3.21 | 0.70 (M) | 0.12 (P) | 1.12 (L) |
| | ST38U | 3.15 | 2.85 | 0.74 (M) | 0.03 (S) | 0.94 (M) |
| Hanoura Formation | SH15 | 3.64 | 3.66 | 0.54 (M) | 0.20 (P) | 1.05 (M) |
| | SH17 | 4.64 | 3.90 | 0.56 (M) | 0.18 (P) | 1.00 (M) |
| | SH18 | 3.74 | 2.68 | 0.83 (M) | 0.15 (P) | 0.88 (P) |
| | SH19 | 3.74 | 3.25 | 0.57 (M) | 0.03 (S) | 0.91 (M) |
| | SH20 | 3.84 | 3.56 | 0.79 (M) | 0.21 (P) | 1.03 (M) |
| | ST13 | 2.51 | 2.37 | 0.51 (M) | 0.21 (P) | 0.75 (P) |
| | ST14 | 3.64 | 3.16 | 0.60 (M) | 0.20 (P) | 1.07 (M) |
| | ST15 | 3.64 | 3.12 | 0.61 (M) | 0.08 (S) | 0.69 (P) |
| | ST16 | 3.64 | 3.15 | 0.66 (M) | 0.13 (P) | 1.00 (M) |
| | ST17 | 3.47 | 3.23 | 0.64 (M) | 0.14 (P) | 0.94 (M) |
| | ST31 | 3.47 | 3.54 | 0.67 (M) | 0.30 (P) | 0.88 (P) |
| | ST34 | 4.32 | 3.29 | 0.85 (M) | 0.11 (P) | 0.96 (M) |
| | ST35 | 2.78 | 2.73 | 0.55 (M) | 0.07 (S) | 1.20 (L) |
| | SH32 | 3.85 | 3.93 | 0.69 (M) | 0.14 (P) | 0.67 (P) |
| | SH33 | 2.78 | 2.88 | 0.60 (M) | 0.20 (P) | 1.01 (M) |
| | SH34 | 3.63 | 2.78 | 0.66 (M) | 0.13 (P) | 0.84 (P) |

TABLE 1. (Continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| Hoji Formation | SH35 | 3.63 | 3.15 | 0.53(M) | −0.07(S) | 1.04(M) |
| | SH36 | 3.06 | 2.34 | 0.83(M) | 0.04(S) | 0.81(P) |
| | SH37 | 3.16 | 2.77 | 0.77(M) | 0.08(S) | 1.23(L) |
| | SH39 | 2.80 | 2.64 | 0.50(M) | 0.08(S) | 1.17(L) |
| | SH42 | 2.80 | 2.80 | 0.64(M) | 0.14(P) | 1.12(L) |
| | SH43 | 3.16 | 2.98 | 0.57(M) | 0.12(P) | 0.96(M) |
| | SH45 | 3.16 | 2.77 | 0.53(M) | 0.20(P) | 0.96(M) |
| | SH46 | 2.57 | 2.05 | 0.71(M) | 0.17(P) | 1.01(M) |
| | SH47 | 2.80 | 2.88 | 0.66(M) | 0.32(P) | 1.16(L) |
| | SH48 | 2.80 | 2.66 | 0.58(M) | 0.08(S) | 0.98(M) |
| | SH49 | 1.61 | 1.72 | 0.78(M) | 0.27(P) | 0.66(P) |
| | SH50 | 2.80 | 2.82 | 0.51(M) | 0.15(P) | 0.51(L) |
| | SH52 | 3.64 | 3.27 | 0.64(M) | 0.08(S) | 1.23(L) |
| | SH53 | 2.80 | 2.85 | 0.51(M) | 0.06(S) | 1.14(L) |
| | SH54 | 3.16 | 3.16 | 0.51(M) | 0.18(P) | 1.11(M) |
| | SH55 | 3.16 | 2.77 | 0.75(M) | 0.13(P) | 0.81(P) |
| | SH61 | 2.80 | 2.77 | 0.65(M) | 0.16(P) | 1.21(L) |
| | ST18 | 4.38 | 3.07 | 0.86(M) | 0.06(S) | 1.01(M) |
| | ST19 | 3.16 | 3.11 | 0.53(M) | 0.10(S) | 1.02(M) |
| | ST20 | 3.16 | 2.85 | 0.54(M) | 0.05(S) | 0.96(M) |
| | ST23 | 1.13 | 1.69 | 0.81(M) | 0.22(P) | 0.99(M) |
| | ST24 | 2.80 | 2.80 | 0.67(M) | 0.24(P) | 1.10(M) |
| | ST25 | 3.64 | 2.97 | 0.77(M) | 0.11(P) | 0.92(M) |
| | ST26 | 2.98 | 2.67 | 0.54(M) | 0.14(P) | 0.91(M) |
| | ST27 | 3.16 | 2.67 | 0.65(M) | 0.19(P) | 0.94(M) |
| | ST30 | 2.80 | 2.66 | 0.55(M) | 0.00(S) | 1.12(L) |
| | ST37 | 1.88 | 2.07 | 0.70(M) | 0.14(P) | 1.11(M) |
| | ST39 | 2.80 | 2.86 | 0.42(W) | 0.19(P) | 0.98(M) |
| | ST40 | 3.64 | 3.21 | 0.49(W) | 0.17(P) | 1.14(L) |
| | ST41 | 3.16 | 2.98 | 0.71(M) | 0.12(P) | 0.95(M) |
| Fujikawa Formation | SH38 | 1.29 | 1.60 | 0.78(M) | 0.20(P) | 1.17(L) |
| | SH40 | 3.16 | 2.97 | 0.67(M) | 0.20(P) | 1.05(M) |
| | SH41 | 3.16 | 3.16 | 0.62(M) | 0.25(P) | 0.99(M) |
| | SH51 | 3.64 | 3.03 | 0.68(M) | 0.11(P) | 1.00(M) |
| | SH60 | 3.64 | 3.38 | 0.64(M) | 0.16(P) | 0.95(M) |
| | SH62 | 3.40 | 3.00 | 0.75(M) | 0.11(P) | 1.09(M) |
| | SH63 | 2.06 | 2.64 | 0.98(M) | 0.39(P) | 1.12(L) |
| | SH64 | 3.16 | 2.32 | 0.97(M) | 0.04(S) | 0.93(M) |
| | ST10L | 4.38 | 2.80 | 0.93(M) | 0.30(P) | 0.77(M) |
| | ST11 | 3.64 | 2.89 | 0.86(M) | −0.10(N) | 1.00(P) |
| | ST12U | 3.64 | 2.73 | 0.88(M) | −0.05(S) | 0.98(M) |
| | ST21 | 3.16 | 2.88 | 0.52(M) | 0.09(S) | 1.15(M) |
| | ST22 | 3.64 | 2.84 | 0.61(M) | 0.14(P) | 0.90(L) |

Note—In the above table the evaluations are denoted as follows: sorting index by M=moderately sorted, W=well-sorted; skewness by P=positive, S=symmetrical, N=negative; kurtosis by P=platykurtic, M=mesokurtic, L=leptokurtic.

from sieving. Even in his procedure, the values of skewness and kurtosis obtained by grain-counting method in thin-section do not correspond well with those parameters by sieving (FRIEDMAN, 1962). However, without further scrutiny of the basical problem, FRIEDMAN's special graph paper is used in this paper. The statistical parameters of mean size ($M_z$), sorting index ($\sigma_I$), skewness ($Sk_I$) and kurtosis ($K_G$) are calculated from the graphic representation according to the formulae of FOLK and WARD (1957). Thus calculated parameters with their evaluations in the individual sandstone are shown in Table 1. The average and range of the parameters in each sample of the four formations are summarized in Table 2. Their values show the similarity among the four samples in every parameter.

The examined specimens belong to moderately sorted sandstone, except for the three specimens of SH06, ST39 and ST40. However, the three specimens are not so different and diverged from moderately sorted ones in the shape of frequency curve and the value of sorting index. Therefore, the sandstone specimens treated herein are classified into nine types on the combined evaluations of kurtosis and skewness, as shown in Table 3. As the major textural types, the leptokurtic, mesokurtic and platykurtic patterns are discriminated, and they may approximately correspond to FUJII's (1956, p. 195, fig. 1) A, B and C types, respectively, which were classified on the apparent acuteness of the peak of frequency curve. The examined specimens in each sample of the four formations overwhelmingly belong to the mesokurtic type. Compared with those of the other three formations, the sample of the Hoji Formation has a relatively large number of specimens of the leptokurtic type. Furthermore, as done by FUJII (1956) on the apparent asymmetry, each of the major types is subdivided into three textural subtypes by the skewness evaluation. About two-third specimens in each sample of the four formations show the positively skewed pattern, and one-third represent the symmetrical one. Only one specimen of ST 11 from the Fujikawa Formation belongs to the negatively skewed pattern.

TABLE 2. AVERAGE AND RANGE OF SIZE PARAMETERS IN THE SANDSTONES OF EACH FORMATION

| | Tatsukawa | Hanoura | Hoji | Fujikawa |
|---|---|---|---|---|
| Average $M_Z$ | 3.10 $\phi$ | 3.20 $\phi$ | 2.78 $\phi$ | 2.79 $\phi$ |
| (Range) | (2.53-3.29) | (2.37-3.90) | (1.69-3.93) | (1.60-3.38) |
| Average $\sigma_I$ | 0.67 $\phi$ | 0.64 $\phi$ | 0.63 $\phi$ | 0.76 $\phi$ |
| (Range) | (0.50-0.98) | (0.51-0.85) | (0.42-0.86) | (0.52-0.98) |
| Average $Sk_I$ | 0.17 | 0.15 | 0.13 | 0.14 |
| (Range) | (−0.07-0.49) | (0.03-0.30) | (−0.07-0.32) | (−0.10-0.39) |
| Average $K_G$ | 1.06 | 0.95 | 1.02 | 1.01 |
| (Range) | (0.77-2.14) | (0.69-1.20) | (0.66-1.37) | (0.77-1.17) |

$M_Z$ — Mean size; $\sigma_I$ — Sorting index; $Sk_I$ — Skewness; $K_G$ — Kurtosis.

2. *Relation between size parameters*

To understand the geological significance of the size parameters, many authors insisted that it is necessary to plot them in each pair on scatter diagrams. FOLK and WARD (1957) discussed theoretically the interrelations or trends between the four parameters of mean size, sorting index, skewness and kurtosis. They have concluded that those relations may be clues to the mode of deposition and will add one or more criteria for identifying environments by size analyses.

Table 4 shows the simple correlation coefficients between the four parameters in each sample and the total specimens, from which no clear linear relation between them is recognized. Furthermore, from the scatter diagrams, general trends as illustrated by FOLK and WARD (1957) are not observed in every pair of the four parameters. As one example of the scatter diagrams, the relation between mean size and sorting index is illustrated in Fig. 4.

Besides, MASON and FOLK (1958), FRIEDMAN (1961), SAHU (1964), MOIOLA and WEISER (1968) and others have demonstrated that sandstones are sensitively separated by the difference of the depositional environments in several combinations of the four parameters. In the present specimens, however, even slight differences among the four samples could not be recognized in any combination of them. This fact may show that such associations among the four samples cannot reliably identify the depositional environment but the attribute of the grain-size distribution reflects the depositional process rather than environment, as pointed out by SOLOHUB and KLOVAN

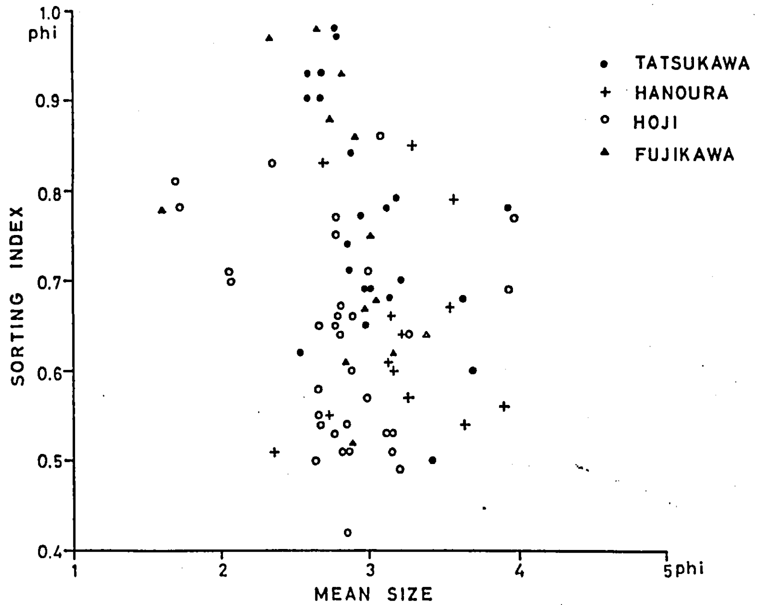


FIG. 4. Scatter plot of sorting index versus mean grain-size in the Lower Cretaceous sandstones of the Katsuuragawa valley.

TABLE 3. NUMBER FREQUENCY OF TEXTURAL TYPES IN EACH FORMATION

| | | Tatsukawa | | Hanoura | | Hoji | | Fujikawa | |
|---|---|---|---|---|---|---|---|---|---|
| Type | P*-P** | 2 | 3 | 3 | 4 | 4 | 5 | 0 | 1 |
| | P -S | 1 | | 1 | | 1 | | 0 | |
| | P -N | 0 | | 0 | | 0 | | 1 | |
| Type | M-P | 9 | 15 | 7 | 8 | 13 | 18 | 6 | 9 |
| | M-S | 6 | | 1 | | 5 | | 3 | |
| | M-N | 0 | | 0 | | 0 | | 0 | |
| Type | L -P | 4 | 5 | 0 | 1 | 5 | 10 | 3 | 3 |
| | L -S | 1 | | 1 | | 5 | | 0 | |
| | L -N | 0 | | 0 | | 0 | | 0 | |
| No. of specimens | | | 23 | | 13 | | 33 | | 13 |

*—evaluation of kurtosis, **—evaluation of skewness.
Denotations are identical with those of Table 1.

(1970). Thus, in the present case, it may be said that a sample from a certain formation which is represented by a certain limited sedimentary environment comprises various sandstones which were formed independently through different depositional processes.

### C. MAJOR MINERAL COMPOSITION

1. *Descriptive remarks on major constituents*

(1) Quartz: Clastic quartz is the most predominant constituent and occupies about a half of all derital framework elements on the average of the total specimens. Its amount ranges from 29.4 (ST13) to 69.1 percent (ST08, ST39).

On the basis of its internal character, namely, the presence or absence of undulose extinction or the polycrystallinity, quartz grains have been genetically classified into major two types of igneous and metamorphic origin by KRYNINE (1940), BOKMAN (1952), WEAVER (1955), POTTER and SIEVER (1956) and others. However, BLATT and CHRISTIE (1963) and BLATT (1967a) have concluded in their studies on quartz grains that polycrystallinity and undulatory extinction are not always a good indicator of their origin.

In this paper, therefore, quartz is only conveniently divided into two types, i.e. non-undulose and undulose ones. The former represents grains with no or slightly undulose extinction, and the latter represents those with intensely undulose extinction and polycrystallinity. The amount of the non-undulose quartz is larger than that of the undulose one on the average of each sample of the four formations.

The quartz grains are generally subangular to subrounded, and have commonly inclusions of globular or ellipsoidal vacuoles and of minerals such as zircon, apatite, mica, etc. Secondary overgrowth is rarely observed.

TABLE 4. SIMPLE CORRELATION COEFFICIENTS BETWEEN SIZE PARAMETERS

| | Tatsukawa | Hanoura | Hoji | Fujikawa | Whole Sample |
|---|---|---|---|---|---|
| $M_Z - \sigma_I$ | −0.4638* | 0.0556 | −0.2621 | −0.4276 | −0.2352* |
| $M_Z - Sk_I$ | −0.2928 | 0.2686 | −0.2025 | −0.2025 | −0.0801 |
| $M_Z - K_G$ | 0.3438 | 0.2676 | 0.0962 | −0.3187 | 0.1310 |
| $\sigma_I - Sk_I$ | −0.2639 | 0.0502 | 0.0542 | 0.0291 | −0.0091 |
| $\sigma_I - K_G$ | −0.3946 | −0.0277 | −0.3678* | −0.2267 | −0.2178 |
| $Sk_I - K_G$ | −0.0967 | −0.0303 | −0.0853 | 0.0267 | −0.0535 |

*—significant at 5 percent risk level.
Other denotations are identical with those of Table 2.

(2) Feldspar: Detrital feldspar grains occur commonly, occupying about 30 percent on the average of the total framework elements and ranging from 6.1 (SH25) to 46.3 percent (SH55).

Feldspar is here classified into three categories of orthoclase, plagioclase and microcline. Perthite is occasionally observed in a small amount, and it is included in orthoclase. Although MIZUTANI (1959), BLATT (1967b) and PITTMAN (1963, 1970) suggested that plagioclase is perhaps the most useful for the provenance determination, further detailed analytical study on it is not carried out in this paper. Feldspar grains are composed mainly of plagioclase and orthoclase, of which the former is slightly larger than that of the latter, and subordinately of microcline, which occupies only less than 0.5 percent on the average of the total framework elements.

Most of feldspar grains are generally cloudy in appearance, but specimens from the Hoji and Fujikawa Formations have a considerably large amount of fresh feldspar grains. Calcite corrosion and sericitization are frequently observed, and these are counted as the component of feldspar if a few isolated remnants of feldspar-patches are recognized. Undulose extinction and bent twin lamella are sometimes observed, but secondary overgrowth and zonal structure are not found.

(3) Rock fragments: Rock fragments are quantitatively analyzed to be divided into chert and others.

Chert grains occupy about 20 percent of the detrital fractions on the average of the total specimens, reaching up to more than 60 percent in the specimen of ST13. They are composed mainly of microcrystalline quartz, and little of chalcedonic one. Some grains have a certain clay mineral shreds as inclusions. In general the chert grain is more rounded than the quartz grain.

Other rock fragments occupy less than 10 percent on the average of the total framework elements, and in a few specimens the amount of more than 20 percent is included. They seem to be composed mainly of sedimentary rocks such as mudstone or clayslate. Volcanic rocks are observable, being more or less altered basaltic or andesitic rocks with intersertal or hyalopilitic texture. Unmistakable metamorphic rocks are not found as rock fragments, though quartz grains with schist-like texture are sometimes met with. Accessory heavy minerals, though not reaching to 1 percent

TABLE 5. QUANTITATIVE DATA ON MAJOR MINERAL COMPOSITION OF SANDSTONES

| Formation | Specimen | Feldspar (%) | | | | Quartz (%) | | | Rock Fragments (%) | | | Matrix (%) | | | Provenance Factor | Mineralogical Maturity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | orthoclase | plagioclase | microcline | Total | non-undulose | undulose | Total | chert | others | Total | clay | carbonate | Total | | |
| Tatsukawa Formation | SH04 | 9.0 | 2.4 | tr | 11.4 | 37.6 | 19.1 | 56.7 | 31.8 | 0.8 | 31.8 | 14.2 | — | 14.2 | 0.36 | 7.25 |
| | SH05 | 2.4 | 14.3 | — | 16.7 | 15.6 | 35.9 | 51.5 | 31.0 | 0.9 | 31.9 | 39.5 | — | 39.5 | 0.52 | 4.69 |
| | SH06 | 17.6 | 11.3 | 2.0 | 30.9 | 37.1 | 7.5 | 44.6 | 11.1 | 13.3 | 24.4 | 11.0 | 14.2 | 25.2 | 1.27 | 1.26 |
| | SH08 | 7.8 | 3.6 | — | 11.4 | 25.1 | 17.3 | 42.4 | 36.3 | 9.9 | 46.2 | 12.5 | — | 12.5 | 0.25 | 3.69 |
| | SH10 | 9.3 | 2.8 | — | 12.1 | 29.4 | 24.7 | 54.1 | 29.5 | 4.3 | 33.8 | 14.9 | 1.2 | 16.1 | 0.36 | 5.10 |
| | SH11 | 8.8 | 2.9 | tr | 11.7 | 26.9 | 22.3 | 49.2 | 32.1 | 7.0 | 39.1 | 18.9 | 0.3 | 19.2 | 0.30 | 4.35 |
| | SH13 | 6.8 | 1.6 | tr | 8.4 | 20.7 | 23.0 | 43.7 | 42.1 | 10.5 | 47.9 | 11.1 | — | 11.1 | 0.18 | 4.54 |
| | SH21 | 16.9 | 5.4 | tr | 22.3 | 37.8 | 21.4 | 59.2 | 16.7 | 1.8 | 18.5 | 18.2 | — | 18.2 | 1.21 | 3.15 |
| | SH23 | 12.0 | 7.9 | 0.7 | 20.6 | 32.3 | 20.8 | 53.1 | 20.0 | 6.3 | 26.3 | 15.3 | — | 15.3 | 0.78 | 2.72 |
| | SH24 | 11.7 | 4.5 | 0.6 | 16.8 | 35.9 | 24.1 | 60.0 | 16.2 | 7.0 | 23.2 | 13.6 | — | 13.6 | 0.72 | 3.20 |
| | SH29 | 20.4 | 9.4 | 0.5 | 30.3 | 36.1 | 16.8 | 52.9 | 9.0 | 7.8 | 16.8 | 13.0 | 0.5 | 13.5 | 1.80 | 1.62 |
| | SH30 | 14.6 | 11.0 | 1.3 | 26.9 | 30.4 | 24.2 | 54.6 | 10.6 | 7.9 | 18.5 | 8.1 | 0.7 | 8.8 | 1.45 | 1.87 |
| | ST01 | 3.9 | 12.2 | — | 16.1 | 19.1 | 21.7 | 40.8 | 34.0 | 9.1 | 43.1 | 21.4 | 2.9 | 24.3 | 0.37 | 2.97 |
| | ST02 | 2.0 | 8.9 | — | 10.9 | 14.1 | 19.8 | 33.9 | 53.5 | 1.7 | 55.2 | 22.2 | — | 22.2 | 0.20 | 6.94 |
| | ST03 | 0.3 | 7.1 | — | 7.4 | 7.7 | 38.9 | 46.6 | 18.4 | 18.5 | 36.9 | 28.9 | 0.7 | 29.6 | 0.20 | 2.51 |
| | ST04 | 3.9 | 14.8 | — | 18.7 | 39.0 | 18.2 | 57.2 | 20.2 | 3.9 | 24.1 | 34.5 | 12.2 | 46.7 | 0.78 | 3.42 |
| | ST05b | 5.9 | 8.6 | — | 14.5 | 21.8 | 32.0 | 53.8 | 26.8 | 4.9 | 31.7 | 38.2 | — | 38.2 | 0.45 | 4.15 |
| | ST06 | 9.9 | 11.2 | — | 21.1 | 36.8 | 24.5 | 61.3 | 15.0 | 2.7 | 17.7 | 40.3 | 8.2 | 48.5 | 1.19 | 3.21 |
| | ST07 | 5.6 | 17.9 | — | 23.5 | 11.7 | 36.6 | 48.3 | 12.2 | 16.0 | 28.2 | 28.8 | 3.8 | 32.6 | 0.83 | 1.53 |
| | ST08 | 6.9 | 12.2 | — | 19.1 | 49.0 | 20.1 | 69.1 | 10.1 | 1.8 | 11.9 | 54.2 | — | 54.2 | 1.61 | 3.79 |
| | ST38L | 5.5 | 14.2 | — | 19.7 | 30.9 | 23.1 | 54.0 | 25.0 | 1.3 | 26.3 | 30.0 | — | 30.0 | 0.75 | 3.76 |
| | ST38U | 6.8 | 13.3 | — | 20.1 | 38.3 | 14.6 | 52.9 | 26.1 | 0.9 | 27.0 | 36.0 | — | 36.0 | 0.74 | 3.76 |
| | SH15 | 9.4 | 4.5 | tr | 14.1 | 33.1 | 20.0 | 53.1 | 19.4 | 13.4 | 32.8 | 30.5 | 3.4 | 33.9 | 0.43 | 2.64 |
| | SH16 | 6.2 | 11.6 | tr | 17.8 | 38.9 | 15.2 | 54.1 | 25.4 | 2.4 | 27.8 | 41.1 | 10.0 | 51.1 | 0.64 | 3.94 |
| | SH17 | 11.4 | 2.4 | — | 13.8 | 37.4 | 12.7 | 50.1 | 21.5 | 14.6 | 36.1 | 24.4 | 9.8 | 34.2 | 0.38 | 2.52 |

TABLE 5. (Continued)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hanoura Formation | SH18 | 13.3 | 4.5 | 1.3 | 19.1 | 28.8 | 26.8 | 55.6 | 13.6 | 11.8 | 25.3 | 20.1 | 0.4 | 20.5 | 0.75 | 2.24 |
| | SH19 | 9.1 | 3.7 | tr | 12.9 | 26.3 | 21.3 | 47.6 | 23.3 | 16.1 | 39.4 | 15.6 | 8.2 | 23.8 | 0.33 | 2.44 |
| | SH20 | 9.5 | 4.9 | 0.3 | 14.8 | 25.5 | 14.0 | 39.5 | 32.1 | 13.6 | 45.7 | 26.6 | 2.9 | 29.5 | 0.32 | 2.52 |
| | SH25 | 2.8 | 3.3 | — | 6.1 | 11.1 | 29.8 | 40.9 | 48.5 | 4.5 | 53.0 | 11.7 | — | 11.7 | 0.12 | 8.43 |
| | SH26 | 11.3 | 6.1 | tr | 17.5 | 19.5 | 28.0 | 47.5 | 27.1 | 7.9 | 35.0 | 18.6 | 2.0 | 20.6 | 0.50 | 2.94 |
| | SH28 | 8.7 | 12.1 | tr | 20.9 | 18.0 | 29.5 | 47.5 | 21.4 | 10.3 | 31.7 | 18.6 | — | 18.6 | 0.66 | 2.21 |
| | ST13 | 0.7 | 7.8 | tr | 8.5 | 18.3 | 11.1 | 29.4 | 61.4 | 0.7 | 62.1 | 18.9 | — | 18.9 | 0.14 | 9.87 |
| | ST14 | 4.4 | 17.4 | — | 21.8 | 33.1 | 21.8 | 54.9 | 22.0 | 1.3 | 23.3 | 33.3 | — | 33.3 | 0.94 | 3.33 |
| | ST15 | 5.7 | 11.9 | — | 17.6 | 24.8 | 39.6 | 64.4 | 16.5 | 1.5 | 18.0 | 43.2 | — | 43.2 | 0.98 | 4.24 |
| | ST16 | 2.3 | 14.2 | — | 16.5 | 37.0 | 21.4 | 58.4 | 25.0 | tr | 25.3 | 28.4 | — | 28.4 | 0.65 | 5.05 |
| | ST17 | 8.1 | 9.7 | — | 17.8 | 29.7 | 22.0 | 51.7 | 27.2 | 3.4 | 30.6 | 28.4 | — | 28.4 | 0.58 | 3.72 |
| | ST31 | 4.9 | 17.2 | 0.4 | 22.5 | 25.0 | 14.4 | 39.4 | 26.6 | 11.5 | 38.1 | 21.5 | 7.6 | 29.1 | 0.59 | 1.94 |
| | ST34 | 3.6 | 26.3 | — | 29.9 | 30.5 | 13.9 | 44.4 | 16.4 | 9.3 | 25.7 | 21.4 | — | 21.4 | 1.16 | 1.55 |
| | ST35 | 11.0 | 19.9 | 0.4 | 31.3 | 35.5 | 11.7 | 47.2 | 14.1 | 7.3 | 21.4 | 14.1 | 1.2 | 15.3 | 1.46 | 1.59 |
| Hoji Formation | SH32 | 22.1 | 7.7 | — | 29.8 | 31.3 | 25.1 | 56.4 | 6.8 | 7.0 | 13.8 | 20.6 | 7.6 | 28.2 | 2.16 | 1.72 |
| | SH33 | 23.8 | 5.4 | tr | 29.2 | 19.6 | 23.6 | 43.2 | 13.4 | 14.2 | 27.6 | 25.8 | — | 25.8 | 1.06 | 1.30 |
| | SH34 | 14.4 | 12.0 | 0.3 | 26.7 | 25.4 | 19.0 | 44.4 | 14.0 | 14.8 | 28.8 | 21.2 | tr | 21.2 | 0.93 | 1.41 |
| | SH35 | 23.6 | 11.4 | — | 35.0 | 32.3 | 16.2 | 48.5 | 11.1 | 5.4 | 16.5 | 16.1 | 0.4 | 16.5 | 2.12 | 1.48 |
| | SH36 | 15.3 | 7.3 | — | 22.6 | 22.1 | 21.4 | 43.5 | 17.3 | 16.6 | 33.9 | 20.6 | — | 20.6 | 0.67 | 1.55 |
| | SH37 | 15.5 | 11.9 | 0.5 | 27.9 | 28.6 | 20.1 | 48.7 | 12.7 | 10.8 | 23.5 | 21.4 | 0.7 | 22.1 | 1.19 | 1.60 |
| | SH39 | 20.8 | 8.6 | — | 29.4 | 25.0 | 27.6 | 52.6 | 9.5 | 8.4 | 17.9 | 16.6 | 0.9 | 17.5 | 1.64 | 1.64 |
| | SH42 | 26.0 | 10.0 | 0.6 | 36.6 | 25.5 | 22.3 | 47.8 | 10.1 | 5.4 | 15.5 | 18.6 | 2.8 | 21.4 | 2.36 | 1.38 |
| | SH43 | 27.4 | 9.4 | — | 36.8 | 32.9 | 20.5 | 53.4 | 5.4 | 4.3 | 9.7 | 17.1 | 0.2 | 17.3 | 3.79 | 1.43 |
| | SH45 | 11.1 | 25.4 | — | 36.6 | 29.5 | 17.1 | 46.6 | 8.6 | 8.2 | 16.8 | 20.3 | 0.6 | 20.9 | 2.18 | 1.23 |
| | SH46 | 16.5 | 9.4 | — | 25.9 | 26.5 | 13.5 | 40.0 | 21.6 | 12.6 | 34.2 | 17.7 | 2.4 | 20.1 | 0.76 | 1.16 |
| | SH47 | 18.8 | 22.1 | — | 40.9 | 29.6 | 14.4 | 44.0 | 7.5 | 7.6 | 15.1 | 21.0 | 0.6 | 21.6 | 2.71 | 1.06 |
| | SH48 | 12.3 | 25.7 | — | 38.0 | 27.8 | 17.6 | 45.4 | 6.2 | 10.5 | 16.7 | 16.8 | 0.2 | 17.0 | 2.28 | 1.06 |
| | SH49 | 2.7 | 24.0 | 2.5 | 29.2 | 25.2 | 16.0 | 41.2 | 22.9 | 6.7 | 29.6 | 16.2 | 0.6 | 16.8 | 0.99 | 1.79 |
| | SH50 | 16.8 | 22.8 | — | 39.6 | 34.3 | 9.5 | 43.8 | 6.8 | 9.8 | 16.6 | 18.4 | 0.6 | 19.0 | 2.39 | 1.02 |
| | SH52 | 11.8 | 17.4 | — | 29.2 | 35.2 | 12.9 | 48.1 | 13.7 | 9.0 | 22.7 | 20.1 | 4.5 | 24.6 | 1.29 | 1.62 |

TABLE 5. (Continued)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH53 | 16.1 | 19.3 | — | 35.4 | 33.1 | 14.0 | 47.1 | 8.2 | 9.4 | 17.6 | 15.1 | 0.9 | 16.0 | 2.01 | 1.23 |
| | SH54 | 18.4 | 14.4 | — | 32.8 | 35.0 | 14.3 | 49.3 | 9.0 | 8.9 | 17.9 | 15.3 | 0.6 | 15.9 | 1.83 | 1.40 |
| | SH55 | 13.0 | 33.3 | — | 46.3 | 30.2 | 10.8 | 41.0 | 5.5 | 7.3 | 12.8 | 13.9 | 0.3 | 14.2 | 3.63 | 0.87 |
| | SH61 | 13.8 | 26.0 | 0.5 | 40.3 | 31.4 | 13.7 | 45.1 | 5.2 | 9.4 | 14.6 | 14.2 | 0.8 | 15.0 | 2.76 | 1.01 |
| | ST18 | 2.3 | 13.5 | — | 15.5 | 22.6 | 23.6 | 46.2 | 34.8 | 3.3 | 38.1 | 39.7 | — | 39.7 | 0.41 | 4.31 |
| | ST19 | 8.9 | 25.6 | 0.3 | 34.8 | 36.4 | 13.4 | 49.8 | 9.8 | 5.6 | 15.4 | 18.7 | — | 18.7 | 2.26 | 1.48 |
| | ST20 | 10.0 | 33.0 | — | 43.0 | 29.5 | 12.0 | 41.5 | 5.9 | 9.7 | 15.6 | 15.4 | 8.4 | 23.8 | 2.76 | 0.90 |
| | ST24 | 10.2 | 33.3 | — | 43.5 | 30.1 | 14.1 | 44.2 | 8.3 | 4.0 | 12.3 | 21.6 | 0.5 | 22.1 | 3.54 | 1.11 |
| | ST25 | 10.0 | 25.7 | — | 35.7 | 20.3 | 19.8 | 40.1 | 13.6 | 10.6 | 24.2 | 22.8 | — | 22.8 | 1.48 | 1.16 |
| | ST26 | 5.4 | 20.5 | tr | 25.9 | 30.8 | 22.6 | 53.4 | 15.8 | 4.9 | 20.7 | 20.6 | — | 20.6 | 1.25 | 2.25 |
| | ST27 | 6.3 | 24.2 | — | 30.5 | 39.8 | 10.5 | 50.3 | 18.6 | 0.6 | 19.2 | 25.5 | 0.7 | 26.3 | 1.59 | 2.22 |
| | ST30 | 6.7 | 22.2 | 0.3 | 29.2 | 26.1 | 28.2 | 54.3 | 10.9 | 5.7 | 16.6 | 19.9 | 0.2 | 20.1 | 1.76 | 1.87 |
| | ST36 | 1.7 | 11.7 | 0.8 | 14.2 | 32.9 | 33.0 | 65.9 | 19.9 | — | 19.3 | 13.2 | — | 13.2 | 0.71 | 6.04 |
| | ST37 | 3.0 | 15.8 | 0.4 | 19.2 | 40.6 | 15.7 | 56.3 | 18.7 | 5.7 | 24.4 | 26.9 | — | 26.9 | 0.79 | 3.01 |
| | ST39 | 1.7 | 11.6 | tr | 13.3 | 49.3 | 19.8 | 69.1 | 16.7 | 0.9 | 17.6 | 18.3 | — | 18.3 | 0.76 | 6.04 |
| | ST40 | 3.8 | 15.4 | — | 19.2 | 38.8 | 15.4 | 54.2 | 25.8 | 0.9 | 26.7 | 26.1 | — | 26.1 | 0.72 | 3.98 |
| | ST41 | 17.7 | 21.2 | 0.5 | 39.4 | 25.4 | 16.9 | 42.3 | 13.4 | 4.0 | 17.4 | 24.0 | — | 24.0 | 2.26 | 1.28 |
| Fujikawa Formation | SH38 | 3.8 | 28.6 | 0.2 | 32.6 | 29.8 | 21.4 | 51.2 | 8.3 | 7.9 | 16.2 | 10.5 | 0.4 | 10.9 | 2.01 | 1.47 |
| | SH40 | 12.4 | 30.1 | tr | 42.5 | 32.6 | 14.1 | 46.7 | 7.4 | 3.3 | 10.7 | 15.0 | — | 15.0 | 3.97 | 1.18 |
| | SH41 | 10.0 | 28.5 | 0.2 | 38.7 | 33.7 | 12.6 | 46.3 | 3.9 | 11.1 | 15.0 | 22.3 | 0.6 | 22.9 | 2.58 | 1.01 |
| | SH51 | 10.9 | 24.3 | — | 35.2 | 31.3 | 18.0 | 49.3 | 9.1 | 6.4 | 15.5 | 19.1 | tr | 19.1 | 2.27 | 1.40 |
| | SH60 | 17.0 | 21.1 | 0.5 | 38.6 | 34.1 | 16.5 | 50.6 | 5.7 | 5.0 | 10.7 | 19.5 | 2.0 | 21.5 | 3.61 | 1.29 |
| | SH62 | 13.0 | 20.1 | 1.2 | 34.3 | 37.9 | 14.9 | 52.8 | 8.9 | 4.1 | 13.0 | 12.3 | — | 12.3 | 2.64 | 1.61 |
| | SH63 | 12.3 | 16.6 | — | 28.9 | 22.5 | 11.1 | 33.6 | 14.4 | 23.1 | 37.5 | 24.5 | — | 24.5 | 0.77 | 0.92 |
| | SH64 | 12.6 | 19.8 | 1.0 | 33.3 | 22.9 | 9.1 | 38.6 | 6.4 | 21.7 | 28.6 | 1.7 | 26.7 | 28.4 | 1.16 | 0.82 |
| | SH66 | 14.6 | 29.1 | tr | 43.8 | 32.8 | 6.5 | 39.2 | 10.5 | 6.5 | 17.0 | 34.7 | 1.8 | 36.5 | 2.58 | 0.99 |
| | SH67 | 20.0 | 33.4 | — | 53.4 | 28.8 | 4.4 | 33.2 | 9.8 | 3.5 | 13.4 | 41.9 | 4.9 | 46.8 | 3.99 | 0.76 |
| | ST10L | 4.7 | 25.7 | 0.5 | 30.9 | 31.7 | 9.5 | 41.2 | 20.5 | 7.4 | 27.9 | 38.3 | tr | 38.3 | 1.11 | 1.61 |
| | ST10U | 16.0 | 19.1 | — | 35.1 | 24.2 | 9.2 | 33.4 | 19.5 | 12.0 | 31.5 | 40.1 | 1.6 | 41.7 | 1.11 | 1.12 |
| | ST11 | 12.4 | 30.0 | tr | 42.4 | 36.8 | 6.6 | 43.4 | 6.3 | 8.0 | 14.3 | 28.1 | 1.2 | 29.3 | 2.97 | 0.99 |
| | ST12L | 10.6 | 36.2 | 0.5 | 47.3 | 26.6 | 9.4 | 36.0 | 5.3 | 11.5 | 16.8 | 21.8 | 3.1 | 24.9 | 2.82 | 0.70 |
| | ST12U | 11.5 | 36.8 | 1.4 | 49.7 | 35.3 | 2.6 | 37.9 | 6.6 | 5.7 | 12.3 | 26.6 | 2.3 | 28.9 | 4.04 | 0.80 |
| | ST21 | 9.4 | 34.0 | 0.3 | 43.7 | 29.6 | 13.9 | 43.5 | 7.5 | 5.2 | 12.7 | 19.4 | — | 19.4 | 3.44 | 1.04 |
| | ST22 | 10.7 | 29.8 | — | 40.5 | 33.1 | 15.2 | 48.3 | 7.6 | 3.6 | 11.2 | 14.5 | 1.1 | 15.6 | 3.62 | 1.27 |

of the total detrital fractions in thin-section, are also grouped into the category of other rock fragments.

(4) Matrix: The interstitial material surrounding sand-grains averages over 20 percent of the total constituents, and is generally composed mainly of secondary clay minerals such as chlorite or chloritic material and sericite, and subordinately of detrital grains smaller than 6 $\phi$ (about 0.016 mm in diameter) and carbonate cement. In a few specimens, however, carbonate cement predominates over other secondary clay minerals in the relative amount, occupying 10 to 20 percent.

Most of the examined specimens have somewhat high content of matrix, and it is uncertain whether the high content is an original detrital feature. Discussing on the greywacke, CUMMINS (1962) postulated that a large part of the matrix is of secondary origin. He insisted that unstable sand grains such as feldspar and various rock fragments are easily altered into clay matrix by means of chemical and/or mechanical disintegrations owing to interstitial water, pressure and temperature under the condition of post-depositional environments, and consequently "normal sands" become to have the high matrix content. KUENEN (1966) also suggests a secondary origin for a part of the matrix. AUDLEY-CHARLES (1967, 1968), OKADA (1967) and MAYER (1968) have argued against CUMMINS' hypothesis. Although his hypothesis must be carefully taken into consideration, no sound evidence to support it, as illustrated by RAHMANI (1968), has been observed in the examined specimens of the Lower Cretaceous sandstones in the Katsuuragawa valley.

2. *Sandstone types*

The quantitative data of major constituents in the individual specimen are given in Table 5, where the percentage of the matrix content is given by the proportion to the total constituents and that of the other content by the proportion to the total framework elements.

Recently a large number of the classification schemes of sandstones have been proposed on the basis of the compositional triangular diagram, and the nomenclature of them have been seriously troubled. The excellent reviews on the classification problem have been given by KLEIN (1963), SHUTOV (1965) and OKADA (1968a, b) In this paper, therefore, no comment on this problem is given and OKADA's (1968a) classification scheme is conveniently used to avoid principally any further confusion, though the problem as to the origin of the matrix content, as stated above, remains unsolved yet.

The examined sandstones are classified into the four lithological types of feldspathic wacke, lithic wacke, feldspathic arenite and lithic arenite, as shown in Figs. 5 and 6. Most of the examined sandstones in each formation belong to the wacke type, having more than 15 percent matrix content. The sandstones from the Tatsukawa and Hanoura Formations are characterized by the lithic wacke. Although the arenite type is more predominant in the former than the latter formation, the both average points and scattered areas are closely similar to each other. The majority in the

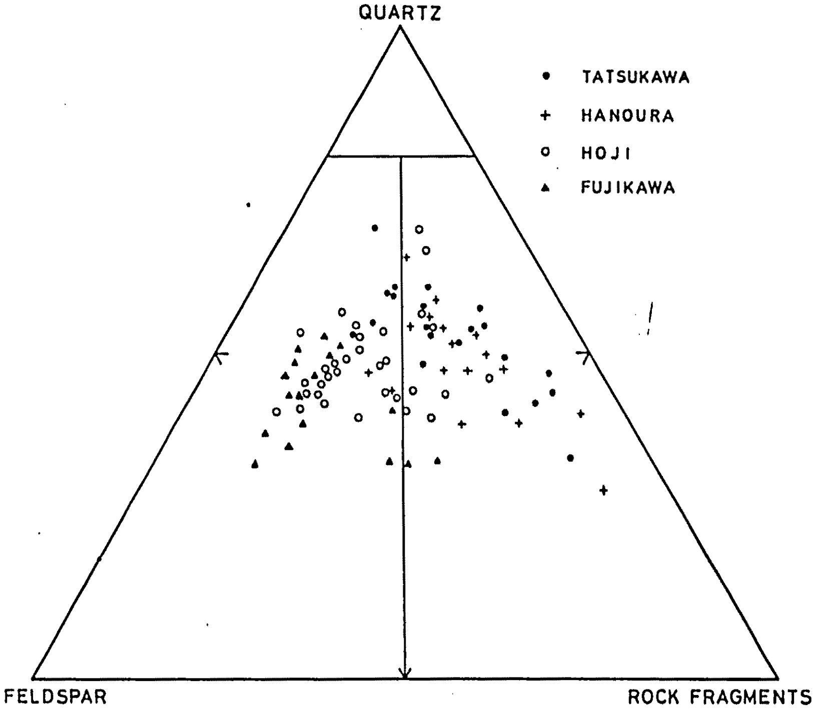


FIG. 5. Compositional diagram of the Lower Cretaceous sandstones in the Katsuuragawa valley.

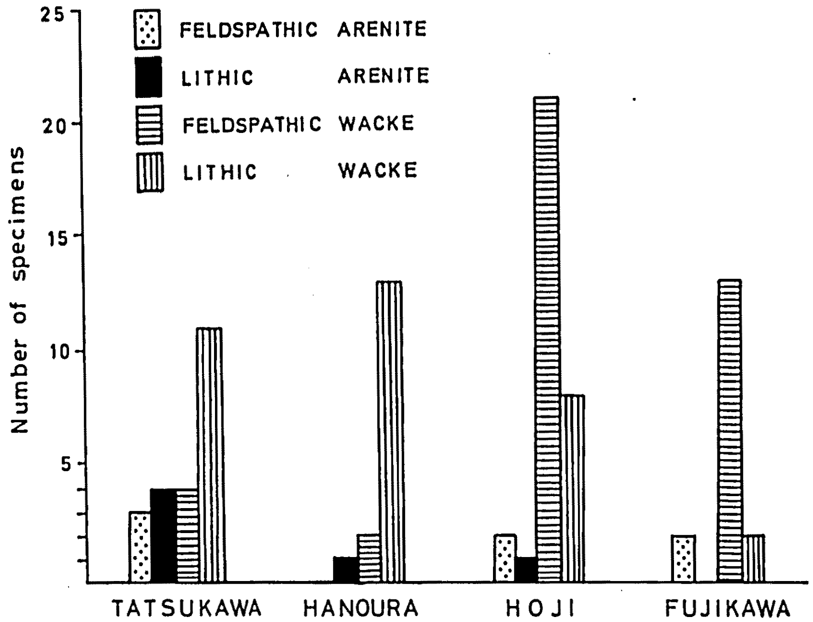


FIG. 6. Number frequency of lithological types in the Lower Cretaceous sandstones of the Katsuuragawa valley.

specimens of the Hoji Formation belong to the feldspathic wacke. Compared with those of the former two formations, the sandstones of the Hoji Formation have high feldspar and low lithic contents, its average composition being put in the feldspathic field. The specimens of the Fujikawa Formation, except for only two of SH40 and SH62, belong to the wacke type, of which the majority are the feldspathic wacke, and its average composition falls into the feldspathic field. The relative content of feldspar becomes higher in the sample of the Fujikawa than in that of the Hoji Formation.

3. *Provenance factor and mineralogical maturity*

(1) Index of the provenance factor

To understand how much sandstones depend on the source of granitic and other unstable rock terrains, DAPPLES and others (1953) proposed the source rock index, which is shown in the compositional ratio of feldspar to rock fragments plus clay matrix. As pointed out by FOLK (1954), this index is a hybrid measurement involving two matters of provenance and textural maturity, and it seems to be undesirable to use a parameter composed of unlike and unrelated items as the index of source rocks. To evade this discrepancy, PETTIJHON (1954) put forward the index of the provenance factor which is expressed in the compositional ratio of feldspar to rock fragments. This is intended to show the relative importance of the plutonic and supracrustal rocks as detritic contribution in sandstones.

The index of the provenance factor in the individual specimen examined is listed in Table 5, and its average and standard deviation in each sample of the four formations are shown in Table 6. The sample of the Tatsukawa Formation has a low index on the average, and is closely similar to that of the Hanoura Formation in its average and range. The sample of the Hoji Formation is characterized with a high index in comparison with the above two, and a distinctive difference is recognized between them. This index becomes higher in the sample of the Fujikawa Formation.

(2) Index of the mineralogical maturity

The maturity of sandstones depends on the intensity of the chemical and mechanical actions which operate on them during their formative processes, and the intense actions may introduce the disappearance of unstable detrital grains. To express the maturity of sandstones in mineralogical terms, PETTIJHON (1954) proposed the index of the mineralogical maturity in the compositional ratio of quartz plus chert to feldspar plus unstable rock fragments. Although it shows conceptually the measurement of the approach of a clastic sediment to the stable end type, this index is also controled with the provenance.

The index of the mineralogical maturity in the individual specimen is listed in Table 5, and its average and standard deviation are shown in Table 6. The sample of the Tatsukawa and Hanoura Formations are characterized by a considerably high index, and no remarkable difference is appreciated between the two. The sample of

TABLE 6. INDICES OF THE PROVENANCE FACTOR AND THE MINERALOGICAL MATURITY

| | Tatsukawa | | Hanoura | | Hoji | | Fujikawa | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Provenance Factor* | 0.47 | 0.49 | 0.63 | 0.35 | 1.79 | 0.91 | 2.63 | 1.09 |
| Mineralogical Maturity** | 3.61 | 1.53 | 3.60 | 2.31 | 1.91 | 1.32 | 1.12 | 0.29 |

SD — standard deviation
*— Feldspar/(Chert+Other rock fragments)
**— (Quartz+Chert)/(Feldspar+Other rock fragments)

the Hoji Formation has a very low index, and this marks a clear distinction from those of the above two formations. This index becomes lower in the sample of the Fujikawa Formation. These differences in the sample of the four formations seem to be referred to the change in provenance rather than to the maturity itself.

4. *Stratigraphical variation of major constituents*

The volumetrical change of the major mineral composition of sandstones is considered to be affected by the significant change of tectonics which may take place in a source area and a basin of sedimentation through the cycle of sedimentation. That is, it is presumed that sandstones from a certain lithological unit have similar mineral composition to one another. BOSWELL (1916) and MILNER (1962b) suggested that an unconformity generally demarcates the significant change in the mineral composition of sandstones. This was supported by OKADA (1961) on some evidence.

OKADA (1968a) pointed out, on the basis of studies by SHIKI (1959, 1961, etc.), FÜCHTBAUER (1967), OKADA (1966) and others, that the mineral composition of sandstones usually varies with some regularity in accordance with the decrease or increase of grain-size and consequently he suggested that it is necessary to deal with samples with similar grain-size when they are compared in mineral composition. As is later discussed in detail, however, the present specimens do not show an intimate relationship between mineral composition and grain-size. Besides, the present four samples of the Lower Cretaceous formations have similar mean values and ranges in grain-size with each other, and the difference of the sandstone pattern based on the size distribution is little appreciable among them.

Table 7 shows the sample mean, standard deviation and coefficient of variation in each major constituent of the four formations. In this paper, of coure, a statistic sample is represented by the specimens from one formation which represents a major cycle of sedimentation and a particular sedimentary environment. From this table, however, the precise and objective judgement as to the compositional difference among the four samples may be hardly decided. In order to estimate clearer the similarity or dissimilarity among them, the population variance and mean which are estimated from the sample statistics must be discussed. Some statistical analyses are carried out, as done by WELSH (1967) on the greywackes of south Scotland, to statistically reveal

TABLE 7. MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF MAJOR MINERAL COMPOSITION IN EACH FORMATION

| | Tatsukawa | | | | Hanoura | | | | Hoji | | | | Fujikawa | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean (%) | (CI) | SD | CV | Mean (%) | (CI) | SD | CV | Mean (%) | (CI) | SD | CV | Mean (%) | (CI) | SD | CV |
| Feldspar | 17.8 | (±2.9) | 6.6 | 0.4 | 17.8 | (±3.3) | 6.5 | 0.4 | 31.3 | (±3.1) | 8.6 | 0.3 | 39.5 | (±3.5) | 6.9 | 0.2 |
| orthoclase | 8.5 | (±2.3) | 5.5 | 0.6 | 7.2 | (±1.9) | 3.7 | 0.5 | 13.0 | (±2.8) | 7.6 | 0.6 | 11.9 | (±2.0) | 4.0 | 0.3 |
| plagioclase | 9.0 | (±2.1) | 4.7 | 0.5 | 10.4 | (±3.5) | 6.8 | 0.7 | 18.1 | (±2.8) | 8.0 | 0.4 | 27.2 | (±3.2) | 6.2 | 0.2 |
| Quartz | 51.8 | (±3.5) | 7.8 | 0.2 | 48.6 | (±4.3) | 8.3 | 0.2 | 48.4 | (±2.4) | 6.8 | 0.1 | 42.3 | (±3.6) | 7.0 | 0.2 |
| non-undulose | 28.8 | (±4.7) | 10.6 | 0.4 | 27.8 | (±4.0) | 7.9 | 0.3 | 30.4 | (±2.2) | 6.3 | 0.2 | 30.8 | (±2.4) | 4.6 | 0.1 |
| undulose | 23.0 | (±3.3) | 7.4 | 0.3 | 20.8 | (±4.1) | 8.0 | 0.4 | 18.0 | (±2.0) | 5.5 | 0.3 | 11.5 | (±2.6) | 5.0 | 0.4 |
| Chert | 24.0 | (±5.1) | 11.6 | 0.5 | 26.0 | (±6.3) | 12.2 | 0.5 | 13.0 | (±2.4) | 6.8 | 0.5 | 9.3 | (±2.4) | 4.7 | 0.5 |
| Quartz+Chert | 75.8 | (±3.9) | 8.9 | 0.1 | 74.5 | (±4.4) | 8.6 | 0.1 | 61.4 | (±3.7) | 10.3 | 0.2 | 51.5 | (±3.6) | 7.0 | 0.1 |
| Other rock fragments | 6.3 | (±2.2) | 5.1 | 0.8 | 7.6 | (±2.8) | 5.4 | 0.7 | 7.3 | (±1.4) | 4.1 | 0.6 | 8.6 | (±2.8) | 5.9 | 0.7 |
| Matrix | 25.9 | (±5.9) | 13.3 | 0.5 | 27.2 | (±4.5) | 8.8 | 0.3 | 21.0 | (±1.8) | 5.1 | 0.2 | 25.7 | (±5.3) | 10.4 | 0.4 |
| No. of specimens | | | 22 | | | | 17 | | | | 33 | | | | 17 | |

CI — Confidence interval of population mean at 95% confidence coefficient; SD — Standard deviation; CV — Coefficient of variation.

the compositional differences. The steps of the analytical procedure are concisely given as follows.

(a) Tabulating the sample mean and unbiased variance of each major constituent.

(b) Computing the variance ratio ($F_o$) in each constituent between compared samples by the following formula;

$$F_o = S_1^2/S_2^2$$

on the condition of $S_1^2 > S_2^2$, where $S_1^2$ is the unbiased variance.

(c) Testing $F_o$ by SNEDECOR's variance ratio test ("F-test"), to estimate whether or not the difference of two population variances is significant at less than 5 percent risk level.

(d) Computing the observed t-value ($t_o$) by the following formulae;

$$t_o = |\bar{X}_1 - \bar{X}_2| / \sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2} \cdot \frac{n_1+n_2}{n_1 \cdot n_2}} \quad \cdots\cdots\cdots\cdots (1)$$

$$t_o = |\bar{X}_1 - \bar{X}_2| / \sqrt{S_1^2/n_1 + S_2^2/n_2} \quad \cdots\cdots\cdots\cdots (2)$$

where $\bar{X}_i$ is the sample mean of a major constituent of a sample, and $n_i$ is the number of the examined specimens of the sample. The formula (1) is used when the difference of the two population variances is not statistically significant, whereas WELCH's formula (2) is used when it is significant.

(e) Testing $t_o$ by Student's t-test, to evaluate whether or not the population mean difference between the compared samples is significant at less than 5 percent risk level.

For further details of this procedure the reader may refer to the text of the statistics (e.g., DIXON and MASSEY, 1957; HOEL, 1966). The practice of the tedious calculation was carried out with the computer of TOSBAC-3400 in the Computer Center of Hiroshima University.

The result of the statistical analysis is summarized in Table 8. The distinctive character of each major constituent among the four formations is as follows.

(1) Feldspar

Total feldspar: The standard deviation is somewhat larger in the sample of the Hoji Formation than in other samples, but the significant difference of the population variances is not revealed at less than 5 percent risk level in any pair of the four samples. As expected from the sample means, the population mean difference is considered to be statistically significant in all pairs except for the Ts-Hn association.[1] Therefore, the volumetrical relation of this composition is expressed as Ts = Hn < Hj < Fj.

Orthoclase: As to this composition, the difference of the population variance is

1) The four samples of the Tatsukawa, Hanoura, Hoji and Fujikawa Formations are often conveniently expressed in the abbreviation of Ts, Hn, Hj and Fj, respectively, in this paper.

revealed to be significant at less than 5 percent risk level in the two pairs of Hn-Hj and Hj-Fj. The sample mean is more or less 10 percent in each sample, but the population mean shows the significant difference at less than 5 percent risk level in the four pairs of Ts-Hj, Ts-Fj, Hn-Hj and Hn-Fj. Consequently, the volumetrical relation of orthoclase content is shown as Ts=Hn<Hj=Fj.

Plagioclase: Although the standard deviation seems to be somewhat different from each other between every pair of the four samples, the statistically siginficant difference of the population variance is recognized only in the pair of Ts-Hj. The significant difference of the population mean is estimated in the pairs of Ts-Hj, Ts-Fj and Hn-Fj, and hence its volumetrical relation among the four samples is expressed again as Ts=Hn<Hj<Fj.

(2) Quartz

Total quartz: As expected from the standard deviation which shows similar values from 7 to 8 percent in the four samples, the significant difference of the population variance is not statistically estimated in any pair. However, the difference of the population mean is revealed to be significant at less than 5 percent risk level in the pairs of Ts-Fj, Hn-Fj and Hj-Fj, and consequently the volumetrical relation is expressed as Ts=Hn=Hj>Fj.

Non-undulose quartz: The difference of the population variance is proved to be significant at less than 5 percent risk level in the pairs of Ts-Hj, Ts-Fj and Hn-Fj. In any pair of the four samples, however, no significant difference of the population mean is recognized. Accordingly the volumetrical relation is shown as Ts=Hn=Hj =Fj.

Undulose quartz: The statistically significant difference is estimated in the pairs of Hn-Hj and Hn-Fj as for the population variance, and so in the pairs of Ts-Hj, Ts-Fj, Hn-Fj and Hj-Fj as for the population mean. The volume of undulose quartz is considered to be smaller in Fj than in the other samples. Its volume of Hj is smaller

TABLE 8. STATISTICAL COMPARISON OF MAJOR MINERAL COMPOSITION BETWEEN THE LOWER CRETACEOUS FORMATIONS

| | Tatsukawa-Hanoura | | | | | Tatsukawa-Hoji | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $F_0$ | Sig | d | $t_0$ | Sig | $F_0$ | Sig | d | $t_0$ | Sig |
| Feldspar | 1.05 | NS | 0.9 | 0.03 | NS | 1.68 | NS | 12.6 | 5.81 | *** |
| orthoclase | 2.03 | NS | 1.3 | 0.87 | NS | 1.96 | NS | 4.5 | 2.44 | * |
| plagioclase | 2.11 | NS | 1.4 | 0.76 | NS | 2.93 | ** | 9.1 | 5.25 | *** |
| Quartz | 1.14 | NS | 3.2 | 1.23 | NS | 1.31 | NS | 3.4 | 1.71 | NS |
| non-undulose | 1.83 | NS | 1.0 | 0.33 | NS | 2.85 | ** | 1.6 | 0.63 | NS |
| undulose | 1.16 | NS | 2.2 | 0.89 | NS | 1.76 | NS | 5.0 | 2.87 | ** |
| Chert | 1.11 | NS | 2.0 | 0.52 | NS | 2.95 | ** | 11.0 | 4.01 | *** |
| Quartz+Chert | 1.07 | NS | 1.3 | 0.46 | NS | 1.34 | NS | 14.4 | 5.35 | *** |
| Other rock fragments | 1.15 | NS | 1.3 | 0.77 | NS | 1.55 | NS | 1.0 | 0.81 | NS |
| Matrix | 1.74 | NS | 1.3 | 0.35 | NS | 6.74 | ** | 4.9 | 1.64 | NS |
| Degree of freedom | | | 37 | | | | | 53 | | |

TABLE 8. (Continued)

| | Tatsukawa-Fujikawa | | | | | Hanoura-Hoji | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $F_0$ | Sig | d | $t_0$ | Sig | $F_0$ | Sig | d | $t_0$ | Sig |
| Feldspar | 1.07 | NS | 20.8 | 9.57 | *** | 1.78 | NS | 13.5 | 5.69 | *** |
| orthoclase | 1.77 | NS | 3.4 | 2.23 | * | 3.98 | ** | 5.8 | 3.58 | *** |
| plagioclase | 1.76 | NS | 18.2 | 10.43 | *** | 1.38 | NS | 7.7 | 3.38 | ** |
| Quartz | 1.23 | NS | 9.5 | 3.93 | *** | 1.50 | NS | 0.2 | 0.09 | NS |
| non-undulose | 5.33 | ** | 2.0 | 0.80 | NS | 1.56 | NS | 2.6 | 1.27 | NS |
| undulose | 2.15 | NS | 11.5 | 5.52 | *** | 2.05 | * | 2.8 | 1.29 | NS |
| Chert | 6.15 | ** | 14.7 | 5.40 | *** | 3.26 | ** | 13.0 | 4.07 | *** |
| Quartz+Chert | 1.61 | NS | 24.3 | 9.24 | *** | 1.44 | NS | 13.1 | 5.37 | *** |
| Other rock fragments | 1.13 | NS | 2.3 | 1.31 | NS | 1.79 | NS | 0.3 | 0.22 | NS |
| Matrix | 1.64 | NS | 0.2 | 0.05 | NS | 2.97 | ** | 6.2 | 2.67 | * |
| Degree of freedom | | | 37 | | | | | 48 | | |

| | Hanoura-Fujikawa | | | | | Hoji-Fujikawa | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $F_0$ | Sig | d | $t_0$ | Sig | $F_0$ | Sig | d | $t_0$ | Sig |
| Feldspar | 1.13 | NS | 21.7 | 9.51 | *** | 1.57 | NS | 8.2 | 3.41 | ** |
| orthoclase | 1.15 | NS | 4.7 | 3.59 | ** | 3.48 | ** | 1.1 | 0.66 | NS |
| plagioclase | 1.20 | NS | 16.8 | 7.51 | *** | 1.66 | NS | 9.1 | 4.08 | *** |
| Quartz | 1.40 | NS | 6.3 | 2.38 | * | 1.07 | NS | 6.1 | 2.96 | ** |
| non-undulose | 2.91 | * | 3.0 | 1.35 | NS | 1.87 | NS | 0.4 | 0.24 | NS |
| undulose | 2.50 | * | 9.3 | 4.08 | *** | 1.22 | NS | 6.5 | 4.05 | *** |
| Chert | 6.81 | ** | 16.7 | 5.26 | *** | 2.09 | NS | 3.7 | 2.01 | NS |
| Quartz+Chert | 1.50 | NS | 23.0 | 8.54 | *** | 2.16 | NS | 9.9 | 3.54 | ** |
| Other rock fragments | 1.17 | NS | 2.3 | 0.50 | NS | 2.09 | NS | 1.3 | 0.91 | NS |
| Matrix | 1.38 | NS | 1.5 | 0.45 | NS | 4.12 | ** | 4.7 | 1.75 | NS |
| Degree of freedom | | | 32 | | | | | 48 | | |

$F_0$—Observed variance ratio; Sig—Significance; d—Difference in means; $t_0$—Observed t value;
*, **, ***—Significant at 5 percent, 1 percent and 0.1 percent risk level, respectively.

than that of Ts, but is not significantly distinguished from that of Hn. The population means of Ts and Hn are estimated to be identical.

(3) Rock fragments

Chert: The standard deviation and sample mean show various values, but the coefficient of variation is constant among the four samples. In the four pairs of Ts-Hj, Ts-Fj, Hn-Hj and Hn-Fj, the statistically significant difference of the population variance is revealed. It is safely said that the degree of variance is large in Ts and Hn, and small in Hj and Fj. The difference of the population mean is considered to be significant at less than 5 percent risk level in the pairs except for the Ts-Hn and Hj-Fj associations, and consequently the volumetrical relation of the four population means is estimated to be Ts=Hn>Hj=Fj.

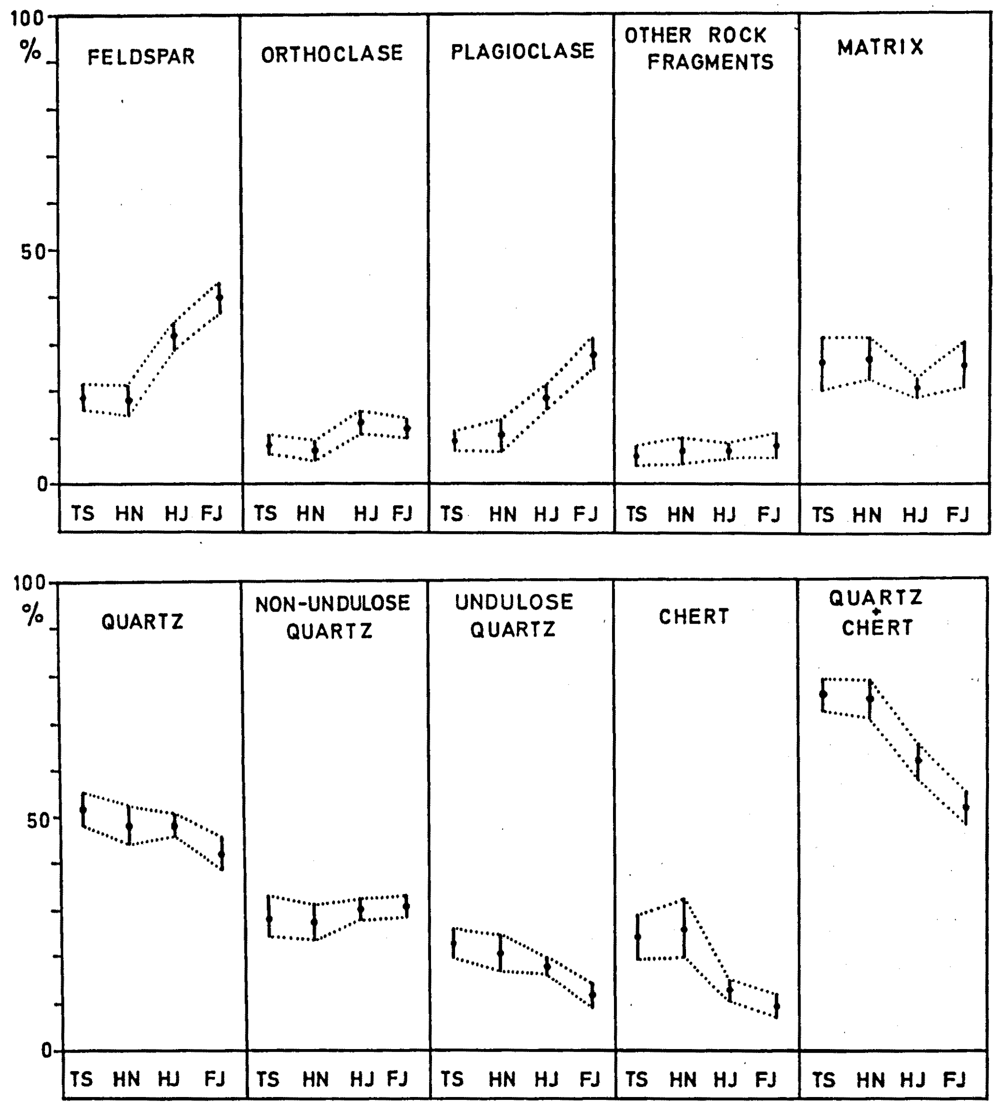


FIG. 7. Stratigraphical variation of major mineral composition in the Lower Cretaceous sandstones of the Katsuuragawa valley. Dot shows the sample mean and solid line shows the confidence interval of the population mean at 95 percent confidence coefficient. TS, HN, HJ and FJ show the samples of the Tatsukawa, Hanoura, Hoji and Fujikawa Formations, respectively.

Other rock fragments: The coefficient of variation has somewhat high values in each sample, and this fact shows that the variation of this content is somewhat large in comparison with that of the contents of other major constituents. The difference of the population variance is not estimated to be significant in any pair of the four samples, and the difference of the population mean is not recognizable in any pair, either. As to this content, therefore, the volumetical relation is shown as Ts=Hn =Hj=Fj.

(4) Matrix

As to this content, the variance difference is estimated to be statistically significant in the three pairs of Ts-Hj, Hn-Hj and Hj-Fj. This fact shows that the degree of the variance is considerably lower in Hj than in Ts, Hn and Fj. The significant difference of the population mean is estimated only in one pair of Hn-Hj with the volumetrical relation of Hn>Hj.

Judging from these results, the compositional difference between the samples of the Tatsukawa and Hanoura Formations is not estimated at all in the population variance and mean of any major constituent. The remarkable volumetrical difference between the samples of the Hanoura and Hoji Formations is appreciated in the contents of orthoclase, plagioclase, chert and matrix, and the considerable difference between the samples of the Hoji and Fujikawa Formations is also recognized in the contents of plagioclase and undulose quartz. The volumetrical variation of each major constituent among the four samples is clearly illustrated in Fig. 7.

### D. MAJOR CONSTITUENTS VERSUS GRAIN-SIZE

There have been many studies on the relation between size parameters and mineral composition in sandstones, as stated above. The general tendency that the volumetrical change of mineral composition of sandstone is controled with size parameters has been considered for such a definite lithological unit as a graded bed by SHIKI (1961), SASAKI and USHIJIMA (1966), OKADA (1966) and others. Through the investigation of sandstones from a stratigraphical unit such as member, formation or group, a similar tendency has been also estimated by some authors.

In the petrographical studies on the Paleozoic and Mesozoic sandstones of the Maizuru Zone in the Inner Side of Southwest Japan, SHIKI (1959, 1962) demonstrated that the amount of feldspar increases with decreasing grain-size. As to this fact, he insisted that feldspar grains are selectively separated away from quartz grains by water current, and that, consequently, feldspar-rich finer grained sands are deposited in different places from quartz-rich coarser grained sands. However, as far as the sandstones in the present study are concerned, no definite relation is appreciated between grain-size and contents of quartz and feldspar, as shown in Figs. 8 and 9.

OKADA (1967) pointed out that the matrix content generally increases linearly with decreasing grain-size. Such a linear tendency has been recognized in sandstones of the Permian formations of the Mugi area by MIZUTANI (1957), those of the Cretaceous

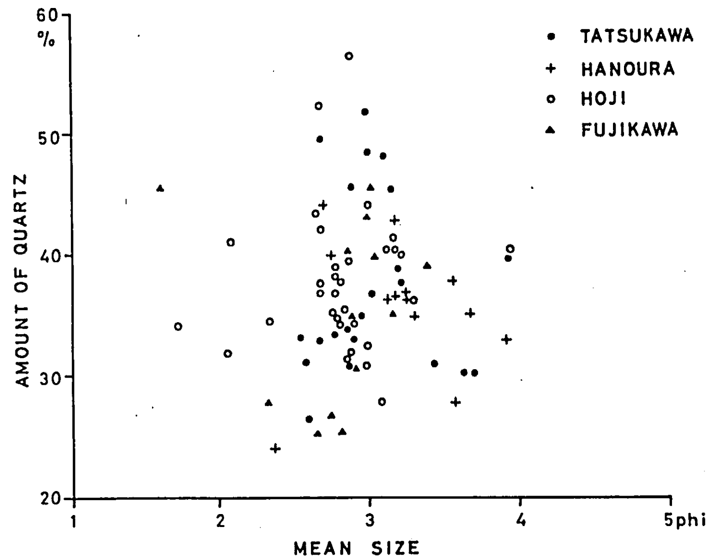


FIG. 8. Scatter plot of quartz content versus mean grain-size.

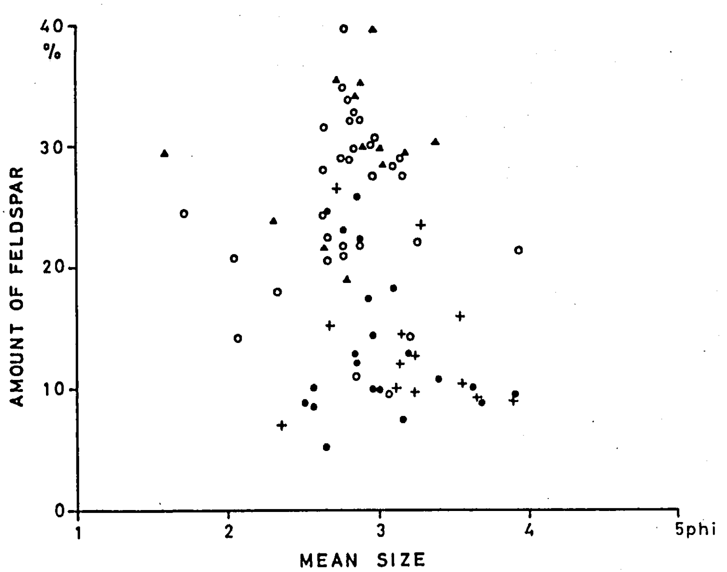


FIG. 9. Scatter plot of feldspar content versus mean grain-size. Symbols are identical with those of Figure 8.

Mifuné Group by OKADA (1960), those of the Paleozoic formations of the Yatsushiro area by FUJII (1962), those of the Lower Permian Sakamotozawa Formation by MIKAMI (1969), etc. In the present specimens, for some reasons, a linear relationship between them is not estimated, as shown in Fig. 10.

In addition to the relation between grain-size and mineral composition, the simple correlation coefficients between other size parameters and major constituents are given in Table 9. Although the coefficients in several associations are tested to be significant at less than 5 percent risk level, none of them are highly correlated at all in the total specimens and even in a sample of a formation which is characterized by a definite sedimentary environment. The results in the present sandstones agree well with those in the Cretaceous sandstones of the Yatsushiro area, Kyushu by FUJII (1956).

TABLE 9. SIMPLE CORRELATION COEFFICIENTS BETWEEN SIZE PARAMETERS AND MINERAL COMPOSITION

| | | Feldspar | (orthoclase) | (plagioclase) | Quartz | (non-undulose) | (undulose) | Chert | Other Rf. | Matrix |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean Size | Tatsukawa | −0.09 | 0.03 | −0.13 | 0.45* | 0.50* | −0.25 | −0.11 | −0.21 | 0.27 |
| | Hanoura | −0.08 | 0.24 | −0.18 | 0.16 | 0.38 | −0.09 | −0.34 | 0.54 | 0.60* |
| | Hoji | 0.14 | 0.31 | −0.11 | 0.25 | 0.16 | 0.11 | −0.28 | −0.21 | 0.25 |
| | Fujikawa | 0.33 | 0.62* | −0.03 | 0.14 | 0.47 | −0.15 | −0.14 | −0.34 | 0.14 |
| | Whole Sample | −0.20 | 0.09 | −0.27* | 0.31** | 0.28* | 0.04 | 0.04 | −0.10 | 0.34** |
| Sorting Index | Tatsukawa | 0.08 | −0.01 | 0.07 | −0.52* | −0.46* | 0.11 | 0.08 | 0.39 | −0.30 |
| | Hanoura | 0.37 | 0.11 | 0.25 | 0.03 | −0.05 | 0.07 | −0.31 | 0.20 | −0.16 |
| | Hoji | −0.06 | −0.08 | −0.01 | −0.50** | 0.53** | 0.06 | 0.38* | 0.26 | 0.40* |
| | Fujikawa | −0.42 | −0.11 | −0.38 | −0.66** | −0.40 | −0.55 | 0.49 | 0.65* | 0.60* |
| | Whole Sample | −0.07 | −0.12 | −0.02 | −0.33** | −0.37** | 0.01 | 0.13 | 0.32** | 0.07 |

*, ** — Significant at 5 percent and 1 percent risk level.

## E. HEAVY MINERAL COMPOSITION

### 1. *General remarks*

The heavy mineral content in weight counts about 0.14, 0.22, 0.97 and 0.61 percent on the average in the samples of the Tatsukawa, Hanoura, Hoji and Fujikawa Formations, respectively. The content does not exceed 1 percent in all the examined specimens except for the specimens of SH45, SH47, SH54 and ST21.

The identified minerals are composed mainly of epidote (including zoisite and clinozoisite), garnet, zircon, tourmaline, chlorite, orthopyroxene, clinopyroxene, amphibole and opaques. As the minor composition, biotite, muscovite, rutile, anatase and others are observed. The indeterminable minerals are included in the others. The quantitative data of the individual specimen analyzed are listed in Table 10, in which the percentage of opaques is given by the proportion to the total number frequency and that of each non-opaque mineral is calculated by making non-opaques 100 percent.

Among the heavy minerals the opaque minerals predominate in most of the ex-

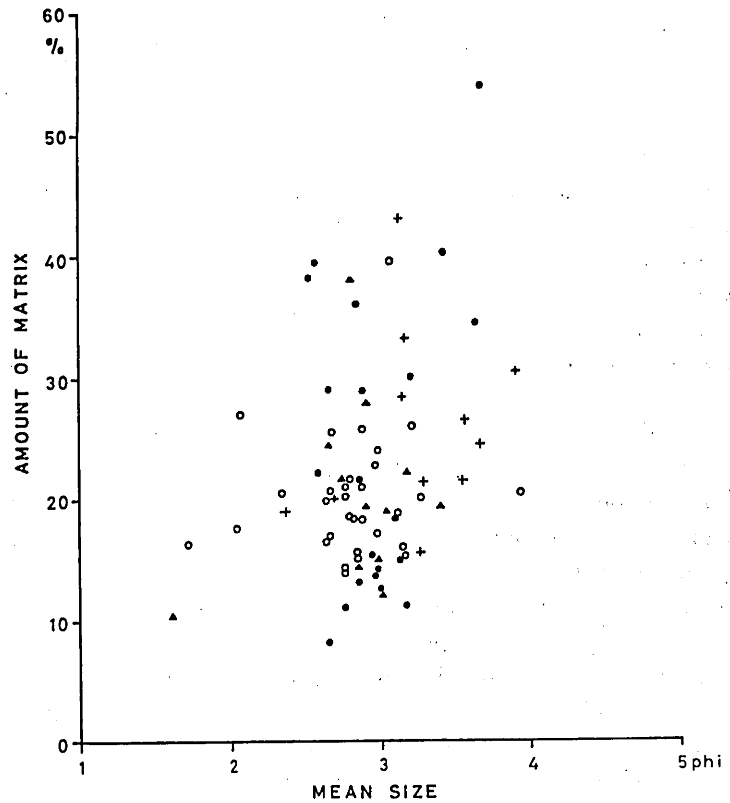


FIG. 10. Scatter plot of matrix content versus mean grain-size. Symbols are identical with those of Figure 8.

amined sandstones, reaching up to about 90 percent in some specimens, and averaging about 49, 42, 32 and 40 percent in number frequency in the samples of the Tatsukawa, Hanoura, Hoji and Fujikawa Formations, respectively.

2. *Descriptive remarks on selected minerals*

Some descriptive remarks on the selected heavy minerals of non-opaques are herein given as follows, generally in the order of relative abundance.

(1) Epidote group: Among non-opaque minerals this group is the most abundant in the majority of the examined specimens through the four formations. Its average content counts about 40 percent in the total specimens. Most of the grains are subrounded to angular and irregularly fractured in shape, and are somewhat cloudy rather than fresh in appearance. Prismatic grains are rarely met with. This group is composed of epidote, clinozoisite and zoisite. Although these mineral species are not distinguished quantitatively, epidote which shows yellowish green color in general and more or less distinct pleochroism predominates in relative number frequency.

In the present sandstones authigenic epidote as commented by PUSTOWALOFF (1955) and FRIEND and others (1963) has not been found, and all the grains of this mineral are considered to be detrital. PETTIJHON (1957) suggested that epidote indicates the provenance of high-rank metamorphic rocks. However, as pointed out by OKADA (1961), there have been many debatable problems as to its origin, and the ultimate sources are hardly decidable.

(2) Garnet: This detrital mineral commonly occurs in every specimen, and its content is about 15 percent on the average of the total non-opaques. This is divided into two varieties, namely, colorless and pinkish ones, of which the former predominates over the latter. Most of the grains are of irregular and subangular fragments with subconchoidal fracture. Roughly equidimensional and rounded grains with crystal surfaces are also frequently observed. The majority of them are very hackly in appearance.

(3) Zircon: This mineral is one of the commonest detrital heavy residuals, occurring persistently in the examined sandstones. This content is about 14 percent on the average of the total non-opaques. It is distinguished herein into two varieties, that is, colorless and pinkish ones. The latter variety is usually smaller in the relative number frequency than the former. Most of the grains display aneuhedral and short prismatic crystal form with pyramidal termination, though the terminal edges of grains are somewhat worn and more or less rounded. A very little of well-rounded and rod-like grains are observed. Pinkish grains seem to be more rounded by abrasion than colorless ones as a general rule. The elongation ratio of length to width in the euhedral crystal is about 2 in the majority, and the grains showing the ratio of more than 4 occur frequently in the specimens from the Hoji and Fujikawa Formations. Acicular or pillar-shaped inclusions are commonly observable in this mineral.

Although the morphological features such as the elongation ratio and roundness have been used as a key to elucidate the ultimate provenance, SAXENA (1966) has casted doubts on its validity in his comprehensive work on the origin of zircon. More detailed investigation of this mineral should be required in the future.

(4) Pyroxene: This mineral group is classified herein into clinopyroxene and orthopyroxene under microscope on the basis of the characteristic extinction angle. Although clinopyroxene seems to be composed mainly of augite and orthopyroxene of hyperthene, more detailed distinction is not carried out.

Clinopyroxene occupies about 8 percent on the average of the total non-opaques, and its grains generally show somewhat fractured and subangular shape and present pale greenish color.

Orthopyroxene averages about 3 percent in the total non-opaques, and most of its grains show prismatic form with irregular termination, having a distinct pleochroism from green to brown.

(5) Tourmaline: This mineral is commonly observed in most of the examined sandstones, and its content is about 4 percent on the average of the total non-opaques. Although KRYNINE (1946) distinguished five varieties to assume the possible sources, this is classified herein into two varieties on the grounds of its color, namely, blue to

TABLE 10. QUANTITATIVE DATA ON HEAVY MINERAL COMPOSITION OF SANDSTONES

| Formation | Specimen | Amphibole | Chlorite | Epidote Group | Garnet | | | Pyroxene | | | Tourmaline | | | Zircon | | | Biotite | Muscovite | Rutile | Anatase | Others | Opaques | Content of heavy minerals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Colorless | Pink | Total | Orthopyroxene | Clinopyroxene | Total | Brown | Blue | Total | Colorless | Pink | Total | | | | | | | |
| Tatsukawa Formation | SH04 | 1 | — | 18 | 25 | 4 | 29 | — | 21 | 21 | 2 | — | 2 | 17 | 4 | 21 | tr | 4 | 1 | 1 | 1 | 45 | 0.09 |
| | SH06 | — | 1 | 53 | 13 | tr | 13 | 5 | 11 | 16 | 2 | tr | 2 | 12 | — | 12 | — | 1 | 1 | 1 | 1 | 33 | 0.07 |
| | SH07 | — | 1 | 28 | 13 | — | 13 | 1 | 19 | 20 | 4 | — | 4 | 25 | — | 25 | — | 2 | — | 3 | 2 | 74 | 0.18 |
| | SH08 | 2 | — | 20 | 27 | 2 | 29 | 3 | 13 | 16 | tr | — | tr | 9 | — | 9 | — | — | 1 | 1 | 21 | 31 | 0.15 |
| | SH10 | 3 | — | 33 | 17 | 5 | 22 | 2 | 12 | 14 | 2 | tr | 2 | 15 | — | 15 | tr | — | — | — | 1 | 31 | 0.08 |
| | SH11 | 1 | — | 16 | 40 | 6 | 46 | 2 | 8 | 10 | 1 | — | 1 | 20 | 2 | 22 | — | — | 2 | 2 | tr | 25 | 0.15 |
| | SH13 | 3 | 1 | 9 | 42 | 4 | 46 | 1 | 9 | 10 | 5 | 1 | 6 | 13 | — | 13 | — | — | 1 | — | 10 | 89 | 0.42 |
| | SH21 | 4 | 28 | 4 | 4 | 2 | 6 | 2 | — | 2 | 17 | — | 17 | 24 | — | 24 | 9 | — | 3 | 3 | — | 56 | 0.14 |
| | SH23 | 1 | — | 10 | 10 | 1 | 11 | — | 10 | 10 | 4 | 2 | 6 | 59 | — | 59 | 1 | — | 1 | — | — | 35 | 0.05 |
| | SH24 | 1 | — | 31 | 14 | 2 | 16 | 3 | 15 | 18 | 4 | 2 | 6 | 26 | 2 | 28 | — | — | — | tr | — | 43 | 0.17 |
| | SH29 | — | 1 | 29 | 18 | 2 | 20 | — | 14 | 14 | 4 | tr | 4 | 28 | — | 28 | 1 | 2 | tr | — | — | 42 | 0.09 |
| | SH30 | 2 | — | 9 | 24 | 14 | 38 | tr | 9 | 9 | 5 | tr | 5 | 24 | 9 | 33 | 3 | — | tr | — | — | 31 | 0.08 |
| | ST01 | 2 | 4 | 21 | 38 | 3 | 41 | — | 7 | 7 | 1 | — | 1 | 19 | — | 19 | — | — | — | 3 | 3 | 42 | 0.13 |
| | ST02 | 1 | tr | 14 | 45 | — | 45 | tr | 10 | 10 | 2 | — | 2 | 14 | tr | 14 | — | 2 | — | 1 | — | 57 | 0.01 |
| | ST04 | tr | 1 | 16 | 31 | tr | 31 | 1 | 7 | 8 | 3 | 1 | 4 | 25 | — | 25 | 8 | — | 1 | 1 | 2 | 56 | 0.06 |
| | ST05b | — | 7 | 32 | 25 | tr | 25 | — | 1 | 1 | — | — | — | 12 | — | 12 | — | — | — | 2 | — | 83 | 0.16 |
| | ST06 | — | 1 | 15 | 31 | — | 31 | — | 19 | 19 | 1 | 2 | 3 | 27 | — | 27 | — | 1 | 2 | — | — | 87 | 0.40 |
| | ST07 | 1 | 4 | 14 | 9 | 3 | 12 | 1 | 8 | 9 | — | — | — | 20 | 1 | 21 | 2 | 1 | 4 | 2 | — | 59 | 0.04 |
| | ST08 | — | 1 | 75 | 3 | — | 3 | 2 | 14 | 16 | — | — | — | 2 | — | 2 | — | — | — | — | 2 | 43 | 0.27 |
| | ST38L | — | — | 50 | 23 | 2 | 25 | 3 | 6 | 9 | 1 | tr | 1 | 10 | — | 10 | — | 2 | 1 | — | 1 | 34 | 0.05 |
| | ST38U | — | 3 | 47 | 17 | 1 | 18 | 7 | 15 | 22 | 2 | 1 | 3 | 8 | — | 8 | 1 | — | 1 | — | 1 | 38 | 0.22 |
| | SH15 | tr | 3 | 15 | 45 | — | 45 | 3 | 11 | 14 | 2 | 1 | 3 | 14 | — | 14 | — | tr | 2 | — | 3 | 22 | 0.03 |
| | SH16 | — | 1 | 33 | 39 | tr | 8 | 8 | 3 | tr | 3 | 14 | — | 14 | — | 14 | — | tr | — | — | 1 | 49 | 0.11 |
| | SH17 | 1 | 5 | 38 | 21 | — | 21 | — | 6 | 6 | 2 | — | 2 | 13 | — | 13 | — | tr | 2 | 4 | 1 | 54 | 0.12 |

TABLE 10. (Continued)

| | | | | | | | | | | | | | | | | | | | | | | | |
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| Hanoura Formation | SH18 | 2 | 1 | 17 | 47 | — | 47 | — | 8 | 8 | — | — | — | 14 | — | 14 | — | 1 | 2 | 1 | 1 | 44 | 0.03 |
| | SH19 | 1 | 1 | 12 | 41 | 2 | 43 | 1 | 8 | 9 | 2 | tr | 2 | 21 | 2 | 23 | 1 | 1 | tr | 1 | 6 | 42 | 0.04 |
| | SH20 | 2 | tr | 20 | 27 | tr | 27 | tr | 1 | 1 | 7 | tr | 7 | 35 | — | 35 | 3 | 1 | 2 | 1 | — | 52 | 0.09 |
| | SH25 | 2 | 1 | 17 | 37 | 13 | 50 | 1 | 7 | 8 | 1 | 2 | 3 | 11 | 3 | 14 | 2 | — | — | 1 | 3 | 80 | 0.12 |
| | SH26 | 1 | 2 | 33 | 25 | — | 25 | — | 11 | 11 | 1 | — | 1 | 18 | 2 | 20 | 2 | 1 | 1 | 2 | — | 65 | 0.49 |
| | ST13 | — | 5 | 15 | 36 | 3 | 39 | 1 | 13 | 14 | — | — | — | 20 | — | 20 | 2 | 1 | 1 | 2 | 1 | 44 | 0.01 |
| | ST14 | 1 | 5 | 66 | 6 | 1 | 7 | 3 | 11 | 14 | 1 | — | 1 | 6 | — | 6 | 2 | — | 1 | — | 1 | 42 | 0.22 |
| | ST15 | tr | 1 | 69 | 4 | — | 4 | 4 | 14 | 18 | 1 | — | 1 | 6 | — | 6 | — | — | — | 1 | — | 32 | 0.63 |
| | ST16 | tr | tr | 70 | 6 | — | 6 | 3 | 13 | 16 | 1 | tr | 1 | 4 | — | 4 | — | — | — | — | 2 | 30 | 0.09 |
| | ST17 | tr | 13 | 54 | 6 | — | 6 | 4 | 12 | 16 | 1 | — | 1 | 8 | — | 8 | — | — | — | — | 1 | 32 | 0.21 |
| | ST31 | 3 | 5 | 12 | 25 | — | 25 | 1 | 7 | 8 | 4 | 1 | 5 | 8 | — | 8 | 1 | 1 | tr | tr | 31 | 37 | 0.09 |
| | ST34 | 20 | 2 | 32 | 1 | — | 1 | 2 | 5 | 7 | 3 | 2 | 5 | 5 | — | 5 | tr | — | — | tr | 26 | 24 | 0.57 |
| | ST35 | 1 | 2 | 57 | 3 | 2 | 5 | 3 | 9 | 12 | 5 | 2 | 7 | 10 | 1 | 11 | 2 | 1 | 1 | — | 3 | 25 | 0.61 |
| Hoji Formation | SH32 | 5 | 13 | 9 | 6 | — | 6 | 2 | 4 | 6 | 5 | 2 | 7 | 12 | — | 12 | 32 | — | 4 | — | 8 | 40 | 0.19 |
| | SH33 | — | — | 88 | 1 | — | 1 | 3 | 2 | 5 | 2 | 2 | 4 | 2 | — | 2 | — | tr | — | — | — | 17 | 0.46 |
| | SH34 | — | 7 | 82 | tr | tr | 1 | 3 | 2 | 5 | tr | tr | tr | 1 | — | 1 | 2 | 1 | — | — | — | 23 | 0.84 |
| | SH35 | — | 2 | 55 | 5 | — | 5 | 13 | 10 | 25 | 4 | tr | 4 | 10 | — | 10 | — | tr | 1 | 1 | — | 21 | 0.54 |
| | SH37 | 3 | 4 | 34 | 5 | — | 5 | 10 | 2 | 12 | 12 | tr | 12 | 13 | — | 13 | 8 | 6 | — | 4 | 1 | 78 | 0.23 |
| | SH39 | 3 | 2 | 37 | 3 | — | 3 | 2 | 6 | 8 | 13 | tr | 13 | 21 | — | 21 | 4 | 1 | — | — | 9 | 59 | 0.17 |
| | SH42 | — | tr | 71 | 2 | 1 | 3 | 4 | 7 | 11 | 2 | tr | 2 | 9 | — | 9 | 1 | — | 1 | tr | 1 | 27 | 0.68 |
| | SH43 | — | 1 | 63 | 3 | — | 3 | 4 | 8 | 12 | 2 | — | 2 | 8 | — | 8 | tr | — | tr | — | 7 | 15 | 0.31 |
| | SH45 | tr | 1 | 81 | 4 | — | 4 | 4 | 6 | 10 | 2 | 1 | 3 | 1 | — | 1 | tr | — | — | — | — | 8 | 11.08 |
| | SH46 | — | — | 79 | — | — | tr | 3 | 5 | 8 | 2 | — | 2 | 3 | — | 3 | 3 | 1 | — | 3 | 1 | 81 | 0.66 |
| | SH47 | — | 1 | 82 | 1 | — | 1 | 5 | 6 | 11 | tr | 2 | 2 | 3 | — | 3 | tr | tr | — | tr | — | 14 | 6.73 |
| | SH48 | — | tr | 92 | 1 | — | 1 | 2 | 2 | 4 | tr | — | tr | 1 | — | 1 | 1 | — | — | — | — | 30 | 0.67 |
| | SH49 | 1 | — | 79 | 3 | 1 | 4 | 3 | 6 | 9 | 1 | 1 | 2 | 2 | — | 2 | 1 | 1 | — | — | — | 30 | 0.31 |
| | SH50 | 3 | 1 | 70 | 4 | — | 4 | 4 | 7 | 11 | 2 | 1 | 3 | 7 | — | 7 | 1 | — | — | — | — | 20 | 0.85 |
| | SH52 | 1 | — | 71 | 8 | — | 8 | 7 | 4 | 11 | 3 | — | 3 | 5 | — | 5 | — | — | 1 | — | — | 17 | 0.20 |
| | SH53 | 3 | 1 | 69 | 1 | — | 1 | 6 | 13 | 19 | 2 | 2 | 4 | tr | — | tr | — | — | — | — | 2 | 19 | 0.45 |
| | SH54 | tr | 3 | 72 | 3 | — | 3 | 3 | 4 | 7 | 2 | tr | 2 | 11 | — | 11 | — | tr | tr | — | — | 10 | 3.05 |

TABLE 10. (Continued)

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SH55 | 4 | 1 | 73 | 1 | — | 1 | 3 | 6 | 9 | 2 | 1 | 3 | 8 | — | 8 | — | — | — | — | — | 33 | 0.31 |
| | SH61 | — | tr | 59 | 9 | — | 9 | 1 | 9 | 10 | 3 | 1 | 4 | 11 | tr | 11 | tr | tr | — | 1 | tr | 33 | 0.09 |
| | ST18 | 1 | 8 | 72 | 5 | — | 5 | 1 | 5 | 6 | 1 | — | 1 | 7 | — | 7 | 2 | — | — | 2 | 1 | 37 | 0.44 |
| | ST19 | — | tr | 29 | 9 | 1 | 10 | tr | 8 | 8 | 7 | 1 | 8 | 31 | 1 | 32 | tr | 2 | — | — | 10 | 32 | 0.34 |
| | ST20 | — | 1 | 23 | 14 | 2 | 16 | 1 | 10 | 11 | 4 | 1 | 5 | 37 | — | 37 | — | — | 3 | — | 2 | 39 | 0.10 |
| | ST24 | tr | — | 71 | 2 | — | 2 | 4 | 9 | 13 | 4 | 4 | 8 | 2 | — | 2 | — | tr | — | — | 3 | 12 | 0.12 |
| | ST25 | 3 | 13 | 68 | 2 | 1 | 3 | 2 | tr | 2 | 2 | tr | 2 | 2 | — | 2 | 3 | tr | — | 1 | 1 | 39 | 0.37 |
| | ST26 | — | 6 | 61 | tr | 1 | 1 | 5 | 6 | 11 | 11 | tr | 11 | 3 | — | 3 | 4 | tr | — | 1 | — | 43 | 0.68 |
| | ST27 | 3 | 2 | 25 | 5 | tr | 5 | 2 | 4 | 6 | 13 | 11 | 24 | 24 | 2 | 26 | 3 | 1 | — | 3 | — | 22 | 0.09 |
| | ST30 | — | 15 | 14 | 9 | 1 | 10 | tr | 3 | 3 | 5 | tr | 5 | 23 | 1 | 24 | 18 | 6 | 1 | 3 | — | 69 | 0.34 |
| | ST36 | 2 | 3 | 76 | 1 | — | 1 | 1 | 5 | 6 | 5 | tr | 5 | 3 | — | 3 | — | — | 2 | 2 | — | 44 | 0.25 |
| | ST37 | tr | tr | 75 | 2 | tr | 2 | 4 | 8 | 12 | 4 | 2 | 6 | 2 | — | 2 | — | — | tr | — | — | 25 | 0.20 |
| | ST39 | — | — | 19 | 34 | — | 34 | 3 | 9 | 12 | 3 | tr | 3 | 21 | — | 21 | 6 | tr | — | 3 | 2 | 33 | 0.11 |
| | ST40 | — | tr | 11 | 47 | 1 | 48 | 1 | 11 | 12 | 6 | tr | 6 | 22 | — | 22 | — | tr | 2 | — | — | 21 | 0.04 |
| | ST41 | 1 | tr | 71 | 2 | — | 2 | 5 | 8 | 13 | 2 | 1 | 3 | 6 | 1 | 7 | 1 | 1 | — | tr | — | 19 | 0.17 |
| Fujikawa Formation | SH38 | — | 7 | 16 | 13 | — | 13 | 4 | 8 | 12 | 10 | 9 | 19 | 24 | — | 24 | 1 | 6 | 1 | — | 3 | 88 | 0.21 |
| | SH40 | 3 | — | 64 | 1 | — | 1 | 9 | 11 | 20 | 4 | tr | 4 | 8 | — | 8 | — | — | — | — | 1 | 14 | 0.34 |
| | SH41 | — | 1 | 74 | 3 | — | 3 | 4 | 7 | 11 | 2 | 2 | 4 | 6 | — | 6 | tr | — | — | — | tr | 27 | 0.95 |
| | SH51 | — | — | 81 | 1 | — | 1 | 4 | 7 | 11 | 3 | — | 3 | 4 | — | 4 | — | tr | — | — | — | 11 | 0.63 |
| | SH60 | — | tr | 67 | 4 | tr | 4 | 4 | 10 | 14 | 2 | — | 2 | 8 | — | 8 | tr | — | tr | — | 2 | 21 | 0.64 |
| | SH62 | — | tr | 15 | 18 | 4 | 22 | — | 11 | 11 | 3 | 1 | 4 | 43 | 1 | 44 | — | 1 | tr | — | — | 34 | 0.08 |
| | SH63 | 3 | 3 | 23 | 13 | 5 | 18 | 1 | 6 | 7 | 6 | 2 | 8 | 31 | — | 31 | — | 3 | 2 | 2 | — | 52 | 0.04 |
| | SH64 | — | 2 | 19 | 36 | 10 | 46 | 1 | 6 | 7 | 1 | — | 1 | 16 | tr | 16 | 3 | 2 | 1 | — | 3 | 44 | 0.12 |
| | SH66 | 1 | — | 72 | 6 | — | 6 | 4 | 9 | 13 | tr | 1 | 1 | 3 | — | 3 | — | — | 1 | — | tr | 32 | 0.35 |
| | SH67 | 2 | 1 | 63 | 5 | 1 | 6 | 7 | 15 | 22 | 1 | 1 | 2 | 3 | tr | 3 | — | — | — | 1 | — | 28 | 0.12 |
| | ST10U | 1 | 1 | 32 | 9 | 4 | 13 | — | 7 | 7 | 7 | 2 | 9 | 34 | — | 34 | — | — | 4 | — | — | 89 | 0.56 |
| | ST11 | tr | 3 | 15 | 17 | 4 | 21 | 2 | 6 | 8 | 4 | 1 | 5 | 25 | — | 25 | 2 | — | 3 | — | 17 | 42 | 0.14 |
| | ST12 | 1 | 3 | 22 | 24 | 5 | 29 | — | 11 | 11 | 4 | — | 4 | 22 | — | 22 | 2 | 2 | 3 | 1 | 1 | 49 | 0.08 |
| | ST21 | — | 11 | 45 | tr | — | tr | — | — | — | — | — | — | 1 | — | 1 | 41 | tr | — | 1 | — | 56 | 4.29 |
| | ST22 | 3 | 7 | 63 | 5 | — | 5 | 2 | 10 | 12 | — | 1 | 1 | 9 | — | 9 | — | — | — | — | 1 | 9 | 0.69 |

Note—The percentage of opaques is given by the proportion to the total number frequency and that of each non-opaque mineral is calculated by making non-opaques 100 percent. The content of heavy minerals is shown in weight percentage.

green and brown ones, of which the latter variety is prevalent over the former in the examined specimens. Granular or irregularly fractured grains occur frequently and prismatic ones are rarely met with.

(6) Chlorite: This mineral is commonly observed in most of the specimens, and occupies 3 percent on the average of the total non-opaques. Most of the grains show pale to deep green in color, and irregular plates in shape. Aggregates of fibrous habits are sometimes observed. Through the thin-section observation chlorite occurs frequently as matrix-constituting mineral, and consequently most of this grains are considered to be of authigenic rathar than detrital fragments.

(7) Amphibole: This mineral occurs sparsely, and averages about 1 percent of the total non-opaques. It seems to be composed chiefly of common hornblende, though more accurate discrimination is hardly concluded. Most of its grains show elongated platy cleavage flakes with irregular termination. Greenish and brownish varieties are observable, but the former is rare. They are of distinct pleochroism.

(8) Mica: This group is distinguished into biotite and muscovite. The grains of the two minerals show platy flakes. In the thin-section study the content of biotite is larger in the specimens of the Hoji and Fujikawa Formations than in those of the Tatsukawa and Hanoura, but the distinctive volumetrical difference is not recognized in the heavy mineral analysis. The reason seems to depend on the fact that mica flakes are easily washed out by decantation.

3. *Stratigraphical variation of selected minerals*

The heavy minerals have been used as an extremely valuable indicator to clarify the ultimate provenance or source rocks of sandstones. As the heavy mineral assemblage is considered to be significantly influenced by depositional processes, comprising the possibility of their polycyclicity, its validity for the determination of their ultimate provenance remains open to question, unless various other ovserved facts, such as major constituents, facies change and sedimentological features, are also taken into consideration. The assemblage is, furthermore, one of the most adequate methods for making the litho-stratigraphical correlation within the basin of the same tectonotope (e.g., VAN ANDEL, 1959; PETTIJHON, 1957; GAZZI, 1965; OKADA, 1960, 1961; FUJII, 1956, 1962).

In the present case, no special mineral which characterizes a particular formation is found at all and hence the sandstones of the four formations seem to be of quite similar assemblage to one another. As shown in Fig. 11 and Table 11, however, the average content of each heavy mineral in the relative number frequency of non-opaques seems to be more or less different among the four samples. To understand the stratigraphical variation of heavy mineral contents, the same statistical test as used in major constituents is carried out. The result is shown in Table 12.

(1) Amphibole: The sample mean and standard deviation of this mineral are larger in the sample of the Hanoura Formation than in those of the other three formations. This fact is probably due to the presence of an exceptional specimen of

TABLE 11. MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF HEAVY MINERAL COMPOSITION IN EACH FORMATION

| | Tatsukawa | | | | Hanoura | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean (%) | (CI) | SD | CV | Mean (%) | (CI) | SD | CV |
| Amphibole | 1.1 | (±0.6) | 1.2 | 1.1 | 2.3 | (± 2.5) | 4.8 | 2.1 |
| Chlorite | 2.5 | (±2.8) | 6.1 | 2.4 | 3.0 | (± 1.7) | 3.2 | 1.1 |
| Epidote Group | 26.9 | (±8.6) | 18.6 | 0.7 | 35.0 | (±11.4) | 21.5 | 0.6 |
| Garnet | 24.8 | (±6.1) | 13.2 | 0.5 | 24.4 | (± 9.4) | 17.7 | 0.7 |
| Orthopyroxene | 1.6 | (±0.8) | 1.8 | 1.1 | 1.7 | (± 0.7) | 1.4 | 0.8 |
| Clinopyroxene | 10.9 | (±2.5) | 5.4 | 0.5 | 9.0 | (± 1.8) | 3.4 | 0.4 |
| Tourmaline | 3.3 | (±1.7) | 3.7 | 1.1 | 2.6 | (± 1.2) | 2.3 | 0.9 |
| Zircon | 20.3 | (±5.5) | 12.0 | 0.6 | 13.4 | (± 4.3) | 8.1 | 0.6 |
| No. of specimens | | | 21 | | | | 16 | |
| | Hoji | | | | Fujikawa | | | |
| | Mean (%) | (CI) | SD | CV | Mean (%) | (CI) | SD | CV |
| Amphibole | 1.1 | (±0.5) | 1.5 | 1.4 | 1.0 | (± 0.7) | 1.3 | 1.3 |
| Chlorite | 2.8 | (±1.5) | 4.1 | 1.5 | 2.7 | (± 1.8) | 3.2 | 1.2 |
| Epidote Group | 58.8 | (±9.0) | 24.9 | 0.4 | 44.7 | (±13.9) | 25.2 | 0.6 |
| Garnet | 6.3 | (±3.6) | 9.9 | 1.6 | 12.5 | (± 7.1) | 12.9 | 1.0 |
| Orthopyroxene | 3.5 | (±1.0) | 2.7 | 0.8 | 2.8 | (± 1.5) | 2.7 | 1.0 |
| Clinopyroxene | 6.1 | (±1.1) | 3.0 | 0.5 | 8.3 | (± 1.9) | 3.4 | 0.4 |
| Tourmaline | 5.0 | (±1.8) | 4.9 | 1.0 | 4.5 | (± 2.6) | 4.7 | 1.0 |
| Zircon | 9.9 | (±3.5) | 9.8 | 1.0 | 15.9 | (± 7.4) | 13.4 | 0.8 |
| No. of specimens | | | 32 | | | | 15 | |

Denotations are identical with those of Table 7.

ST34 from the Hanoura which occupies 20 percent amphibole content in the number frequency of non-opaques, while its content reaches only a few percent in all the other examined sandstones. Of course, the significant difference of the population variance is revealed statistically when the sample of the Hanoura is compared with the other three. However, no difference is estimated to be significant at less than 5 percent risk level between the four population means. Therefore, its volumetrical relation is expressed as Ts=Hn=Hj=Fj.

(2) Chlorite: The sample of the Tatsukawa Formation has larger values in the standard deviation than those of the other three formations. This reason may be due to the extremely large amount, about 30 percent, in the specimen of SH21. The significant difference of the population variance is statistically estimated in the associations of the samples of the Tatsukawa and the others. In any pair of the four samples, however, no significant difference of the population mean is estimated at all. Hence, the volumetrical relation is shown as Ts=Hn=Hj=Fj.

(3) Epidote group: As to this mineral group, the four samples have almost equal

coefficients of variation and have somewhat different sample means from one another. The difference of the population variance is not estimated to be significant at less than 5 percent risk level in any pair of the four samples, but the population mean difference is statistically significant in the three pairs of Ts-Hj, Ts-Fj and Hn-Hj. Consequently, its volumetrical relation in the number frequency of non-opaques is expressed as Ts<Hj, Ts<Fj and Hn<Hj.

(4) Garnet: The four samples show considerably different values of the standard deviation, but the statistically significant difference of the population variance is revealed only in one pair of Hn-Hj. The population mean difference is considered to be significant at less than 5 percent risk level in the four pairs of Ts-Hj, Ts-Fj, Hn-Hj and Hn-Fj, and consequently its volumetrical relation is represented as Ts=Hn>Hj=Fj.

(5) Orthopyroxene: The four pairs of Ts-Hj, Ts-Fj, Hn-Hj and Hn-Fj display the statistically significant difference of the population variance. The population mean is significantly differentiated at less than 5 percent risk level in the pairs of Ts-Hj and Hn-Hj. As for the population mean in the number frequency of non-opaques, it is safely said that Hj has a larger amount of this mineral than Ts and Hn, and that Fj has no appreciable difference in comparison with the other three samples.

(6) Clinopyroxene: The coefficients of variation in the four samples have almost equal values, and the variation in this mineral content is fairly small in every sample. The four pairs of Ts-Hn, Ts-Hj, Ts-Fj and Hn-Fj show the statistically significant difference of the population variance. The population mean difference is revealed to be significant at less than 5 percent risk level in the three pairs of Ts-Hj, Hn-Hj and Hj-Fj, and hence the volumetrical relation is shown as Ts=Hn=Fj>Hj.

(7) Tourmaline: The samples of the four formations have almost equal values in the coefficient of variation. The statistical significance of the population variance is revealed when the sample of the Hanoura Formation is compared with the other three. The population mean difference is estimated to be significant at less than 5

Table 12. Statistical Comparison of Heavy Mineral Composition between the Lower Cretaceous Formations

| | Tatsukawa-Hanoura | | | | | Tatsukawa-Hoji | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $F_0$ | Sig | d | $t_0$ | Sig | $F_0$ | Sig | d | $t_0$ | Sig |
| Amphibole | 16.43 | ** | 1.2 | 0.97 | NS | 1.45 | NS | 0.1 | 0.24 | NS |
| Chlorite | 3.55 | ** | 0.5 | 0.32 | NS | 2.21 | * | 0.3 | 0.19 | NS |
| Epidote Group | 1.34 | NS | 8.1 | 1.65 | NS | 1.79 | NS | 31.9 | 5.02 | ** |
| Garnet | 1.80 | NS | 0.4 | 0.08 | NS | 1.78 | NS | 18.5 | 5.85 | *** |
| Orthopyroxene | 1.60 | NS | 0.1 | 0.18 | NS | 2.28 | * | 1.9 | 3.08 | ** |
| Clinopyroxene | 2.52 | * | 1.9 | 1.30 | NS | 3.24 | ** | 4.8 | 3.71 | *** |
| Tourmaline | 2.58 | * | 0.7 | 0.70 | NS | 1.75 | NS | 1.7 | 1.36 | NS |
| Zircon | 2.20 | NS | 6.9 | 1.98 | NS | 1.50 | NS | 10.4 | 3.46 | ** |
| Degree of freedom | | | 35 | | | | | 51 | | |

TABLE 12. (Continued)

| | Tatsukawa-Fujikawa | | | | | Hanoura-Hoji | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $F_0$ | Sig | d | $t_0$ | Sig | $F_0$ | Sig | d | $t_0$ | Sig |
| Amphibole | 1.21 | NS | 0.1 | 0.24 | NS | 10.00 | ** | 1.2 | 0.97 | NS |
| Chlorite | 3.65 | ** | 0.2 | 0.12 | NS | 1.65 | NS | 0.2 | 0.17 | NS |
| Epidote Group | 1.84 | NS | 17.8 | 2.44 | * | 1.34 | NS | 23.8 | 3.26 | ** |
| Garnet | 1.05 | NS | 12.3 | 2.78 | ** | 3.19 | ** | 18.1 | 3.80 | ** |
| Orthopyroxene | 2.28 | * | 1.2 | 1.50 | NS | 3.65 | ** | 1.8 | 3.03 | ** |
| Clinopyroxene | 2.52 | * | 2.6 | 1.76 | NS | 1.35 | NS | 2.9 | 3.01 | * |
| Tourmaline | 1.36 | NS | 1.2 | 0.85 | NS | 4.35 | ** | 2.4 | 2.30 | * |
| Zircon | 1.25 | NS | 4.4 | 1.03 | NS | 1.46 | NS | 3.5 | 1.23 | NS |
| Degree of freedom | | | 34 | | | | | 46 | | |

| | Hanoura-Fujikawa | | | | | Hoji-Fujikawa | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $F_0$ | Sig | d | $t_0$ | Sig | $F_0$ | Sig | d | $t_0$ | Sig |
| Amphibole | 13.53 | ** | 1.3 | 1.04 | NS | 1.35 | NS | 0.1 | 0.22 | NS |
| Chlorite | 1.00 | NS | 0.3 | 0.26 | NS | 1.65 | NS | 0.1 | 0.08 | NS |
| Epidote Group | 1.37 | NS | 9.7 | 1.48 | NS | 1.02 | NS | 14.1 | 1.80 | NS |
| Garnet | 1.88 | NS | 11.9 | 2.12 | * | 1.70 | NS | 6.2 | 1.81 | NS |
| Orthopyroxene | 3.65 | ** | 1.1 | 1.40 | NS | 1.00 | NS | 0.7 | 0.83 | NS |
| Clinopyroxene | 1.00 | NS | 0.7 | 0.56 | NS | 1.29 | NS | 2.2 | 2.26 | * |
| Tourmaline | 4.17 | ** | 1.9 | 1.41 | NS | 1.09 | NS | 0.5 | 0.46 | NS |
| Zircon | 2.73 | * | 2.5 | 0.62 | NS | 1.87 | NS | 6.0 | 1.74 | NS |
| Degree of freedom | | | 29 | | | | | 45 | | |

Denotations are identical with those of Table 8.

percent risk level in only one pair of Hn-Hj with the volumetrical relation of Hn <Hj.

(8) Zircon: As to this mineral, the difference of the population variance is estimated to be significant at less than 5 percent risk level in the two pairs of Ts-Hn and Hn-Hj. The statistical significance of the population mean is revealed in the pair of Ts-Hj, of which the volumetrical relation in the relative number frequency of non-opaques is shown as Ts>Hj.

From these results the following fact is recognized. The samples of the Tatsukawa and Hanoura Formations have almost equal proportion of heavy mineral composition. The greatest compositional change is recognized between the samples of the Hanoura and Hoji Formations, and besides the compositional change is also appreciated slightly between the samples of the Hoji and Fujikawa Formations. Thus, the mode of the compositional changes in heavy minerals among the four samples corresponds well with the result which was obtained from the statistical analysis on the major mineral composition.

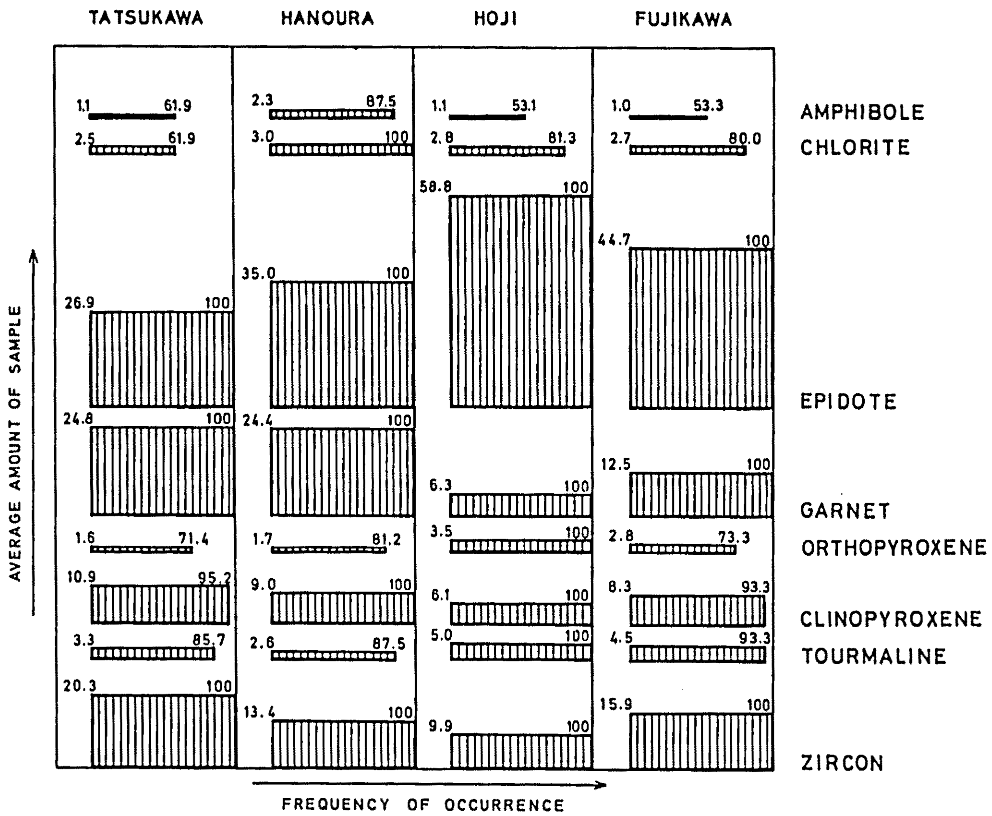


Fig. 11. Stratigraphical variation of heavy mineral composition in the Lower Cretaceous sandstones of the Katsuuragawa valley. The left-hand values show the frequency of occurrence, i.e. the percentage of the number of specimens in which the mineral occurs, and the right-hand values show the average percentage amount of each sample in which the mineral occurs. Therefore, the rectangle area is proportional to the average percentage amount in the total specimens investigated.

## IV. Sedimentological Remarks

### A. Provenance

One of the most important objectives in the sandstone petrography is to find a clue to the problem of source rocks on the basis of heavy minerals and some major constituents. Its settlement is not so easily attained because many problems on the origin of minerals remain unsolved yet, and besides the polycyclicity of them from older sedimentary rocks makes the provenance problem to be more complicated, as stated in the preceding page. However, a close investigation of the mineral composition of sandstones should be very useful for tracing back to their adequate provenance and for evading an introduction to inapposite source rocks. The distinct changes of the mineral composition may provide useful information on the vicissitudes of provenance.

Some comments on the possible source rocks of the Lower Cretaceous formations in the Katsuuragawa valley are given below. The inference is drawn not only from the mineral composition of sandstones but also from the kind of pebbles of conglomerates.

1) Tatsukawa Formation

The pebbles of conglomerates from this formation are composed mainly of chert, and subordinately of mudstone (or clayslate ?), limestone, sandstone and basic volcanic (mostly basaltic) rocks. This composition is almost equal to that of the rock fragments of sandstones. These detritus can be traced back to older sedimentaries and basic volcanics. These rocks are at present exposed in two areas; one is the Paleozoic Chichibu terrain in which the Cretaceous strata are developed, and the other is the Triassic to Jurassic Sambosan terrain which is situated in the southern part of the Chichibu terrain. With the most possibility, it is inferred that those detritus were derived from the Paleozoic Chichibu Supergroup which is characterized with eugeosynclinal deposits. As to the altered basic volcanics, the Mikabu green rocks may have contributed to them at least partly, but the precise decision cannot be made out.

According to KRUMBEIN and PETTIJHON (1938), PETTIJHON (1957), MILNER (1962b), TICKELL (1965) and others, the following heavy mineral suites may be ideally constructed;

suite (1)......Anatase, Apatite, Biotite, Hornblende, Muscovite, Rutile, Tourmaline, Zircon

suite (2)......Anatase, Hornblende, Pyroxene, Rutile, Zircon

suite (3)......Anatase, Biotite, Epidote, Garnet, Hornblende, Muscovite, Rutile, Tourmaline

suite (4)......reworked, rounded minerals

The suite (1), (2), (3) and (4) suggest the acid igneous, basic igneous, metamorphic and older sedimentary source rocks, respectively. As stable mineral grains are predominant in quantity and there are no sound igneous and metamorphic fragments in sandstones and conglomerates, most of the heavy minerals may be considered to have been drawn from older sedimentaries of the Chichibu terrain. However, the existence of unstable minerals such as hornblende and biotite which are fresh in appearance suggests the contribution of granitic rocks as source rocks at least. This inference is reinforced by the existence of fresh grains of microcline, perthite and albite-twinned plagioclase in most of sandstones. Furthermore, a considerable amount of epidote may be connected with granitic rocks, as suggested by FUJII (1956) and OKADA (1961). Although the Ryoke gneiss complex, which is extensive to the north of the Median tectonic line, and the Mitaki igneous complex, which is accompanied with the Terano metamorphic rocks and the Silurian strata along the Kurosegawa tectonic zone (ICHIKAWA and others, 1956), may be taken up as the possible source of granitic rocks, the precise judgement cannot be decided in the present state of knowledge.

A considerable amount of undulose quartz may be derived from metamorphosed rocks in part at least, but no sound evidence has been obtained. Although the Sambagawa crystalline schists are extensively developed at present in the northern part of the Chichibu terrain, any rock fragments or pebbles and heavy minerals which could support its exposure are not known in the sandstones and conglomerates of this formation at all.

2) Hanoura Formation

The rock fragments of sandstones and the pebbles of conglomerates in this formation are composed of the quite same kinds of rocks as those in the Tatsukawa Formation. The conglomerates of the Hanoura Formation are characterized with the common occurrence of limestone pebbles in which the Paleozoic fusulinids are sometimes found. It is, therefore, inferred that the Paleozoic sedimentaries and basic volcanics of the Chichibu terrain were mostly contributed as the source rocks during sedimentation of this formation. Judging from the heavy mineral suites and major constituents, the igneous rocks as suggested in the Tatsukawa Formation may have been also contributed as the source rocks at least partly.

As confirmed by the statistical analysis, the compositional change of the major and accessory minerals in their population means is not estimated at all between the sandstones of the Tatsukawa and Hanoura Formations. There is, of course, no remarkable difference between the two formations in the indices of the provenance factor and mineralogical maturity and the containing percentage of heavy minerals. These facts suggest probably that no significant change of the provenance took place between the two formations, though they are clearly distinguishable from each other in their sedimentary environments.

3) Hoji Formation

The rock fragments of sandstones and the pebbles of conglomerates in this formation are also mainly composed of the Paleozoic sedimentaries and basic volcanics. However, in the common influx of granitic pebbles, the Hoji Formation is distinguished from the other three formations. Judging from this fact, it is likely inferred that granitic rocks as well as the Paleozoic rocks became to play an important role as the source rocks in this stage. This inference does not seem to be always reflected on the quality of minerals in sandstones. In reference to heavy minerals, for example, there is no special mineral which characterizes the Hoji Formation, and then the same suites may be conceptually constructed as done in the Tatsukawa and Hanoura Formations. However, the most remarkable change of major and accessory minerals in their quantity is significantly appreciated between the Hanoura and Hoji Formations, as confirmed statistically and clearly shown in the lithological types of sandstones. This significant change of the quantity of mineral composition suggests probably a change of source rocks in the background rather than that of sedimentary environment.

As the evidence that granitic rocks predominated as the source rocks in this stage, the significant increase of the contents of orthoclase and plagioclase should be taken up, and most of their grains become more fresh in appearance in the sandstones of this formation than in those of the Tatsukawa and Hanoura Formations. Biotite occupies a considerable amount as a constituent of the rock fragments, though this was not confirmed in the heavy mineral analysis. Besides, a remarkable rise of epidote in amount may support the important role of granitic rocks in the provenance, as suggested in the preceding page.

A part of undulose quartz grains may have been derived from some metamorphic rocks, and besides the heavy mineral suite which characterizes metamorphics may be constructed in this formation as well as in the other formations, though available evidence is by no means decisive. As far as the mineral composition of sandstones and the kind of pebbles of conglomerates are concerned, however, the crystalline schists that could indicate the Sambagawa metamorphic rocks do not seem to have been exposed in this stage.

4) Fujikawa Formation

The rock fragments of sandstones and the pebbles of conglomerates in this formation are also composed of sedimentaries and basic volcanics, which seem to have been inherited from the Paleozoic rocks of the Chichibu terrain. Although granitic pebbles were not found in the conglomerates of this formation, it is considered on the basis of the mineral composition of sandstones that one of the major source rocks was granitic rocks in this stage.

In comparison with the Tatsukawa and Hanoura Formations, the sandstones of this formation as well as the Hoji are characterized by the feldspathic type, and show a remarkable difference of the mineral composition in the population means. Compared with the sandstones of the Hoji Formation, the significant volumetrical change is appreciated in the increase of feldspar and the decrease of quartz. Such a change might be affected by a change of a depositional environment. In this case, however, judging from the gross lithological features of sandstone-bodies in the Hoji and Fujikawa Formations which are closely similar to each other, it is better to infer that this change owed more strongly to a change in the provenance. In other words, it is preferably considered that granitic rocks played a more important role as the source rocks during the sedimentation of this formation.

B. Sedimentation and Tectonics

1) Tatsukawa Formation

It has been considered that the Paleozoic Chichibu Supergroup which was formed under an eugeosynclinal condition during the Paleozoic ages had been already uplifted in the Pre-Triassic age with an intense and extensive orogenic movement (Ichikawa and others, 1953). As far as the present basin is concerned, this upheaved terrain contributed seriously as the basement and provenance of the Cretaceous deposits. The basin-making depression of this terrain has been considered to have taken place under influence of an orogeny in the Oga phase of the Sakawa orogenic cycle (KOBAYASHI, 1941; MATSUMOTO, 1947). On the basis of the gross lithological features which are remarkably changeable in lateral and vertical directions, this formation was probably formed in a very undulating basin.

Until the Cretaceous sedimentation bigins, the uplifted terrain retained an upland. Some region of this upland probably underwent lateritization under favorable climate condition or it produced some reddish soils under oxidizing condition through a considerably long age. This seems to be represented by the reddish sandstone and conglomerate at the basal part of this formation. Hematitic opaque grains occur abundantly, and most of the sandstone grains are coated with their red-pigment. Besides, all of basic volcanic pebbles in the conglomerate are oxidized and characterized by red-coloration. The clastics are much ill-sorted, and are of very angular grains or pebbles. This fact may support that they were deposited under relatively low energy condition and the source area was not in a distance. In the succeeding part sandstones generally become bluish grey in color and altered basic volcanic pebbles show also bluish color. It may indicate that eroded part of the Paleozoic rocks was reached to non-oxidized zones, and/or that the depositional site was changed from oxidizing condition to somewhat reducing one.

During the sedimentation of this formation, it is inferred that the basin itself was fluctuating rigorously, as judged from the very heterogeneous lithological characters as represented by several intercalations of conglomerate. The fluctuation reflects on the property of sandstones. They comprise lithic arenite, feldspathic arenite, lithic wacke and feldspathic wacke, of which the former two show a high textural maturity while the latter two display a very low textural one. The two sandstone types which indicate different energy conditions appear in the stratigraphical sequence at random.

The fossil evidence undoubtedly indicates that the present basin was restricted in a non-marine environment in this stage. This may suggest that a certain barrier, which is called the "Ryoseki barrier" by KOBAYASHI (1941), distributed in the southern part of the present area and prevented the interfusion of open sea water. It has been inferred by YAMASHITA (1957, 1958) that the uplift of the complex rocks along the Kurosegawa tectonic zone had played the role of such a barrier.

2) Hanoura Formation

In this stage the Cretaceous basin extended northwards, and this formation abutted against the Paleozoic rocks, overlapping the Tatsukawa Formation. The deposits of this abutting part are composed of much ill-sorted conglomerate and texturally immature sandstone. They are characterized by red-coloration, and it is inferred that these red beds were formed in a characteristic environment as interpreted in the reddish detritus of the Tatsukawa Formation. Non-marine mollusks are obtained from these sediments. Except for the abutting part, such a red bed is not developed.

The lower half of the Hanoura Formation is composed of medium- to fine-grained sandstones, most of which belong to the lithic wacke though the arenite type occurs in coarse-grained sandstones. However, the sandstones of the Hanoura Formation are quite similar to those of the Tatsukawa Formation in the composition of major and accessory minerals, as confirmed by statistical analysis. Besides, the serious difference of the textural property is hardly estimated between them, though the sandstones of the Hanoura Formation seem to be somewhat better sorted in comparison with those of the Tatsukawa. These facts suggest that any intense tectonism which could give rise to a remarkable change of the provenance did not take place in the interval between the two formations and support that the depositional site changed gradually from non-marine to shallower marine environment.

The upper half of this formation becomes to be occupied with fine-grained sediments of siltstone and shale, which must have been deposited in the relatively offshore environment of rather calm-currents, as shown by the fossils of open-sea element.

Thus, in this stage marine-water became to transgress over the uplift of the "Ryoseki barrier", and the Cretaceous basin became to face to open-sea. This may be mainly resulted by the gradual subsidence in the depositional site, as judged from the gross lithological features in addition to the sandstone property.

3) Hoji Formation

This formation is composed mainly of massive and medium-grained sandstones. A few thin beds of coal or coaly shale and conglomerate are sometimes intercalated. Judging from the gross lithological features and the fossil evidence, the depositional site was considerably fluctuated in the transitional zone from prodeltaic or littoral to non-marine environment. Thus this formation is characterized by a somewhat regressive facies in comparison with the Hanoura Formation. In this stage, however, the Cretaceous basin itself was extended further northwards and the Hoji Formation overstepped the Hanoura Formation.

The sandstones of this formation are chiefly represented by feldspathic wacke, and the abrupt change of the mineralogical composition of sandstones is recognized from the Hanoura to the Hoji. In comparison with those of the Hanoura Formation, the sandstones of the Hoji Formation have a considerably low index of the mineralogical maturity. The abrupt change of this index may be brought forth by the rapid accumulation of sand-clastics. However, the textural maturity is somewhat higher in the sample of the Hoji Formation than the others, and therefore the present sandstones seem to have been deposited in a relatively higher energy condition than the comparing ones. It is considered that the abrupt change of major and accessory minerals, which is especially expressed in the large arise of feldspar content, was mainly reflected by the intense change in the provenance rather than the slight change of depositional condition in the basin.

In the interval between the Hanoura and Hoji Formations a fairly remarkable tectonic uplift took place, and contemporaneously some granite rocks were exposed extensively, as considered above. The tectonic movement in this stage seems to correspond with the movement in the Oshima phase of the Sakawa orogenic cycle (Kobayashi, 1941; Matsumoto, 1947).

4) Fujikawa Formation

In this stage the Cretaceous basin was more extended northwards, and the Fujikawa Formation, overlapping the Hoji Formation, abutted against the Paleozoic Chichibu Supergroup. However, the stratigraphical relation between the Hoji and Fujikawa Formations is conformable.

The lower half of this formation is composed of massive and medium-grained sandstones with the basal conglomerate or very coarse-grained sandstone. They are mostly characterized by feldspathic wacke as in the case of the Hoji Formation. As is discussed in the preceding page on the basis of the compositional change in some minerals, granitic rocks played a more important role as source rocks in this stage than in the preceding stage. However, this does not always mean that an intense movement occurred in the source area. In the interval between the Hoji and Fujikawa Formations, a tectonic movement was not intense. Besides, the environment in the depositional site is closely similar to that of the Hoji Formation. The textural immaturity suggests that a comparatively low energy environment was prevailing in general.

Downwarp proceeded gradually, and the upper half of this formation was formed in a phase of marine inundation. The beds of black shale or mudstone are formed thickly and monotonously, though a few thin beds of sandstone are intercalated. It is considered that these deposits were laid offshore in the environment of rather calm-currents.

### C. Comparison with the Lower Cretaceous Sandstones of the Yatsushiro Area

It has been considered that the Cretaceous deposits in the Yatsushiro area of Kyushu were formed under the similar tectono-environment to those of the Katsuuragawa basin. The lithological and biological features in the two basins resemble each other. The Lower Cretaceous System in the Yatsushiro area is divided into the four formations, namely, the Kawaguchi, Hachiryuzan, Hinagu and Yatsushiro Formations in ascending order, on the basis of a major cyclicity, and they represent the Ryoseki Group, the Lower Monobegawa Group, the lower half of the Upper Monobegawa Group and the upper half of the Upper Monobegawa Group, respectively. However, there are some discrepancies in the correct time-stratigraphical correlation of each cycle between the two areas, as pointed out by Matsumoto (1967).

Fujii (1956) has discussed in detail on the Cretaceous sedimentation in the Yatsushiro area through his sandstone petrography. To understand the sedimentological character in the Chichibu terrain during the Lower Cretaceous ages, I attempt here to compare the sandstone property and the historical change of sedimentation in the Katsuuragawa valley with those in the Yatsushiro area. The following prominent points may be enumerated.

(1) As compared with the sandstones of the Katsuuragawa valley, the Lower Cretaceous sandstones of the Yatsushiro area generally have a smaller amount of rock fragments (including chert) and the majority fall in the feldspathic field in OKADA's (1968a) classification diagram (Fig. 12). Although they are characterized by the wacke type with more than 15 percent matrix content for the most part (Fig. 13), the sandstones of the Yatsushiro area must not be referred to the greywacke associations, as can be judged from the gross lithological and biological features. In this point the sandstones in the two area are similar.

(2) There is a close resemblance in the major components and heavy mineral associations between the sandstones of the two areas, except for the characteristic occurrence of kyanite and schist-fragments in the Yatsushiro area.

(3) The source rocks of the clastic detritus in the Yatsushiro area as well as in the Katsuuragawa valley were composed of older sedimentaries, basic volcanics, granitic rocks and metamorphics. These source rocks had been always contributed to the Lower Cretaceous deposits of the whole succession, but the vicissitudes of them occurred in harmony with the cyclicity of sedimentation. This fact is reflected on the volumetrical change of many mineral constituents in the Katsuuragawa valley, as confirmed statistically, while in the Yatsushiro area this is mainly represented by a rhythmic variance of feldspar content.

(4) The change of the provenance from the Kawaguchi to the Hachiryuzan Formation in the Yatsushiro area is not significantly appreciated and a serious tectonic movement does not seem to have taken place in the transitional age. This point

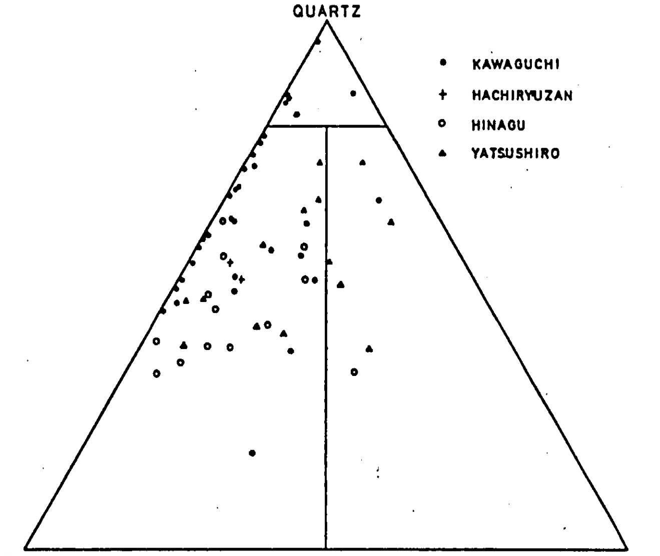


FIG. 12. Compositional diagram of the Lower Cretaceous sandstones in the Yatsushiro area. (Data from FUJII, 1956).

corresponds well with the relation between the Tatsukawa and Hanoura Formations in the Katsuuragawa valley. From the Hachiryuzan to the Hinagu Formation a considerable change of the provenance seems to have taken place, though this was not pointed out by FUJII (1956). The Hinagu Formation is characterized by the occurrence of granitic pebbles in conglomerates, and by a greater amount of feldspar in sandstones, if compared with the lower two formations. Judging from this point of view, the petrographical relation between the Hachiryuzan and Hinagu Formations in the Yatsushiro area may be in harmony with that between the Hanoura and Hoji Formations in the Katsuuragawa valley, though there are some discrepancies in the time-stratigraphical correlation and also in the environmental features between the two basins. The most remarkable change of the provenance in the Yatsushiro area has been shown between the Hinagu and Yatsushiro Formations by FUJII (1956, p. 23, fig. 8), and a remarkable unconformity has been recognized by MATSUMOTO and KANMERA (1964) and others. However, such an intense movement in this stage is not displayed in the Katsuuragawa valley.

The essential features of the sandstone properties as well as of the gross litho- and bio-facies are common to the Katsuuragawa and Yatsushiro basins. Although it is presumed that the two basins were developed with a close resemblance in major features in a probably related tectono-environment during the Lower Cretaceous time, they show some diversities in the mode of change of sedimentation and tectonism. As to this point, further comparative works in many Cretaceous basins of the Chichibu terrain would be needed.

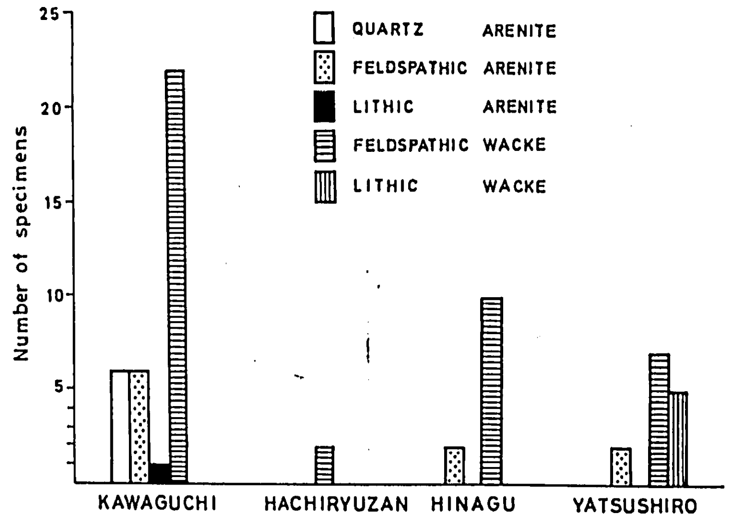


FIG. 13. Number frequency of lithological types in the Lower Cretaceous sandstones of the Yatsushiro area. (Data from FUJII, 1956).

## V. CONCLUSIONS

The Lower Cretaceouce System in the Katsuuragawa valley of eastern Shikoku is divided into the Tatsukawa, Hanoura, Hoji and Fujikawa Formations in ascending order, each of which represents a major cycle of sedimentation. In this paper the Lower Cretaceous sandstones are described in detail on grain-size, major constituents and heavy minerals as one of the effectual means to make clear the sedimentological character of the strata. Furthermore, the sedimentological problem is especially focused on the point how those properties change through the above four cycles.

Although the examined sandstones are classified into nine textural types on the basis of the evaluation of size parameters, no remarkable difference between four formations is appreciated in the frequency. They belong mostly to moderately sorted sandstones, but if the matrix content is taken into consideration, they generally belong to texturally immature and considerably ill-sorted ones. Each sample from a formation, which represents a particular sedimentary environment, does not clearly show a definite relationship between size parameters themselves and between size parameters and mineral composition. This fact may show that the character of size parameters is sensitively controled by various sedimentary processes rather than by sedimentary environments. That is to say, various sandstones which were formed through different processes are contained even in a limited formation.

The Lower Cretaceous sandstones are classified into four lithological types, according to OKADA's (1968a) scheme of classification based on the major framework constituents. The samples of the Tatsukawa and Hanoura Formations are characterized by the lithic wacke type, and those of the Hoji and Fujikawa Formations by the feldspathic wacke type, though each sample of the four formations comprises the arenite types.

It is presumed that the clastic detritus of the Lower Cretaceous formations were predominantly derived from older sedimentary, basic volcanic and granitic terrains, with a smaller contribution from a metamorphic terrain, as can be judged from the heavy minerals and major constituents of sandstones and the pebbles of conglomerates. The former two are probably referred to the Paleozoic Chichibu rocks, but the ultimate sources of granitic and metamorphic rocks are not precisely decided.

Although these source rocks contributed always to the whole succession, the vicissitudes of them through the cyclic movement are proved by the stratigraphical variations of mineral composition which are tested statistically. No compositional difference between the samples of the Tatsukawa and Hanoura Formations is estimated at all. This suggests that an intense tectonic uplift did not occur at this stage too significantly to bring forth the significant change of the provenance, though their depositional environment gradually changed from non-marine to marine. The most remarkable compositional difference between the Hanoura and Hoji Formations supports that a considerable intense movement took place to expose granitic rocks extensively in the interval of them. The movement in this stage seems to correspond with the geologic movement in the Oshima phase of the Sakawa orogenic cycle (KOBAYASHI, 1941; MATSUMOTO, 1947). The contribution of granitic rocks as the source rocks became much promoted in the Fujikawa Formation, but no intense tectonism took place in the interval between them. These results on the changes of the Lower Cretaceous sedimentation support MATSUMOTO's (1947, 1954, 1963, etc.) consideration on the tectonic history of the Outer Zone of Southwest Japan in the Lower Cretaceous Period.

Taking a general view, the Lower Cretaceous sandstones were formed under the condition of normal current or wave action, as judged from the gross litho- and bio-facies, though the majority are texturally closely similar to "greywacke". They are reasonably referable to a variety of the arenite-wacke associations defined by KRUMBEIN and SLOSS (1963).

## REFERENCES CITED


AUDLEY-CHARLES, M.G. (1967): Greywackes with a primary matrix from Viqueque Formation (Upper Miocene-Pliocene), Timor. *Jour. Sed. Petr.*, **37**, (1), 5-11.

——— (1968): Greywackes with a primary matrix from the Viqueque Formation (Upper Miocene-Pliocene), Timor: Reply to discussion to Riyadh A. RAHMANI. *Jour. Sed. Petr.*, **38**, (1), 273.

BLATT, H. (1967a): Original characteristics of clastic quartz grains. *Jour. Sed. Petr.*, **37**, (2), 401-424.

——— (1967b): Provenance determinations and recycling of sediments. *Jour. Sed. Petr.*, **37**, (4), 1031-1044.

——— and CHRISTIE, J.M. (1963): Undulatory extinction in quartz of igneous and metamorphic rocks, and its significance in provenance studies of sedimentary rocks. *Jour. Sed. Petr.*, **33**, (3), 559-579.

BOKMAN, J.W. (1952): Clastic quartz particles as indices of provenance. *Jour. Sed. Petr.*, **22**, (5), 417-449.

BOSWELL, P.G.H. (1916): The application of petrological and quantitative methods to stratigraphy. *Geol. Mag.*, [N. S.], Decade **6**, (3), 105-111; *Ibid.*, (4), 163-169.

CHAYES, F. (1949): A simple point-counter for thin-section analysis. *Am. Miner.*, **34**, (1), 1-11.

CUMMINS, W.A. (1962): The greywacke problem. *L'pool Manch. Geol. Jour.*, **3**, Pt. 1, 51-72.

DAPPLES, E.C., KRUMBEIN, W.C. and SLOSS, L.L. (1953): Petrographic and lithologic attributes of sandstones. *Jour. Geol.*, **61**, (4), 291-317.

DIXON, W.J. and MASSEY, F.J. JR. (1957): *Introduction to statistical analysis.* McGraw-Hill, New York, 638 pp.

FOLK, R.L. (1954): The distinction between grain size and mineral composition in sedimentary-rock nomenclature. *Jour. Geol.*, **62**, (4), 344-359.

——— and WARD, W.C. (1957): Brazos River bar: a study in the significance of grain-size parameters. *Jour. Sed. Petr.*, **27**, (1), 3-27.

FRIEDMAN, G.M. (1958): Determination of sieve-size distribution from thin-section data for sedimentary petrological studies. *Jour. Geol.*, **66**, (4), 394-416.

——— (1961): Distinction between dune, beach, and river sands from their textural characteristics. *Jour. Sed. Petr.*, **31**, (4), 514-529.

——— (1962): Comparison of moment measures for sieving and thin-section data in sedimentary petrological studies. *Jour. Sed. Petr.*, **32**, (1), 15-25.

FRIEND, P.F., HARLAND, W.B. and HUDSON, J.D. (1963): The Old Red Sandstone and the Highland Boundary in Arran, Scotland. *Trans. Edinb. Geol. Soc.*, **19**, Pt. 4, 363-425.

FÜCHTBAUER, H. (1967): Die Sandsteine in der Molasse nördlich der Alpen. *Geol. Rundsch.* **Bd. 56**, 266-300.

FUJII, K. (1956): Sandstones of the Mesozoic formations in the Yatsushiro district, Kumamoto Prefecture, Kyushu, Japan (in Japanese). *Jour. Geol. Soc. Japan*, **62**, (727), 193-211.

——— (1962): Petrography of the Upper Palaeozoic sandstones from the Yatsushiro area, Kyushu. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **12**, (3), 179-218.

GAZZI, P. (1965): On the heavy mineral zones in the geosyncline series. Recent studies in the northern Appennines, Italy. *Jour. Sed. Petr.*, **35**, (1), 109-115.

HAYAMI, I. and NAKAI, I. (1965): On a Lower Cretaceous pelecypod, "*Cyrena*" *naumanni*, from Japan. *Trans. Proc. Palaeont. Soc. Japan*, N.S., (59), 114-125.

HIRAYAMA, K., YAMASHITA, N., SUYARI, K. and NAKAGAWA, C. (1956): *Explanatory text of the geological map of Kenzan, in Tokushima Prefecture* (in Japanese). Tokushima Pref., 52 pp.

———, ———, ——— and ——— (1958): *Explanatory text of the geological map of Tomioka-Hiwasa, in Tokushima Prefecture* (in Japanese). Tokushima Pref., 24 pp.

HOEL, P. G. (1966): *Elementary statistics*. [2nd Ed.]. John Wiley & Sons, New York, 351 pp.

ICHIKAWA, K., ISHII, K., NAKAGAWA, C., SUYARI, K. and YAMASHITA, N. (1953): On "Sakashu-unconformity" (in Japanese). *Jour. Gakugei, Tokushima Univ.*, **3**, 61-74.

———, ———, ———, ——— and ——— (1956): Die Kurosegawa-Zone (Untersuchungen über das Chichibu-Terrain in Shikoku-III) (in Japanese). *Jour. Geol. Soc. Japan*, **62**, (725), 82-103.

KLEIN, G. DE V. (1963): Analysis and review of sandstone classifications in the North American geological literature, 1940-1960. *Geol. Soc. Am. Bull.*, **74**, 555-576.

KOBAYASHI, T. (1941): The Sakawa orogenic cycle and its bearing on the origin of the Japanese Islands. *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. II*, **5**, (7), 219-578.

——— (1942): On the climatic bearing of the Mesozoic floras in Eastern Asia. *Japan. Jour. Geol. Geogr.*, **18**, (4), 157-196.

——— (1954): *The origin of the Japanese Islands and the Sakawa orogenic cycle-An introduction to the regional geology of Japan* (in Japanese) [3rd Ed.]. Asakura Book Co., Tokyo, 352 pp.

KRUMBEIN, W. C. (1934): Size frequency distribution of sediments. *Jour. Sed. Petr.*, **4**, (1), 89-124.

——— (1936): Application of logarithmic moments to size frequency distribution of sediments. *Jour. Sed. Petr.*, **6**, (1), 35-47.

——— and PETTIJHON, F. J. (1938): *Manual of sedimentary petrography*. Appleton-Century-Crofts, Inc., New York, 549 pp.

——— and SLOSS, L. L. (1963): *Stratigraphy and sedimentation* [2nd Ed.]. W. H. Freeman and Co., San Francisco, 660 pp.

KRYNINE, P. D. (1940): Petrology and genesis of the Third Brasford Sand. *Penn. State Coll. Min. Ind. Exp. Sta. Bull.*, **29**, 1-134.

——— (1946): The tourmaline group in sediments. *Jour. Geol.*, **54**, (2), 65-87.

KUENEN, Ph. H. (1966): Matrix of turbidites: experimental approach. *Sedimentology*, **7**, 267-297.

MASON, C. C. and FOLK, R. L. (1958): Differentiation of beach, dune, and eolian flat environments by size analysis, Mustang Island, Texas. *Jour. Sed. Petr.*, **28**, (2), 211-226.

MATSUMOTO, T. (1947): The geologic research of the Aritagawa valley, Wakayama Prefecture-A contribution to the tectonic history of the Outer Zone of Southwest Japan (in Japanese). *Sci. Rep. Fac. Sci., Kyushu Univ., Geol.*, **2**, (1), 1-12.

——— [Ed.] (1954): *The Cretaceous System in the Japanese Islands*. Japan. Soc. Prom. Sci. Res., Tokyo, 324 pp.

——— (1963): The Cretaceous, in TAKAI, F., MATSUMOTO, T. and TORIYAMA, R. [Ed.] (1963), *Geology of Japan*. Univ. Tokyo Press, Tokyo, 279 pp.

——— (1967): The Cretaceous, in ASANO, K. and others [Ed.] (1967), *Historical Geology* Vol. 2 (in Japanese). Asakura Book Co., 317-683pp.

——— and KANMERA, K. (1964): *Hinagu: Explanatory text of the geological map of Japan* (in Japanese). Geol. Surv. Japan, 147 pp.

MATSUZAWA, I. (1931): Stratigraphy and structure in the Nakagawa district, Awa Province (in Japanese). *Jour. Geol. Soc. Japan*, **38**, (450), 140-144.

MAYER, W. (1968): The stratigraphy and structure of the Waipupa Group on the Islands of Motutapu, Rakino and the Noisies Group near Auckland, New Zealand. *Trans. R. Soc., N. Z., Geol.*, **5**, (9), 215-233.

MIKAMI, T. (1969): A sedimentological study of the Lower Permian Sakamotozawa Formation. *Mem. Fac. Sci., Kyushu Univ., Ser. D. Geol.*, **19**, (3), 331-372.

MILNER, H. B. (1962a, b): *Sedimentary Petrography* [4th revised Ed.].

Vol. 1. Methods in sedimentary petrography (1962a), 643 pp.;

Vol. 2. Principles and applications (1962b), 715 pp. George Allen & Unwin Ltd., London.

MIZUTANI, S. (1957): Permian sandstones in the Mugi area, Gifu Prefecture, Japan. *Jour. Earth Sci., Nagoya Univ.*, **5**, (2), 135-151.

——— (1959): Clastic plagioclase in Permian graywacke from the Mugi area, Gifu Prefecture, Central Japan. *Jour. Earth Sci., Nagoya Univ.*, **7**, (2), 108-136.

MOIOLA, R. J. and WEISER, D. (1968): Textural parameters: an evaluation. *Jour. Sed. Petr.*, **38**, (1), 45-53.

NAKAI, I. (1968): Cretaceous stratigraphy of the Katsuuragawa valley of Tokushima Prefecture, Shikoku-Especially on the correlation with the European standard based on ammonites (in Japanese). *Jour. Geol. Soc. Japan*, **74**, (5), 279-293.

——— and MATSUMOTO, T. (1968): On some ammonites from the Cretaceous Fujikawa Formation of Shikoku. *Jour. Sci., Hiroshima Univ., Ser. C*, **6**, (1), 1-15.

NUMANO, K. and NAKANO, M. (1965): Cretaceous System in the western part of the Katsuragawa basin, Tokushima Prefecture, Shikoku, Japan (in Japanese). *Geol. Rept., Hiroshima Univ.*, (14), 105-116.

OKADA, H. (1960): Sandstones of the Cretaceous Mifuné Group, Kyushu, Japan. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **10**, (1), 1-40.

——— (1961): Cretaceous sandstones of Goshonoura Island, Kyushu. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **11**, (1), 1-48.

——— (1966): Non-greywacke "turbidite" sandstones in the Welsh geosyncline. *Sedimentology*, **7**, 211-232.

——— (1967): Composition and cementation of some Lower Palaeozoic grits in Welsh. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **18**, (2), 261-276.

——— (1968a): Classification and nomenclature of sandstone (in Japanese). *Jour. Geol. Soc. Japan*, **74**, (7), 371-384.

——— (1968b): Notes on classification and nomenclature of sandstone (in Japanese). *Jour. Geol. Soc. Japan*, **74**, (12), 617-622.

PAGE, H. G. (1955): Phi-millimeter conversion table. *Jour. Sed. Petr.*, **25**, (4), 285-292.

PETTIJHON, F. J. (1954): Classification of sandstones. *Jour. Geol.*, **62**, (4), 360-365.

——— (1957): *Sedimentary rocks* [2nd Ed.]. Harper & Brothers, New York, 718 pp.

PITTMAN, E. D. (1963): Use of zoned plagioclase as an indicator of provenance. *Jour. Sed. Petr.*, **33**, (2), 380-386.

——— (1970): Plagioclase feldspar as an indicator of provenance in sedimentary rocks. *Jour. Sed. Petr.*, **40**, (2), 591-598.

POTTER, P. E. and SIEVER, R. (1956): Sources of basal Pennsylvanian sediments in the Eastern Interior Basin. 2. Sedimentary petrology. *Jour. Geol.*, **64**, (4), 317-335.

PUSTOWALOFF, L. W. (1955): Über sekundäre Veränderungen der Sedimentgesteine. *Geol. Rund.*, **43**, 535-550.

RAHMANI, R. A. (1968): Greywackes with a primary matrix from the Viqueque Formation (Upper Miocene-Pliocene), Timor: Comment on a paper by M. G. AUDLEY-CHARLES. *Jour. Sed. Petr.*, **38**, (1), 271-273.

ROSENFELD, M. A., JACOBSON, L. and FERM, J. C. (1953): A comparison of sieve and thin-section technique for size analysis. *Jour. Geol.*, **61**, (2), 114-132.

SAHU, B. K. (1964): Depositional mechanics from the size analysis of clastic sediments. *Jour. Sed. Petr.*, **34**, (1), 73-83.

SASAKI, K. and USHIJIMA, N. (1966): Sedimentation of graded sandstones in Shiiya and Nishiyama formations, Higashiyama oil belt, Niigata Prefecture (in Japanese). *Jour. Japan Assoc. Mineralogists, Petrologists and Petroleum Geologists*, **56**, (4), 161-182.

SAXENA, S. K. (1966): Evolution of zircons in sedimentary and metamorphic rocks. *Sedimentology*, **6**, 1-33.

SHIKI, T. (1959): Studies on sandstones in the Maizuru Zone, Southwest Japan. I. Importance of some relations between mineral composition and grain size. *Mem. Coll. Sci., Univ. Kyoto, Ser. B*, **25**, (4), 239-246.

——— (1961): Studies on sandstones in the Maizuru Zone, Southwest Japan. II. Graded bedding and mineral composition of sandstones of the Maizuru Group. *Mem. Coll. Sci., Univ. Kyoto, Ser. B*, **27**, (3), 293-308.

——— (1962): Studies on sandstones in the Maizuru Zone, Southwest Japan. III. Graywacke and arkose sandstones in and out of the Maizuru Zone. *Mem. Coll. Sci., Univ. Kyoto, Ser. B*, **29**, (4), 291-324.

SHUTOV, V. D. (1965): Review and analysis of mineralogical classification for arenaceous rocks (by the paper of American and Russian lithologists for the past twenty years) (in Russian). *Lithology and Mineral Resources*, (1), 95-112.

SOLOHUB, J. T. and KLOVAN, J. E. (1970): Evaluation of grain-size parameters in lacustrine environments. *Jour. Sed. Petr.*, **40**, (1), 81-101.

SUZUKI, K. (1941): On the Lower Cretaceous System in the western part of Hanoura-machi, Tokushima Prefecture (in Japanese). *Jour. Geol. Soc. Japan*, **48**, (568-579), 291-292.

TICKELL, F. G. (1965): *The techniques of sedimentary mineralogy.* Elsevier Publishing Co., Amsterdam, 220 pp.

TSUKANO, Z. (1931): An outline of the geology of the Katsuuragawa basin, Tokushima Prefecture (in Japanese). *Chikyu* (*The Earth*), **16**, (1), 7-22.

VAN ANDEL, TJ. H. (1959): Reflections on the interpretation of heavy mineral analyses. *Jour. Sed. Petr.*, **29**, (2), 153-163.

WEAVER, C. E. (1955): Mineralogy and petrology of the rocks near the Quardrant-Phosphoria boundary in southwest Montana. *Jour. Sed. Petr.*, **25**, (3), 163-192.

WELSH, W. (1967): The value of point-count modal analysis of greywackes. *Scott. Jour. Geol.*, **3**, (2), 318-328.

YABE, H. (1927): The Cretaceous stratigraphy of the Japanese Islands. *Sci. Rep., Tohoku Imp. Univ., 2nd Ser., Geol.*, **11**, (1), 27-100.

YAMASHITA, N. (1947): Fossil beds of the Lower Cretaceous System in the Katsuuragawa basin, Province Awa (in Japanese). *Jour. Geol. Soc. Japan*, **53**, (610-612), 80-81.

——— (1949): On the Cretaceous System of the Katsuuragawa basin in Tokushima Prefecture (in Japanese). *Jour. Geol. Soc. Japan*, **55**, (648-649), 117-118.

——— (1957, 1958): *The Mesozoic.* Earth Sci. Ser., Vol. 10 (1957), 94 pp.; *Ibid.*, Vol. 12 (1958), 116 pp. Assoc. Geol. Collab. Japan.

YEHARA, S. (1924): On the *Trigonia*-sandstone group in the Katsuragawa basin, containing Ryoseki plants. *Japan. Jour. Geol. Geogr.*, **2**, (3), 59-84.

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