

## Cretaceous Sandstones of Goshonoura Island, Kyushu

Okada, Hakuyu  
Faculty of Sciences, Kyushu University

<https://doi.org/10.5109/1526114>

---

出版情報 : 九州大学理学部紀要 : Series D, Geology. 11 (1), pp.1-48, 1961-03-25. Faculty of Science, Kyushu University

バージョン :

権利関係 :



## Cretaceous Sandstones of Goshonoura Island, Kyushu\*

By

**Hakuyu OKADA**

### Abstract

Goshonoura Island, off the west coast of the main island of Kyushu is the type area of the Goshonoura group, which is mainly composed of sandstones. The overlying Himenoura group has also some sandstones. This paper contains the results of the petrographical study of these Cretaceous sandstones. In the Goshonoura group, basal arkose, lower to middle feldspathic graywacke, and upper lithic graywacke are in regular sequence in ascending order, as are the arkose and feldspathic suites in the overlying Himenoura. The mineral constituents likewise show a serial change. On the basis of the assemblage of minerals, seven zones are discriminated in the former and two in the latter.

Relationship between the Goshonoura and Himenoura groups is discussed from petrographical and mineralogical points, with a suggestion that there should be a significant gap between them.

The graywacke suite of the Goshonoura group is rather unique in character like that of the contemporaneous Mifuné group. Genetic significance is commented on the graywacke suite as well as arkose suite. Further comments are given on the regional paleotectonics which controlled the Goshonoura and Mifuné groups. The term molasse facies cannot be adequately referred to these deposits.

### Contents

#### *Text*

	Page
I. Introductory Remarks .....	3
A. Purpose of study .....	3
B. Notes on stratigraphy .....	3
1. Goshonoura group .....	3
2. Himenoura group .....	6
C. Acknowledgements.....	7
II. Petrographic Descriptions .....	8
A. Procedure .....	8
1. Material for study .....	8
2. Petrographic procedure.....	8
B. Summary of sandstone patterns .....	14
C. Mineral composition .....	16
1. Major constituents .....	16
2. Heavy minerals .....	19
D. Notes on the chemical composition of selected samples from the Goshonoura group .....	24
III. Petrographic Remarks .....	26
A. Stratigraphic zonation of the Goshonoura group based on mineral assemblage .....	26

---

\* Received January 10, 1961.

B. Provenance .....	32
C. Depositional environments and tectonics .....	36
D. A few comments on the Goshonoura graywacke .....	39
E. Relationship between the Goshonoura group and the Himenoura group..	40
IV. Concluding Remarks .....	41
A. Summary of the petrographic analyses .....	41
B. Regional paleotectonic environments of sedimentation .....	41
1. Comparison with the contemporaneous Mifuné group .....	41
2. Regional paleotectonics .....	43
References Cited .....	43
Appendix .....	48

### *Illustrations*

Text-figure	Page
1. Generalized stratigraphic section in Goshonoura Island.....	4
2. Location of petrographic samples in Goshonoura Island .....	12
3. Compositional diagram of the Goshonoura sandstones, showing five sandstone types.....	14
4. Compositional diagram of the sandstones of the Himenoura group.....	16
5. Heavy residue of sandstone of the Goshonoura group, showing preponderance of epidote.....	20
6. Heavy residue of sandstone of the Himenoura group, showing the garnet concentrate .....	22
7. Vertical variations of major constituents of sandstones from Goshonoura Island .....	27, 28
8. Vertical variations of selected heavy minerals of sandstones from Goshonoura Island .....	29
9. Vertical variations of selected constituents of sandstones of the Himenoura group in the type section .....	30
10. Geological map showing distribution of mineral zones in Goshonoura Island .....	33
11. Summarized chart showing petrographic characters of sandstones examined	42
Plate	
1. Photomicrographs of arkose	
2. Photomicrographs of graywacke and subgraywacke	

### *Tables*

Table	
1. List of petrographic samples .....	9
2. Sandstone patterns.....	13
3. Sandstone groupings characteristically recognized in the Goshonoura group .....	15
4. Compositions of major constituents of sandstones .....	16/17
5. Compositions of heavy minerals of sandstones.....	20/21
6. Chemical composition of arkose .....	24
7. Chemical composition of red siltstone .....	25
8. Scheme of mineral zones in the Goshonoura and Himenoura groups ....	32

## I. Introductory Remarks

### A. Purpose of study

The Goshonoura group represents the western part of the Cretaceous deposits in Middle Kyushu. The Cretaceous basin is framed by the Mifuné group (MATSUMOTO, 1939a; OKADA, 1958, 1960b) in the adjoining eastern part and is characterized by red beds. Good displays of the Goshonoura group are in two islands, Goshonoura and Shishi-jima, of the Amakusa archipelago in the Shiranuhi sea, off the coast of Yatsushiro City, Kumamoto Prefecture (MATSUMOTO, 1938, 1954; AMANO *et al.*, 1958a, b). Of the two islands Goshonoura Island is geologically best studied, being the type area of the group (MATSUMOTO, 1938, 1954).

The stratigraphy of the Goshonoura and Mifuné groups was studied by MATSUMOTO (1938, 1939a), who gave some remarks on their significance in paleotectonic history.

At the suggestion of Professor MATSUMOTO I have been engaged in the petrographical study of the sandstones of the Mifuné and Goshonoura groups to get clearer knowledge on the geologic history. The results of my study of the Mifuné group have recently been published (OKADA, 1960b).

In this paper the petrography of the sandstones of the Goshonoura group is described. On the basis of the observed facts comments are given in regard to the intrinsic nature of the group itself, to its relationship with the overlying Himenoura group, and finally to a relation between sedimentation and tectonics. In this connection, the paper contains also the petrography of some sandstones of the Himenoura group.

### B. Notes on stratigraphy

#### 1. Goshonoura group

The succession of the Cretaceous Goshonoura group displays typical exposures in Goshonoura Island. The very base of the Goshonoura group is nowhere exposed in and near this place; the group is apparently concordantly overlain by the Upper Cretaceous Himenoura group in the southwestern part of the island but the relation is not seen in the main part where the two groups are separated by a fault; in one place the Himenoura group unconformably covers the granite (MATSUMOTO, 1938, 1954, 1960).

A framework of stratigraphy of the Goshonoura has been established in an excellent way by MATSUMOTO (1938). According to his original definition, the Goshonoura group, which attains a total thickness of about 950 meters, consists of three formations: Lower, Middle, and Upper formations, presenting a cycle of sedimentation (Text-fig. 1). The strata of the Goshonoura group constitute a major syncline (see the geological map prepared by MATSUMOTO, 1938; Text-fig. 10 in this paper).

The clastic ratio of the Goshonoura group is highest among other closely connected contemporaneous successions of the Mifuné and Lower Onogawa groups. Es-

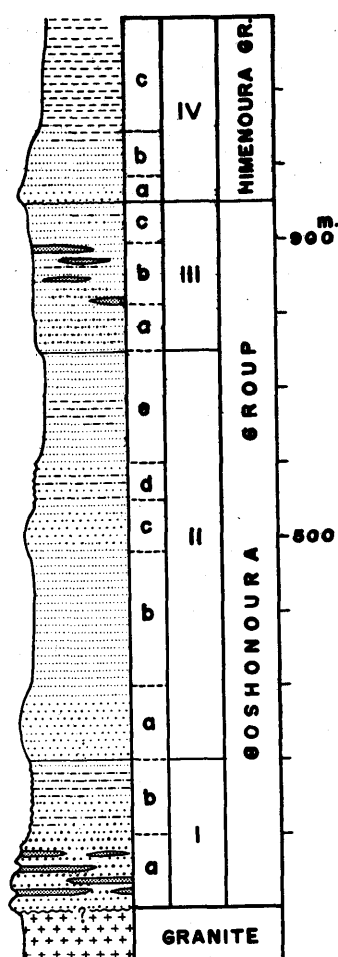


Fig. 1. Generalized stratigraphic section in Goshonoura Island (H. OKADA Del.).

Dark lenticular form stands for red beds. Others are same as customary usage, as explained in Text-fig. 4 of MATSUMOTO, [Editor], 1954.

pecially sandstones constitute a significant proportion of the clastic rocks, counting about 72 percent of the whole deposits (MATSUMOTO, 1954, p. 198, Fig. 43).

Through the recent field work of Hisakazu OGURI and I (OKADA *et al.*, 1960), we have confirmed that the stratigraphic classification of MATSUMOTO (1938) is quite adequate. Here the stratigraphic sequence of the Goshonoura group is concisely described in ascending order, depending chiefly on MATSUMOTO (1938, 1954) (see. Text-fig. 1).

(a) *Lower formation* [I]. The Lower formation, approximately 200 meters thick, is stratigraphically divisible into two members, Ia and Ib, which respectively have particular lithologic features.

(i) Ia: The lower member Ia is dominated by massive, ill-sorted, coarse-grained and/or conglomeratic arkose sandstones, being characterized by various occurrences of red siltstones. Cross-lamination is well developed in these sediments, although its direction cannot be ruled by observations. No fossil remains are obtained. Although the very base of the formation is not exposed, the lithologic features of the arkose suggest the existence of granitic basement rocks beneath Member Ia.

(ii) Ib: The upper member Ib consists chiefly of feldspathic graywackes of various grain sizes, accompanying thin layers of mudstone and shale. Prolific remains of molluscan fossils of brackish and/or shallow-sea elements are contained.

Throughout the formations are scattered pebbles or cobbles of biotite granite, aplite, gneiss, hornfels, chert, porphyrite, altered andesite, and the like.

(b) *Middle formation* [II]. The Middle formation is composed mainly of massive, medium- to fine-grained feldspathic graywacke sandstones, containing abundant fossils of trigonians and other sea shells. The total thickness of the formation is estimated at about 600 meters. The Middle formation is subdivided into the following five members:

(i) IIa: The lowest member IIa is represented by coarse-grained sediments, comprising rather massive, coarse- to medium-grained feldspathic graywackes and pebble to granule conglomerates. An irregular cross-laminated structure is common. Trigonians and brackish gastropods are sometimes found. The thickness of this member

is about 100 meters.

(ii) IIb: This member, nearly 180 meters thick, exhibits a predominant distribution in this entire island. Rather massive, medium- to fine-grained, somewhat well-sorted feldspathic graywackes are prevalent, presenting dusky yellow green to grayish green colors. Subgraywackes are accompanied subordinately. Molluscan fossils of trigonians, ammonites, *Callista*, etc. are very abundant in lenticular beds and/or nodules.

(iii) IIc: Coarse-grained sediments are predominant, consisting mainly of massive, ill-sorted, coarse-grained or conglomeratic feldspathic graywackes and partly of pebble to granule conglomerate layers; sometimes cross-laminated. Trigonians and gastropods are sporadically found. 70 meters or less thick.

(iv) IId: This member, some 50 meters thick, is most narrowly distributed. It comprises alternated sediments of conglomerates, conglomeratic or coarse- to fine-grained feldspathic graywackes, and partly subgraywackes, being infrequently accompanied by red sediments. Molluscan fossils of brackish element are contained. Penecontemporaneous erosion or diastem is recorded at places within the strata.

(v) IIe: The uppermost member IIe is another important part of the Middle formation, in addition to the above-mentioned Member IIb. Massive, medium- to fine-grained feldspathic graywackes, together with arkoses and subgraywackes, prevail, interbedding massive, sandy mudstone at the middle horizon of the member. Marine molluscs of ammonites, trigonians, etc. are very common. Species of ornate ammonites, *Graysonites* and *Mariella*, are identified among others (MATSUMOTO, 1960). The thickness of the member is estimated at 150 meters or less.

As pebbles or cobbles are borne abundantly quartz-porphry, porphyrite, delenite, and rhyolite, and also infrequently altered andesite, granitic rocks, chert, hornfels, slate, etc.

(c) *Upper formation* [III]. The Upper formation of the Goshonoura group comprises alternated succession of mainly lithic and partly feldspathic graywackes of various grain sizes, conglomerates, mudstones, and reddish siltstones, intercalating some fossiliferous beds. This formation can be regarded as the deposits of the closing stage of a cyclic sedimentation, as is pointed out by MATSUMOTO (1938, p. 38). It grades both downwards and upwards concordantly into the underlying and overlying formations respectively. Especially, a pelecypod fossil *Trigonioides* of fresh water element is contained in addition to abundant molluscs of brackish water (MATSUMOTO, 1938; ОТА, 1959). Penecontemporaneous erosions and the like frequently occur, together with rapid changes of lithologic facies. The maximum thickness is estimated at some 200 meters. The subdivisions originally defined are as follows:

(i) IIIa: The lower member IIIa, 45 meters or less thick, is not always well recognizable in this entire island. So far as it is observed, it comprises alternation of ill-sorted, conglomeratic to coarse-grained sandstones mainly referable to the feldspathic graywacke, sandy mudstone, and shale. Brackish-type molluscan fossils are prolific.

(ii) IIIb: The middle member IIIb, about 70 meters thick, is the deposits charac-

terized by the red sediments. They are usually fine-grained and lenticular in occurrence, alternating with rather thick beds of coarse-grained lithic graywackes and thin layers of shales, which bear molluscan fossils of brackish or fresh water like "*Cerithium*", *Trigonioides*, and so forth. Coaly matter is also intercalated. Very locally remarkable deposits of fanglomerate are met with, which consists mainly of boulders of granite and its related gneissose rocks.

(iii) IIIc: The upper member IIIc, 50 meters or more thick, consists of coarse- to medium-grained, lithic graywackes, fossiliferous sandy mudstones, and a few thin beds of coaly shale.

The pebbles in the Upper formation are made up of granite, aplite, gneiss, hornfels, dacite, rhyolite, delenite, quartz-porphry, porphyrite, andesite, tuffaceous rocks, and occasional fragments of sandstone and shale.

Concerning the geological age of the Goshonoura group, MATSUMOTO (1960), giving some modification to his previous correlation, has recently concluded that from the occurrence of ammonites of *Graysonites* cf. *fountaini* YOUNG and *Desmoceras kossmati* MATSUMOTO the Middle formation of the Goshonoura group is mainly Lower Cenomanian. Although the Upper and Lower formations of the tripartite Goshonoura group have no ammonites, from the stratigraphic sequence and the molluscan fossils the Lower formation is considered as ranging down to a part of the Albian. Whether the Upper formation represents the rest of the Cenomanian only or both the Cenomanian and Turonian is questionable.

## 2. *Himenoura* group

(a) *Himenoura* group of Goshonoura Island [IV]. The Upper Cretaceous Himenoura group in Goshonoura Island is intermittently exposed mainly along its western coastal line. The present group, on the one hand, overlies the Goshonoura group concordantly to all outward appearance, with transitional part of some thickness (at most 30 meters), and on the other hand, rests with remarkable unconformity on granitic rocks. As to its relationship with the Goshonoura group, some problems have arisen from the newly added fossil evidence, as cited above. This question is to be commented from a petrographical and mineralogical point of view in Chapter III (p. 40).

The subdivisions of the Himenoura group in Goshonoura Island are as follows in an ascending order, according to MATSUMOTO (1938):

(i) IVa: The basal member IVa is the above-mentioned transitional part to the Goshonoura group in the southwestern part, and basal beds are made up of conglomerates and/or arkose sandstones resting on the granitic rocks in the northeastern part. The former is composed mainly of heterogeneous, ill-sorted, conglomeratic and coarse- to medium-grained arkosic sandstones. No fossil remains are obtained.

(ii) IVb: Rather massive, medium- to fine-grained, pale blue to grayish green arkosic sandstones, containing *Glycymeris*, *Inoceramus*, etc.

(iii) IVc: Massive, dark gray mudstone prevails, containing many fossils of ammonites and inocerami. Leading fossils are *Gaudryceras denseplicatum* (JIMBO), *Hauericeras angustum* (YABE), *Polyptychoceras haradanum* (YOKOYAMA), *Texanites* sp., *Inoceramus amakusensis* NAGAO & MATSUMOTO, and *Inoceramus japonicus* NAGAO & MATSUMOTO.

(iv) IVd: Shale and fine-grained sandstone in frequent alternation.

The whole of the above subdivision is assigned in age to the Lower and Middle formations of the Himenoura group in the type area, Amakusa-Kamishima and neighbouring islets, as defined by UEDA *et al.* (1960). Thus it is appropriate to review at a glance the Himenoura group in the type area.

(b) *Himenoura group of the type area.* According to a renewed study of UEDA *et al.* (1960), the Himenoura group lies on the eroded surfaces of gneiss and granodiorite, consists of the Lower, Middle, and Upper formations, and is succeeded by the Paleogene Tertiary deposits with a great unconformity.

The stratigraphic sequences may be briefly summarized as follows, depending on UEDA *et al.* (1960):

(i) Lower formation [I]: The Lower formation, 90 to 220 meters thick, consists of conglomerates, bluish gray to greenish gray medium-grained arkoses, and dark gray fine-grained sandstones or sandy siltstones, containing fossils of trigonians, inocerami, glycymerids, *etc.* It is subdivided into four members.

(ii) Middle formation [II]: Mainly greenish or grayish mudstone and shale, containing abundant fossils of open-sea elements and calcareous nodules. 400 to 500 meters thick.

(iii) Upper formation [III]: Medium-bluish gray, medium-grained feldspathic graywackes, sandy shales, and dark gray shales in frequent alternation; nonfossiliferous. Approximately 90 meters thick.

The Himenoura group is assigned in its lower and middle parts to the Urakawan, approximately Coniacian to Lower Campanian in terms of international scale, and in its upper part presumably to the Lower Hetonian, Middle to Upper Campanian.

### C. Acknowledgements

I wish to express my most sincere appreciation to Professor Tatsuro MATSUMOTO of the Kyushu University, who has constantly supervised the study and has critically read the manuscript. Special thanks are due to Professor Tôru TOMITA and Professor Ryuzo TORIYAMA of the Kyushu University, who have kindly provided me with many facilities for study and continued encouragement for my efforts. I am also indebted to Assistant Professors Kametoshi KANMERA and Tsugio SHUTO of the same university for their valuable criticism and advice. Messrs. Yoshiro UEDA and Nobutsune FURUKAWA, when they were in the Department of Geology, Kyushu University, kindly provided me for study with specimens of sandstones collected from the Himenoura group in the type section, and Mr. Hisakazu OGURI, when he was a student in the same department, assisted me in collecting a part of the sandstone specimens and



kindly offered me some of his own collections. Appreciation is also acknowledged to Messrs. Yukio MATSUMOTO, Yoshiro UEDA, Takeshi AKATSU, Yoshifumi KARAKIDA, Jyonosuke OHARA, Ikuwo OBATA, and Koji FUJII for their help in various ways. Mr. Masayoshi WAKIJIMA of the village office in Goshonoura Island, Amakusa, kindly offered many facilities during my field work.

Assistance was given by Messrs. Ichisaku SAKAI and Masato NAGASAWA in preparing numerous thin-sections; and by Miss Chizuko OKAMURA in preparing the typescript.

This study was partly financed through Professor MATSUMOTO with the Grant in Aid for Scientific Researches by the Ministry of Education.

## II. Petrographic Descriptions

### A. Procedure

#### 1. *Material for study*

The specimens studied petrographically are mainly concerned with the sandstones, which would give more interpretable informations on patterns of clastic sedimentation, as stated in the introductory chapter. The majority of them were collected according to a predetermined design to ensure geographic and stratigraphic coverage as effectively as possible throughout the type area of the Goshonoura group in Goshonoura Island, and at the same time others were sampled at several localities, where the overlying Himenoura group is exposed.

The stratigraphical and geographical positions of the examined specimens are tabulated and illustrated in Table 1 and Text-fig. 2, respectively. As to the stratigraphic units from which the material came, **Notes on stratigraphy** in Chapter I is to be referred to (pp. 3-7).

#### 2. *Petrographic procedure*

The stratigraphic analyses of the sandstone samples have been carried out in just a similar way to those of the Cretaceous Mifuné group explained in my previous paper (OKADA, 1960b, p. 4), although the evaluation of size-distribution is not attempted in this study. The primary emphasis is placed on the petrographic analysis through thin-section and heavy mineral examination, the detailed procedures of which are included in the same paper (OKADA, 1960b, pp. 4-5). In addition, two particularly selected samples are chemically analysed. Concerning the color of rocks, the rock-color chart prepared by the Rock-Color Chart Committee in U.S. (GODDARD [Chairman], 1951) is used.

From thin sections are evaluated some of the textural elements and the proportion of the major constituents of a given sandstone. The relative abundance of each of quartz, chert, feldspar, rock fragments, clay matrix, and calcite is estimated by using a microintegrator. Especially, quartz varieties are discriminated by the same method as that I previously used (OKADA, 1960a, b), dividing the grains into the two

Table 1. List of petrographic samples.

Specimen No.	Strati-graphic position	Locality	Collectors
GS 10	Ia	Ca. 150 m north of Tanoshiri	H. OKADA
GS 13	Ia	Ca. 500 m, ditto	—
GS 17	IIb	Enokuchi	—
GS 18	IIb	Ditto	—
GS 20	Ia	Ditto	—
GS 21	Ia	Ditto	—
GS 23	IIb	Kobunenosako	—
GS 24	Ia	Aradachi	—
GS 30	Ile	Ca. 15 m south of Furuyashiki	—
GS 32	Ile	Ditto	—
GS 35	IIIb	Ca. 400 m south of Karakizaki	—
GS 36	IIIb	Ditto	—
GS 37	IIIb	Ditto	—
GS 38	Ile	Mouth of the Naruko R.	—
GS 39	Ile	Ditto	—
GS 46	IIb	Enokuchi	—
GS 47	IIb	Ditto	—
GS 48	IIb	Ditto	—
GS 49	IIb	Ditto	—
GS 53	Ia	Ca. 500 m north of Momonokisako	—
GS 54	Ia	Momonokisako	—
GS 55	Ib	Ozé, ca. 700 m southwest of Momonokisako	—
GS 56a	Ib	Judan, ca. 900 m southwest of Momonokisako	—
GS 56b	Ib	Ditto	—
GS 56c	Ib	Ditto	—
GS 58	Ib	Ditto	—
GS 59	Ila	Ditto, ca. 1100 m southwest of Momonokisako	—
GS 60a	Ila	Hobashira-ishi	—
GS 60b	Ila	Ditto	—
GS 60c	Ila	Ditto	—
GS 62	IIIc	Okubo	—
GS 63	IIIc	Ditto	—
GS 64a	IIIb	Ditto	—
GS 64b	IIIb	Ditto	—
GS 66	IIIa	Ditto	—
GS 67	IIIa	Ditto	—
GS 68	IIIa	Ditto	—
GS 69	IIIa	Ditto	—
GS 70	IIc	Ditto	—
GS 76a	IIb	Kurosaki	—
GS 78a	IIb	Umeki	—

Table 1.—(Continued)

GS 78b	IIb	Umeki	H. OKADA
GS 79a	IIb	Gannohana	—
GS 79b	IIb	Ditto	—
GS 79c	IIb	Ditto	—
GS 91	IVa	Maeshima	T. MATSUMOTO, H. OKADA, and H. OGURI
GS 92	IVa	Ditto	—, —, —
GS 93a	IVb	Ditto	—, —, —
GS 93b	IVb	Ditto	—, —, —
GS 94	IVa	Ditto	—, —, —
GS 97	IId	Senohana	—, —, —
GS 98	IId	Ditto	—, —, —
GS 99	IId	Ditto	—, —, —
GS 100	IVb	Midpoint between Senohana and Kwannon-iwa	—, —, —
GS 101	IVb	Kwannon-iwa	—, —, —
GS 102	IId	Ca. 150 m south of Kwannon-iwa	—, —, —
GS 103	IId	Ca. 200 m, ditto	—, —, —
GS 104	IId	Ca. 250 m, ditto	—, —, —
GS 105	IId	Ca. 350 m, ditto	—, —, —
GS 106	IId	Ca. 450 m, ditto	—, —, —
GS 107	IVc	Owubayama	—, —, —
GS 108	IVc	Ditto	—, —, —
GS 113	IIIc	Kyodomari	—, —, —
GS 114	IIIc	Ditto	—, —, —
GS 115	IIIc	Ditto	—, —, —
GS 116	IIIc	Ditto	—, —, —
GS 117	IIIc	Ditto	—, —, —
GS 124	IIb	Furuyashiki	H. OKADA
GS 127	IIb	Pass between Furuyashiki and Momonokisako	—
GS 128	IIb	Ditto	—
GS 129	IIb	Ditto	—
GS 130	IIb	Ditto	—
GS 131	IIb	Ditto	—
GS 132	IIIb	Akasé	H. OKADA and H. OGURI
GS 133	IIIb	Ditto	—, —
GS 135	IId	Kakuchi-bana	—, —
GS 136	IId	Ditto	—, —
GS 137	IId	Ditto	—, —
GS 138	IId	Ditto	—, —
GS 139	IId	Ditto	—, —
GS Ex. 1	Ia	Midpoint between Akutan and Kobunenosako	H. OKADA
GS Ex. 2 (G13)	Ia	Kobunenosako	H. OGURI
GS Ex. 3 (G8232)	IIb	Enokuchi	—

Table 1.—(Continued)

GS Ex. 4 (G8233)	IIb	Enokuchi	H. OGURI
GS Ex. 5 (G53)	IIb	Tanoshiri	—
GS Ex. 6 (G54)	IIc	Ditto	—
GS Ex. 7 (G57)	IIb	Ditto	—
GS Ex. 8 (G8273)	Ia	Momonokisako	—
GS Ex. 9 (G722)	IIIc	Kuroso	—
GS Ex. 10 (G719)	IIIc	Ditto	—
GS Ex. 11	IVa	Nosabazaki	—
GS Ex. 12 (G612)	IVb	Dadaku	—
GS Ex. 13 (G36)	IIIb	South of the Naruko R., Karakizaki	—
GS Ex. 14 (G35)	IIIb	Ditto	—
GS Ex. 15 (G1216)	IIIb	Karakizaki	—
Hm K-2	Lower	Hinoshima Is.	Y. UEDA
Hm K-3	Lower	East coast of Hinoshima Is.	—
Hm K-4	Lower	Ditto	—
Hm K-19	Upper	Akazaki, Kamishima	—
Hm 009c	Lower	Wadanohana, ditto	N. FURUKAWA
Hm 120B	Lower	Ca. 800 m southeast of Higashiura, ditto	—
Hm 151	Middle	Ca. 1000 m south of Nishiura, ditto	—
Hm 173	Middle	Nishiura	—
Hm K-250	Upper	Daisakuyama, kamishima	Y. UEDA and N. FURUKAWA
Hm 315	Lower	Furukamiyo, ditto	N. FURUKAWA
Hm 360	Lower	Kamiyo, ditto	—
Hm 403	Lower	Ca. 800 m west of Shitanoki, ditto	—
Hm 438	Lower	Northern tip of Hinoshima Is.	—
Hm 440	Lower	Ditto	—
Hm 575	Lower	Kugushima Is.	—
Hm 587	Lower	Ditto	—
Hm 630	Upper	Western coast of Yokoura Is.	—
Hm 631	Upper	Ditto	—
Hm 643	Upper	Futamado, Kamishima	—
Hm 659	Lower	Ditto	—
Hm 860	Lower	West of Wakiura, Kamishima	—
Hm 893A	Upper	Southern coast of Yokoura Is.	—
Hm 897	Upper	Ditto	—
Hm 917	Lower	Opposite shore of Bonzu Islet, Hinoshima	—
Hm 936	Lower	Northern tip of Hinoshima	—

N. B. G: OGURI's sample number

Hm K: UEDA and FURUKAWA's (1960) sample number

Hm: FURUKAWA's sample number



liquid of THOULET's solution (S.G.=2.9), and 200 or more grains are counted to estimate heavy mineral composition.

As to the errors to be introduced in the procedure, the examination depends on the previous works by DRYDEN (1931), DRYDEN (1935), IJIMA (1959), OKADA (1960b), *etc.*

Table 2. Sandstone patterns.

STRATI- GRAPHIC DIVISION	TYPE		ARKOSE	FELDSPATHIC GRAYWACKE	LITHIC GRAYWACKE	SUBGRAY- WACKE
GOSHONOURA GROUP	I	a	GS 21, 24, Ex. 2, Ex. 8	GS 13		
		b		GS 56a, 56b, 56c, 58		
	II	a		GS 59, 60a, 60b, 60c		
		b		GS 17, 18, 23, 46, 47, 48, 49, 79c, 127, 130, Ex. 3, Ex. 4, Ex. 5, Ex. 7		GS 128, 129, 131
		c		GS 70		GS Ex. 6
		d		GS 99, 102		GS 97, 98
		e	GS 30, 32, 104, 106	GS 38, 39		GS 105, 136
	III	a		GS 66, 67, 68	GS 69	
		b		GS 36	GS 35, 64a, 64b, 124 132, Ex. 13, Ex. 41	GS 37, Ex. 15
		c		GS 62, 63, Ex. 9, Ex. 10	GS 113, 115	GS II4, 117
HIMENOURA GROUP	IV*		GS 92, 93, 100, 101	GS Ex. 11, Ex. 12		
	I**		Hm K-2, K-3, K-4, 009c 315, 659, 860, 936			
	II**			Hm 151		
	III**		Hm 643	Hm 631, 893A		

N. B. \* Himenoura group in Goshonoura Island.

\*\* Himenoura group in the type area, Amakusa-Kamishima.

The results obtained are presented in Tables 4 and 5.

### B. Summary of sandstone patterns

The sandstones of the Goshonoura group and the Himenoura group fall within the four lithologic types of arkose, feldspathic graywacke, lithic graywacke, and sub-graywacke, according to the scheme of classification by PETTIJOHN (1957), among which the former three are important. These types characteristically occur in the order of stratigraphic sequence in each of the two groups. The facts are shown in Table 2. With regard to the Goshonoura group, the lower member of the Lower formation (Ia) is as a whole represented by a typical basal arkose, the upper member of the Lower formation (Ib) and the overlying Middle formation (II) are by the feldspathic graywacke, and the main part of the Upper formation (III) is by the lithic graywacke. The Himenoura group is again controlled by the same rule in that its lower part (I) is represented by the basal arkose, and the upper part (II and III) is defined by the feldspathic and lithic graywackes.

In addition, such a tendency as mentioned above is more clearly confirmed, when

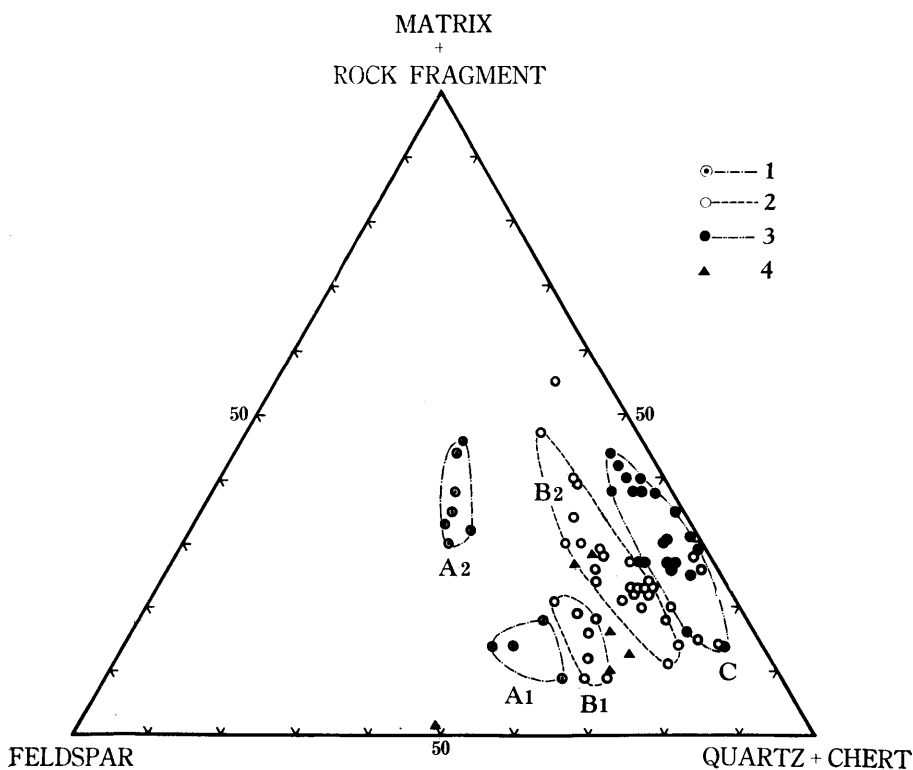


Fig. 3. Compositional diagram of the Goshonoura sandstones, showing five sandstone types (H. OKADA Del.).

- |                          |  |
|--------------------------|--|
| 1: Lower formation (I)   | 2: Middle formation (II)                     |
| 3: Upper formation (III) | 4: Himenoura group in Goshonoura Island (IV) |

the feldspar content is examined. The facts are illustrated in Text-fig. 3, which demonstrates that the sandstones of the Goshonoura group can be definitely grouped into five types, A<sub>1</sub>, A<sub>2</sub>, B<sub>1</sub>, B<sub>2</sub>, and C. The stratigraphic distribution of the sandstones of these five types is shown in Table 3. In the same way, sandstones of the Himenoura group may be also preliminarily classified into at least two major types, to which, however, no nomination is given at present (Text-fig. 4).

To sum up, the discriminated types of sandstones occur zone by zone in accordance with the stratigraphic succession.

Table 3. Sandstone groupings characteristically recognized in the Goshonoura group.

STRATI- GRAPHIC DIVISION	TYPE	A1	A2	B1	B2	C
I	a	21, 24, Ex. 2, Ex. 8	13			
	b		56a, 56b, 56c, 58			
II	a			60c	59, 60b	
	b			46, Ex. 4, Ex. 5	17, 18, 23, 47, 48, 49, 79a, 79c, 127, 128, 129, 130, 131, Ex. 3, Ex. 7	
	c				70, Ex. 6	
	d					97, 98, 99, 102
	e			30, 32, 106	38, 39, 104, 105, 136	
III	a					66, 67, 68, 69
	b					35, 36, 37, 64a, 64b, 124, 132, Ex. 13, Ex. 14, Ex. 15
	c					62, 63, 113, 114, 115, 117, Ex. 9, Ex. 10

N.B. Prefix GS is omitted in each specimen number.



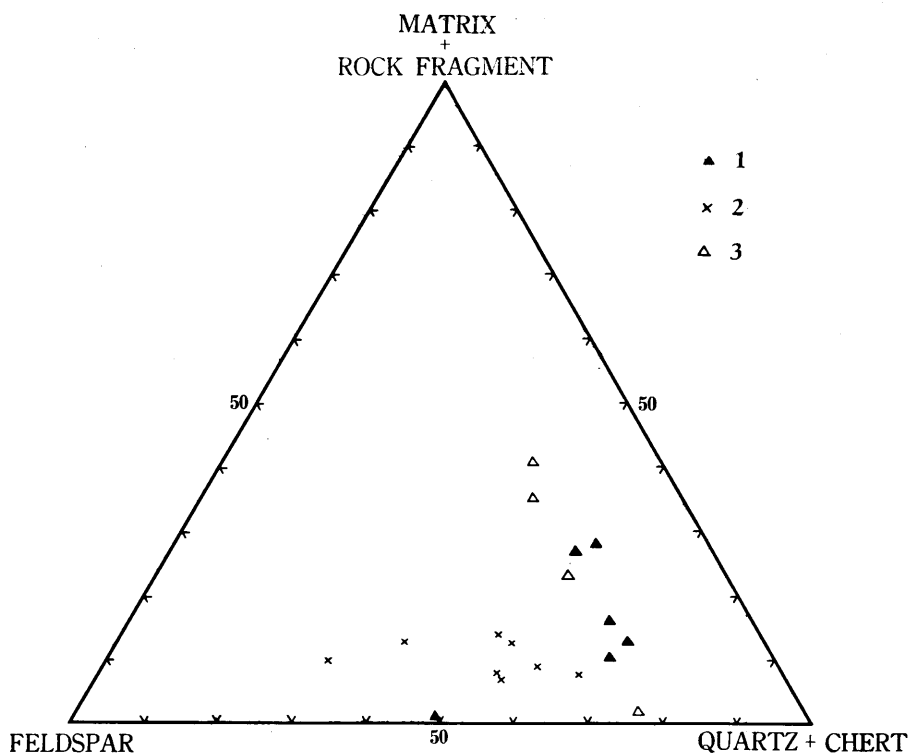


Fig. 4. Compositional diagram of the sandstones of the Himenoura group (H. OKADA Del.).

- 1: Himenoura group in Goshonoura Island.
- 2: Lower formation of the Himenoura group in the type section.
- 3: Middle and Upper formations of the type Himenoura group.

### C. Mineral composition

#### 1. Major constituents

##### a. Arkose

Pl. 1, Figs. 1-6

(1) *Quartz*. Quartz is ubiquitously the chief component even of this kind of sandstones. It comprises two kinds of different origins, igneous and metamorphic. In the basal arkose of the Goshonoura group (Ia), the quartz grains constitute 54 percent on the average, among which the igneous or plutonic variety occupies as much as 51 percent. On the contrary the metamorphic quartz is at most only 7 percent or even less than 1 percent. As to the Himenoura group for comparison, the basal arkose contains on the average about 45 percent for quartz, of which the igneous variety is 25 percent and the metamorphic one 20 percent.

The arkosic sandstones of the intermediate member (IIe) in the Goshonoura group contain quartz of about 56 percent on the average, in which metamorphic variety is 25 percent. Thus they have much larger amount of metamorphic quartz

Table 4. Compositions of major constituents of sandstones.

STRATIGRAPHIC DIVISION		SPECIMEN NUMBER		QUARTZ			CHERT	FELDSPAR						MATRIX ROCK FRAGMENTS CALCITE			GRAIN SIZE	ROUNDNESS	ROCK COLOR			
				Igneous	Metamorphic			ORTHOCASE	PLAGIOCLASE	PERTHITE	MICROCLINE	MYRMEKITE	Total									
					Total																	
GOSHONOURA GROUP	Ia	GS 13	28	2	30	4	32	1	+			33	33			c.	.2	5 R	4/6 (moderate red)			
		GS 21	62	+	62	+	21	8	+			29	9	+		c.	.3	5GY	7/2 (grayish yellow green)			
		GS 24	49	4	53	2	18	9	+			27	16	+	2	c.	.2	5GY	7/2			
		GS Ex. 2	42	7	49	4	29	4		+		33	14	+		c.	.3					
		GS Ex. 8	49	1	50	4	26	10			+	36	10				.3					
	Ib	GS 56a	28		28	2	20	6	+		+	26	43		1	f.	.4	5GY	5/2 (dusky yellow green)			
		GS 56b	32	1	33	1	26	4	+		1	31	35		+	m.	.2	5GY	5/2			
		GS 56c	31	1	32	6	22	4	+	2	2	30	28	2	2	m.	.4					
		GS 58			30							24	43		+	m.	.4	5 G	3/1 (dark greenish gray)			
	IIa	GS 59	31	15	46	18	7	2		1	+	10	22	+	4	m.	.5	10 Y	5/4 (light olive)			
		GS 60a	18	15	33	14	19	7				26	33		4	m.	.5	5GY	5.5/2			
		GS 60b	29	9	38	13	8	7				15	28		6	m.	.5	10 Y	5/4			
		GS 60c	20	19	39	15	16	2	1	+	1	20	14	3	9	m.	.5	10 Y	5/4			
	IIb	GS 17	25	12	37	16	11	1			+	12	28	7	+	m.	.4	5GY	5/2			
		GS 18	14	22	36	22	12	4				16	21	5	+	m.	.5	10 G	5.5/2 (pale green)			
		GS 23	20	16	36	35	5	4			+	9	16	3	1	m.	.4	5 G	5/2 (grayish green)			
		GS 46	20	21	41	14	17	7		+		24	21	+		m.	.5	10 Y	5/4			
		GS 47	32	10	42	23	10	3				13	21	1		m.	.5	5GY	5/2			
		GS 48	24	25	49	18	8	3	+			11	17	5		m.	.5	5GY	4.5/2			
		GS 49	25	9	34	24	11	3				14	25	3		m.	.5	5GY	5/2			
		GS 78a			35	3						7	54	+	1	v. f.		5 G	4/2			
		GS 79a			32	4						12	44	2	6	f.		5BG	4/2 (grayish blue green)			
		GS 79c	19	16	35	13	8	4				12	39	+	1	m.	.4	5GY	5/2			
		GS 127	16	13	29	35	12	1				13	19	4		m.	.5	5GY	4/2			
		GS 128	23	25	48	24	8	2				10	7	11		m.	.5	5GY	5/2			
		GS 129	23	11	34	23	13	1				14	14	15		m.	.5	10 Y	5/4			
		GS 130	25	14	39	23	8	3	+	+	+	11	17	10		m.	.5	10 Y	5/4			
		GS 131	23	14	37	28	8	4				12	12	11		m.	.5	5GY	5/2			
		GS Ex. 3	38	15	53	11	11	4		+		15	19	1	1	m.	.4	5GY	4/2			
		GS Ex. 4	29	14	43	16	13	8			+	21	13	3	4	m.	.5	5GY	6.5/2			
		GS Ex. 5	19	16	35	24	13	6		+	+	19	16	1	5	m.	.4	5GY	4/2			
		GS Ex. 7	26	20	46	13	14	3				17	23	1	+	m.	.5	5GY	5/2			
	IIc	GS 70	23	22	45	16	8	7			15	22	2		m.	.5	5GY	5/2				
		GS Ex. 6	20	19	39	27	7	3	+		+	10	13	11		m.	.5	5GY	5/2			
	IId	GS 97	18	20	38	39	4	4			8	13	2		m.	.5	10 Y	5/4				
		GS 98	26	22	48	27	2	3			5	10	4	6	m.	.4	5GY	6/2				
		GS 99	30	10	40	30	1	1			2	28	+		m.	.5	5GY	5/2				
		GS 102	16	28	44	28	1	1		+	2	26	+		m.	.4	5 Y	4/4				
	IIe	GS 30	32	25	57	7	15	9	+		+	24	12	+		m.	.5	5 B	6/1 (medium bluish gray)			
		GS 32	34	21	55	10	19	7	+	+	26	9	+		m.	.6	5 Y	7/2 (yellowish gray)				
		GS 38	17	20	37	21	12	4			16	22	4		m.	.5						
		GS 39	19	9	28	24	14	4			18	20	9	1	m.	.4	10 G	6/2 (pale green)				
		GS 104	20	17	37	38	12	2			14	7	4		m.	.5	5GY	5.5/2				
		GS 105	25	21	46	20	7	2			1	10	10	14	m.	.5	10 Y	5.5/4				
		GS 106	26	28	54	14	20	3		+	+	23	9	+		m.	.4	10 Y	5/4			
		GS 136	25	18	43	21	7	4			11	13	12	+	m.	.5	5GY	5/2				
	IIIa	GS 66	16	24	40	15	3	2			5	38	+	2	m.	.4						
		GS 67			33	9					5	36		11	f.		5 G	5/2				
		GS 68	16	19	35	18	5	+			5	41	+	1	m.	.4	5 G	5.5/2				
		GS 69	5	30	35	22	3	+			3	31	7	2	c.	.4	5GY	4.5/2				
	IIIb	GS 35	9	45	54	17	1	3			4	20	4	1	m.	.5	5GY	4/2				
		GS 36	14	21	35	16	1	4			5	44	+		m.	.5	10 G	4.5/2				
		GS 37	25	18	43	32	5	3			8	9	8		m.	.5						
		GS 64a	15	29	44	13	3	2			5	31	5	2	m.	.4						
		GS 64b	14	31	45	13	3	+			3	35	4	+	m.	.4	10 Y	5/2				
		GS 124	11	28	39	21	1	1			2	22	16		v. c.	.5	10 Y	4/2 (grayish olive)				
		GS 132	31	14	45	18	6	2			8	21	8		m.	.5	5GY	5/2				
		GS Ex. 13	14	39	53	12	+	5			5	26	4		m.	.4	10 G	4/2				
		GS Ex. 14	15	36	51	17	+	1			1	25	6	+	v. c.	.5	5GY	4/2				
		GS Ex. 15	23	25	48	9	6	3			9	14	11	9	v. c.	.4	10GY	5/2 (grayish green)				
	IIIc	GS 62	28	14	42	13	5	6			11	30	4	+	m.	.4	5GY	4/2				
		GS 63	40	16	56	12	4	2			+	6	26	+		m.	.5	10 Y	5/4			
		GS 113	16	29	45	23	+	5			+	5	17	10		m.	.5	10 Y	5/4			
		GS 114	7	41	48	16	1	+			1	10	25		c.	.4	5GY	4.5/4				
		GS 115	10	26	36	34	1	+			+	1	18	11		m.	.5	5 Y	4/4 (moderate olive green)			
		GS 117	27	23	50	31	3	2			5	13	4		m.	.5	5 Y	5/6 (light olive brown)				
		GS Ex. 9	27	29	56	2	5				5	21	2	14	m.	.4	5GY	5/2				
		GS Ex. 10	29	16	45	15	3	3	+	+	6	24	3	7	m.	.5	5 G	4.5/1				
HIMENOURA GROUP	IVa*	GS Ex. 11	35	15	50	5	15	3	+	+	18	27	+		m.	.4	5GY	5/2				
		GS 92	3	63	66	2	20	2	+		22	10	+		c.	.2	10 Y	5/4				
		GS 93a			37	2					14	10		23	m.	.3	5BG	4.5/2 (grayish blue green)				
	IVb*	GS 100	22	19	41	18	11	6			17	15	+	9	m.	.3	5 G	5/1				
		GS 101	39	7	46	3	22	28		+	50	1			m.	.3	5PG	6.5/2 (pale blue)				
		GS Ex. 12			36	1					11	20		28	f.		5 G	4/1				
	I**	Hm K-2	27	20	47	2	20	10			30	12	1	8	m.	.2	5 B	5/1				
		Hm K-3	54	3	57	2	13	19		+	+	32	7	+	2	m.	.3	5 B	6/1			
		Hm K-4			40	2					32	6		16	m.		5 B	6/1				
		Hm 009c	38	12	50	1	21	14			35	14	+		m.	.2	5BG	6/1 (greenish gray)				
		Hm 315	28	26	54	+	30	8		+	38	8			m.	.2	5BG	6/1				
		Hm 659	8	9	17	3	30	10		+	40	7	+	33	m.	.4						
		Hm 860	28	27	55	5	18	7		+	25	7	+	8	m.	.4						
		Hm 936	22	9	31	1	24	15			39	11	+	18	m.	.2	5 B	5/1				
	II**	Hm 151			26	22				19	20	1	12	m.			5 B	5/1				
	III**	Hm 631	26	4	30	9	7	10			17	28	3	13	m.	.4	5 B	6/1				
		Hm 643	20	17	37	13	10	5			15	1	1	33	m.	.5	5 B	5/1				
		Hm 893A	19	5	24	12	6	11			17	41	6		m.	.6	5 B	5/1				

N. B. Symbol+ stands for less than 1 percent.  
\* Himenoura group in Goshonoura Island.  
\*\* Himenoura group in the type area, Amakusa-Kamishima.

than the basal arkoses of this group.

The prevailing igneous quartz grains contain as a rule inclusions and minute spherical cavities. The roundness of the quartz grains particularly of the basal arkose is the worst, as is shown by the values of 0.2 and 0.3 or at best 0.4 (see Table 4).

(2) *Feldspar*. The feldspar comes next in abundance, constituting on the average as much as 32 percent of the rock in the basal arkose, and 23 to 26 percent in the intermediate member (Ile) of the Goshonoura. The feldspar grains include orthoclase, plagioclase, perthite, and microcline, together with myrmekite. Among them, orthoclase is overwhelmingly abundant, presenting about 26 percent on the average, more than 5 times as much as plagioclase. Other varieties are only occasionally met with.

Both fresh and weathered feldspar grains are present, of which the latter is prominent. Weathered grains show various degrees of kaolinitization.

Plagioclase displays for the most part albite twinning, and in some cases Carlsbad and Carlsbad-albite twinings. It ranges approximately from  $\text{Ab}_{65}\text{An}_{35}$  to  $\text{Ab}_{60}\text{An}_{40}$  in composition.

(3) *Matrix*. The arkosic sandstones of the Goshonoura group present on the average 10 percent for the clay matrix, and those of the Himenoura only nearly 6 percent on the average. Although the clay minerals have not been determined in detail, the clay matrix seems to be for the most part sericitized and/or chloritized.

(4) *Rock fragments*. The rock fragments are very small in amount, being only 2 percent on the average in the arkoses of the Goshonoura. The Himenoura group likewise contains very small quantity of rock fragments, presenting less than 1 percent. These fragments are somewhat more rounded than other grains.

The rock fragments include volcanic and sedimentary rocks. Most of the igneous rock fragments have pilotaxitic or hyalopilitic texture.

Chert grains are as a rule absent or less than 5 percent in the basal arkoses of the Goshonoura group and the Himenoura group, whereas arkoses of Member Ile of the Goshonoura contain as much as about 17 percent on the average for chert. In certain parts of this paper, chert is contained in the quartz clan, being separated from other rock fragments.

(5) *Calcite*. Calcite occurs as a cementing matter filling up the pore spaces or corroding and replacing other mineral grains. In the Goshonoura group, it is very rarely met with (*e.g.* Sp. No. GS 24), whereas in the Himenoura it forms a significant constituent, although its content is variable. In the case of high content of calcite, its replacement and corrosion advance along margins and cleavages of grains, and especially along dust rings of quartz (HEALD, 1956a, b; CAROZZI, 1960) as well as along twinning lamellae of feldspar, to a greater or lesser degree. A spongy mass of quartz reduced by dissolution due to calcite attack is not detected.

#### b. *Feldspathic graywacke*

Pl. 2, Figs. 1, 2

(1) *Quartz*. Quartz constitutes on the average 31 percent in the Lower formation of the Goshonoura group, 35 percent in the Middle formation, and 43 percent in

the Upper formation. That of the Himenoura group makes up 35 percent of the rock on the average. Of the two varieties of quartz, the metamorphic one is very few, at most 1 percent, in the Lower formation, showing a sudden rise upwards in amount from that to 16 percent in the Middle formation and 20 percent in the Upper formation. This variety hence gets much significant in the majority of this sandstone series, although the igneous quartz is still somewhat predominant. Chalcedonic quartz is also sometimes detected as detritus.

The quartz grains are as a whole better rounded than those of the arkosic sandstones. Extremely well rounded ones to be estimated at the roundness of 0.7 to 0.8 are sometimes met with, which may be of sedimentary origin through multicycles. A secondary overgrowth has been detected on a completely rounded quartz grain.

(2) *Feldspar*. The feldspar content in the feldspathic graywacke of the Lower formation is as great as in the arkosic sandstones, whereas in the overlying Middle formation it decreases to 14 percent and in the Upper formation to 6 percent. Further, in the Himenoura group it is estimated at about 16 percent on the average. In all of these, orthoclase is more abundant than plagioclase. Other varieties such as microcline, perthite, and myrmekite are also sometimes met with. Composition of the plagioclase mostly presenting albite and albite-Carlsbad twinning laws is almost as same as that in the arkosic sandstones.

(3) *Matrix*. Clay matrix takes significant parts in content; it occupies on the average 36 percent in the Lower formation, 22 percent in the Middle formation, and 38 percent in the Upper formation. Furthermore it is nearly 27 percent in the Himenoura group. Many parts of the matrix are converted into chloritic or sericitic matters.

(4) *Rock fragments*. Volcanic rock fragments usually present hyalopilitic or pilotaxitic texture. They are negligibly small in amount throughout the group, counting less than 2 percent on the average.

The content of chert fragments is variable; in the Lower formation of the Goshonoura group it is less than 3 percent and in the Himenoura group it is also only 7 percent on the average, while in the Middle and Upper formations it shows considerable amounts, that is, 20 percent and 13 percent on the average respectively. Chert grains are somewhat better rounded than other grains. Sometimes reddish chert is detected. There are some grains which show an originally fractured texture.

(5) *Calcite*. Calcite is more or less traceable as a cementing matter. Feldspathic graywacke from the lowest member (IIa) of the Middle formation is uniformly calcareous, containing 4 to 9 percent for calcite. It patches the interspaces of matrix.

### c. *Lithic graywacke*

Pl. 2, Figs. 3-5

(1) *Quartz*. Quartz is as usual the main constituent, presenting on the average nearly 45 percent. As to the varietal forms of quartz, the metamorphic quartz is more than twice as much as the igneous one. Moreover, the former seems to be slightly better rounded than the latter.

(2) *Feldspar*. Feldspar content is considerably small, being always less than 8 percent. Orthoclase is not always more abundant than plagioclase. The latter commonly shows the twinning of albite and albite-Carlsbad laws. In addition to these two species, myrmekite is rarely met with.

(3) *Matrix*. Matrix occupies about 25 percent on the average in this sandstone.

(4) *Rock fragments*. They consist mainly of volcanic rocks and are slightly larger in amount than the feldspar. Most of them have pilotaxitic texture, and some intersertal or hyalopilitic.

The average content of chert grains is about 19 percent.

(5) *Calcite*. Insignificantly small amount of calcite is discernible in a limited number of specimens. Particularly, in some parts of the calcite cement sideritic matter is found in the same mode of occurrence as described for the Lower Tertiary calcareous sandstones from Hokkaido (OKADA, 1960a).

#### d. *Subgraywacke*

Pl. 2, Fig. 6

(1) *Quartz*. Subgraywacke in the Middle formation contains on the average nearly 41 percent quartz, and that in the Upper formation about 47 percent quartz, of which the igneous variety is 23 percent in the former and 20 percent in the latter. The quartz grains in the subgraywacke are rather better rounded than those in other types of sandstones.

(2) *Feldspar*. Feldspar content is considerably lower as in the lithic graywacke, being about 11 percent in the Middle formation and about 5 percent in the Upper formation. Among the feldspar varieties, orthoclase occurs dominantly, counting about 7 percent in the former and nearly 4 percent in the latter, although plagioclase occurs ubiquitously. Other varieties such as perthite and myrmekite are quite rarely detected.

(3) *Matrix*. This type of sandstones is rather poor in matrix, presenting nearly 11 percent on the average for it. It is more or less altered to chloritic matters.

(4) *Rock fragments*. Volcanic rock fragments are most abundant in this type of sandstones, constituting about 11 percent of the rock on the average. There is a specimen which shows exceptionally high content of them rising up to as much as 25 percent (Sp. No. GS 114). They exhibit pilotaxitic, hyalopilitic, or intersertal textures.

Chert amounts to about 24 percent on the average.

(5) *Calcite*. This is only very rarely detected in a few samples.

## 2. *Heavy minerals*

The heavy minerals constitute a minor fraction, about 1.9 percent on the average by weight, of the sandstones of the Goshonoura group, although there are a few specimens that present as much as 6 to 9 percent heavy concentrates. On the other hand, those of the overlying Himenoura group count nearly 3.0 percent on the average,

rising sometimes up to ten or more percent.

The identified minerals are as follows:

*Goshonoura group*—Epidote, chlorite, biotite, zircon, garnet, muscovite, tourmaline, hornblende, augite, spinel, rutile, apatite, hypersthene, anatase, and glauconite, together with iron minerals of pyrite, magnetite or ilmenite, hematite, *etc.* Among them, epidote can be regarded as an index mineral of the Goshonoura.

*Himenoura group*—In addition to the same species of iron opaques as above, garnet, epidote, biotite, chlorite, muscovite, zircon, hornblende, tourmaline, apatite, rutile, spinel, augite, and glauconite. In the Himenoura garnet may be regarded as an index mineral.

The relative proportions of the heavy minerals are shown in Table 5. Their significance is commented in Chapter III. Herein brief notes on selected minerals are given as follows:

(a) *Epidote*. Epidote is the most abundant and widespread non-opaque constituent of the Goshonoura group (Text-figs. 5, 8, 11). It is hence worthwhile to be reckoned as an index mineral of the present group just as in the Mifuné group (OKADA, 1957, 1960b). It is still the insistent mineral even in the overlying Himenoura group, especially in its Lower formation (Text-figs. 8, 9, 11). This mineral occurs as somewhat rounded or oblate grains, irregularly fractured pieces, and infrequently as prismatic pieces, presenting in most cases bright yellowish green color, although some are colorless or almost so. Pleochroism is distinct for the colored epidote; Y=yellowish green, Z or X=colorless to less yellowish green. This kind of mineral in the

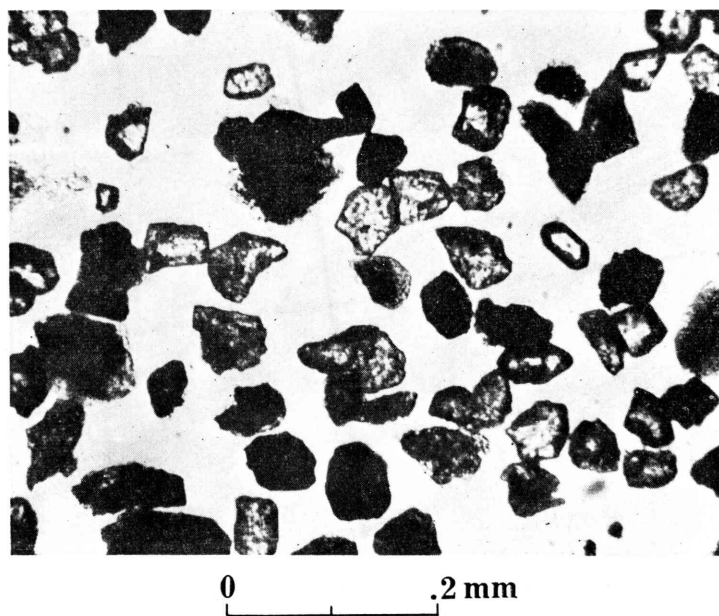


Fig. 5. Heavy residue of sandstone of the Goshonoura group, showing preponderance of epidote (Sp. No. GS 137). Epidote, zircon (prismatic form terminated by pyramids), and opaques. Photo by H. OKADA.

Table 5. Compositions of heavy minerals of sandstones.

STRATIGRAPHIC DIVISION		SPECIMEN NUMBER	ZIRCON				GARNET		EPIDOTE	TOURMA- LINE	HORN- BLENDE												HEAVY MINERAL %	GRAIN SIZE	REMARKS					
			Euhedral		Rounded																				ROCK COLOR					
			colorless	pale pink yellow purple	colorless	pale pink yellow purple	colorless	pale pink orange			blue brown green	brown green	AUGITE HYPERSTHENE APATITE RUTILE SPINEL ANATASE GLAUCONITE CHLORITE BIOTITE MUSCOVITE IRON OPAQUES																	
GOSHONOURA GROUP	Ia	GS 13	3	1				+			+			+								4	15	61		c.	5 R	4/6 (moderate red)		
		GS 20	2	6			+	+	+		+		3									4	24	1 14		m.	5GY	5/2 (dusky yellow green)		
		GS 21	6	7		+		3			+		3		+								1		7 28		c.	5GY	7/2 (grayish yellow green)	
		GS 24	+	3							1													+	2 48		c.	5GY	7/2	
		GS 53	2	4		+	+				+												4	1	49		v.c.	5 R	6/2 (pale red)	
		GS 54	18	2		+		+			1		+										+	12	+	67	m.	10 G	5.5/2 (pale green)	
	Ib	GS 55		2				2	5	58	+				+					1				1	31		m.			
		GS 56a	6	16		+	2		+	55	+		+		+										21		f.	5GY	5/2	
		GS 56b	6	13	1		3	2		61		2													1 11		m.	5GY	5/2	
		GS 56c	7	18	5	+	+	5	+	1		2	1		1								2		58		m.			
		GS 58	3	22	+	+	3			5						5								+	62		m.	5 G	3/1 (dark greenish gray)	
	IIa	GS 59	1	1		1	+		2	3	65	3	+						+						24		m.	10 Y	5/4	
		GS 60a	+	+						74	+	+		+	+								1	+	1 24		m.	5GY	5.5/2	
		GS 60b	+	2		+	+		+	60	1		+	+											1 33		m.	10 Y	5/4	
	IIb	GS 17	+	+		+		1	+	62	+			4				+	+	+			23	+	+	10	m.	5GY	5/2	
		GS 18	2	1		+	+		4	3	69	3			1								3	+		13	m.	10 G	5.5/2	
		GS 46	+	4				1	2	70	+	2		+				+	+				1	1	1 17		m.	10 Y	5/4	
		GS 48	1						2	68													2		+	27	m.	5GY	4.5/2	
		GS 49	+	+				1	+	70	+	1											+		28		m.	5GY	5/2	
		GS 76a	1	2			+		1	25		6	+						+				+		4 61		v.f.	N	3 (dark gray)	
		GS 78a	+	8			1		3	53		2	+						+	+		+	+	+	30		v.f.	5 G	4/2	
		GS 78b	2	+		+	1		+	64	+	+		+								1		2 29		v.f.	5GY	5/2		
		GS 79a	6	8			2		2	51		1	1										+	+	26		f.	5BG	4/2 (grayish blue green)	
		GS 79b	1	+				+	+	41		1							+		+	+	3	+	8 43		f.	5 B	5/1 (medium bluish gray)	
		GS 79c	3	2			1	+	2	52				+					+	+	+		4	+	+	36		m.	5GY	5/2
		GS 131	1					3		85													4		7		m.	5GY	5/2	
	IIc	GS 70		1			1	+	38	2		2		2		2			2		+		5	+	49		m.	5GY	5/2	
		GS Ex. 6	2	4		1		1	+	78															14		m.	5GY	5/2	
	IId	GS 97	2			3			1	73	2										+		+	1	18		m.	10 Y	5/4	
		GS 99	2	2		2	4		4	60									+		+	+	+	+	23		m.	5GY	5/2	
		GS 102	3	4		1		2		52	1												1	1	5	30		m.	5GY	5/2
	IIe	GS 30	2	2		+	+	+	2	27	1	1									1		2	+	60		m.	5 B	6/1	
		GS 32	+	7			3		2	31		1							+					4 45		m.	5 Y	7/2 (yellowish gray)		
		GS 38		1				3	1	77		+	1		1		+						7	+	2 7		m.			
		GS 39	4	+				+		75		1		+									7	+	5 8		m.	10 G	6/2 (pale green)	
		GS 104	3	2				6	3	69		2				+	+							+	14		m.	5GY	5.5/2	
		GS 105		+			+		+	79	+			+		1		+					4	+	+	16		m.	10 Y	5.5/4
		GS 106	6	3		2	2	+	4	24	+			+									4	+	3 45		m.	10 Y	5/4	
		GS 135	1	1			+		2	48	+	+											2	1	44		c.	5GY	5/2	
		GS 136	3	1			1		2	65									+				2	2	23		m.	5GY	5/2	
		GS 137	3	1				2		50	+												1	+	43		f.	5 B	5/1	
		GS 138	5	5		1	2		2	22		2	1		+						2	+		2	53		f.	5 G	4/1 (dark greenish gray)	
		GS 139	4			1		5		70									+				1	2	+	17		v.f.	5 G	4/1
	IIIa	GS 66	+	+				1	2	42	+	+		1		+			+				17	+	1 36		m.			
		GS 67	+	+		+		+	+	62	+				+		+		+		+	+	+	+	37		f.	5 G	5/2	
		GS 68	+	2				3		54	+			+				+	2				4		35		m.	5 G	5.5/2	
		GS 69	+					1	+	51	+	+								5			7		36		c.	5GY	4.5/2	
	IIIb	GS 35	+	1	+	+			1	46	+			2						+	+			7	+	1 42		m.	5GY	4/2
		GS 64a		1		+			2	47	1		+		+				+	1			+		1 47		m.			
		GS 64b						2	+	64	+		+							2		+	2		1 29		m.	10 Y	5/2	
		GS 65	5	7	1	1	2	+	6	37		3	+	+						1				5	4	23		m.	5 G	4/1
		GS 124	1	1		+		1	2	37				+						1				8	2	47		v.c.	10 Y	4/2 (grayish olive)
		GS 132	4	2		+	+	6	3	52	+								+				2	3	3 25		m.	5GY	5/2	
	IIIc	GS 62	1			1		+	2	57	1									1			1		1 34		m.	5GY	4/2	
		GS 63	4	4		+	3	3		33	2	+		+					+						2 40		m.	10 Y	5/4	
		GS 114	2	1				3	2	52	+									1			1			38		c.	5GY	

Mifuné group has been identified as the epidote *sensu stricto* by the X-ray analysis (OKADA, 1960b, p. 15, Table 4).

The origin of epidote in sedimentary rocks is a controversial problem. This has been discussed in some detail in the study of the Mifuné sandstones (OKADA, 1960b, p. 32), and additional comments are contained herein. In the investigation of the Mifuné sandstones I have been inclined to conclude that the epidote grains have been derived mainly from green schists and the like of metamorphic terrains, judging primarily from its intimate association with such metamorphic rock fragments. On the other hand, FUJII and other authors pointed out that epidote in the Mesozoic sandstones of the Yatsushiro district is closely associated with igneous rock fragments (FUJII, 1956; AKATSU, 1959). Furthermore, PUSTOWALOFF (1955), commenting comprehensively on the secondary alteration of sedimentary rocks, emphasized the existence of epidote produced secondarily in the sediments without metamorphic or hydrothermal action. In these connections, in order to generalize the problem of its origin, individuality of mineral composition and other attributes of sediments in each depositional basin should be clarified.

In the Goshonoura group, epidote is abundantly found in the two extreme types of sandstones composed mainly, on the one hand, of igneous detritus and, on the other hand, of metamorphic one. Therefore, both the metamorphic and igneous terrains may have been its main provenance, either of which is presumed to have prevailed depending on tectonic changes.

(b) *Chlorite*. Chlorite is common in most of the examined sandstones and abundant in some others. It occurs as pale to deep green plates, being sometimes slightly pleochroic. Some grains appear isotropic. They may be orthohexagonal Fe-chlorite which is genetically restricted to the environment of low temperature (SHIROZU, 1959). This type of chlorite was reported from the Lower Tertiary sandstones in Kyushu (SHIROZU, 1956; SHIROZU *et al.*, 1958).

(c) *Biotite*. Biotite occurs as brown, irregularly-shaped, basal cleavage flakes, of which some are hexangle-shaped and others are bent and fibrous. It is partly altered to chloritic matter. Inclusions are zircon with pleochroic halo and black opaque matter.

This is widespread and especially abundant in the basal part of both the Goshonoura and Himenoura groups (Text-figs. 8, 9, 11).

(d) *Zircon*. This is common and ubiquitous in all of the specimens examined. Among four varieties recognized, colorless and pale pink varieties are predominant in approximately equal proportions. The rest yellow and purple ones occur infrequently, although purple zircon is locally common especially in Member IIIc of the Goshonoura group (Table 5). Most of the zircon grains exhibit a euhedral crystal, sometimes presenting slight rounding of crystal edges especially at the terminations, among which prevails the zircon of the habitual form of KARAKIDA's C-type (KARAKIDA, 1954). Very infrequently grains of zircon show pronounced rounding, to which purple zircon belongs. Colored zircon tends to be more rounded. A large proportion of the zircon grains presents the elongation ratio of 1.5 to 3, and a few attain 4 or more. Inclusions of bubble, opaque matter, and needles and rods of unidentified crystals are



common.

(e) *Garnet*. Garnet is common and persistently widespread. It tends to be more common upwards in the Cretaceous succession (Text-figs. 8, 11). In particular, it is the most important non-opaque constituent of the Himenoura group as an index mineral (Text-fig. 6). Pale pink and colorless varieties commonly occur in almost

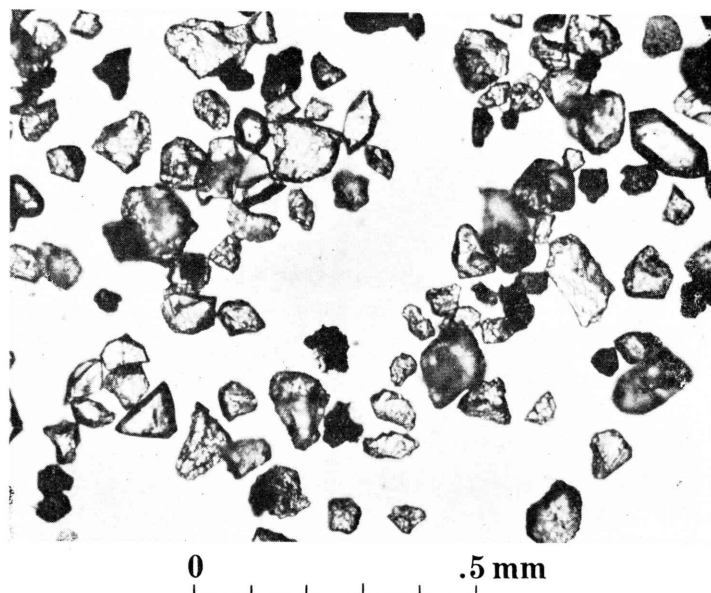


Fig. 6. Heavy residue of sandstone of the Himenoura group, showing the garnet concentrate (Sp. No. Hm. 009 c). Garnet, zircon (prismatic form terminated by pyramids), and opaques. Photo by H. OKADA.

equal amounts in the Goshonoura group, whereas in the Himenoura group the former prevails over the latter. Orange- to brown-colored garnet is infrequently met with. The grains are generally of roughly equidimensional or sometimes splintery fragments which show usually a conchoidal fracture. Euhedral garnet of dodecahedron or trapezohedron is rather meager. A large proportions of the grains display an intense hackly appearance especially of a minute rhomb-pattern which is a prevailing character among the garnet grains particularly of the Himenoura group. This is a passage appearance of corrosion of garnet, according to SMITHSON (1941). He states in his study of the Mesozoic rocks of Yorkshire that a corrosion of garnet develops from the first stage of a slightly mammillated surface through a development of a minute rhomb-pattern to a formation of a "skeleton crystal" and finally leads to the total disappearance of the mineral. Inclusions are not common. Although most of the grains are isotropic, only a few grains show anomalous incomplete extinction. Rounded grains are less common.

(f) *Muscovite*. Muscovite is commonly found throughout the formations. It is present as thin, colorless or grayish, irregularly shaped flakes in basal cleavage and scaly aggregates which may be sericite.

(g) *Tourmaline*. Tourmaline is not uncommon but persistently widespread in this Cretaceous succession. It occurs in general as a normal prismatic crystal. Three major varieties are discriminated; brown, green, and blue ones. According to KRYNINE (1946), brown variety is a tourmaline from pegmatized injected metamorphic terrains, green one is a granitic tourmaline, and blue one is a pegmatitic tourmaline. In the present case a brown variety is prevalent. A blue variety of very small amount might be indicolite, although it could not be precisely identified.

Opaque inclusions and spherical cavities are sometimes met with.

(h) *Hornblende*. Common hornblende is widespread and locally abundant. Two varieties are recognized, green and brown. The pleochroism noted is the change from pale color to darker shades with regard to the above colors. Almost all of the grains are of green hornblende. They occur usually as thick prismatic flakes. A hacksaw structure is detectable in some grains.

The present mineral tends to be more common in the basal parts of the groups where granitic detritus prevails (Text-fig. 11). Thus it is suggested that hornblende is derived mainly from the granitic rocks.

(i) *Augite*. This is infrequently met with. It presents faint greenish color. Prismatic grains are rare. Opaque dust and other inclusions are present but not common.

(j) *Spinel*. The present mineral occurs as sprinterly or irregularly-shaped, dark blood-red flakes with uneven fracture. It is of a low frequency but widely detected.

(k) *Rutile*. Rutile is not widespread but occasionally found. It occurs generally as more or less worn prismatic grains, and sometimes as irregularly-shaped angular fragments. Ovoidal form is rare. Euhedron with bipyramidal terminations is also met with. Geniculately twinned form is not detected. An oblique striation is often observed on the prismatic grains. This is deep red or amber in color, exhibiting weak pleochroism.

(l) *Apatite*. The apatite grains are an infrequent constituent but very locally not uncommon. They are recognized chiefly by their lack of color and gray interference color with straight extinction. They are present as an unaltered spherical to elliptical form or euhedron. The grains commonly contain spherical cavities, unidentified rod-shaped inclusions, and black opaque dusts.

(m) *Hypersthene*. This is very restricted in occurrence. The grains usually show subhedral prismatic habit with strong pleochroic scheme from green to pinkish brown, and sometimes well-worn grains are also met with. They often take a large form as compared with other heavy residues, attaining the maximum size of 0.19 mm by 0.11 mm. Opaque inclusions are contained.

(n) *Anatase*. Only one individual grain is found (Sp. No. GS 138). It shows a typical euhedral crystal of bipyramidal form, presenting brownish yellow color. It is striated in parallel to the intersection of  $[110]$  and  $[111]$ .

(o) *Opaque minerals*. Pyrite, magnetite, and ilmenite are present in considerable amounts in all the specimens, although variable. Hematite is not widespread.

Pyrite is the most abundant and widespread opaque, occurring as pyritohedra, octahedra, clusters as well as aggregates of spherical and/or stellate forms. Some of

the irregular and stellate forms may be marcasite as has been identified in the Lower Tertiary sandstones of Hokkaido (OKADA, 1960a).

#### D. Notes on the chemical composition of selected samples from the Goshonoura group

Available data on the chemical composition of sedimentary rocks, especially sandstones are very few in Japan, although chemical data of this sort seem to be very useful for clarifying diagnostic features of the sediments. In this respect, a chemical analysis has been attempted for selected samples from the Goshonoura group. They are basal arkose and red siltstone which are the most remarkable sediments of the Goshonoura.

For the chemical analysis of the basal arkose specimen GS 21 has been selected, because it is relatively homogeneous and free from carbonate cement. The results obtained are presented in Table 6 (Anal. 1). The data of the classical arkose deposits and the averaged chemical composition of arkose given by PETTIJOHN (1957) are cited

Table 6. Chemical composition of arkose.  
(percent)

	1	2	3	4	5	6	7
SiO <sub>2</sub>	77.28	76.94	75.57	73.32	79.30	80.89	76.37
TiO <sub>2</sub>		0.20	0.42	—	0.22	0.40	0.41
Al <sub>2</sub> O <sub>3</sub>	15.32	10.70	11.38	11.31	9.94	7.57	10.63
Fe <sub>2</sub> O <sub>3</sub>	0.64	0.10	0.82	3.54	1.00	2.90	2.12
FeO		1.05	1.63	0.72	0.72	1.30	1.22
MnO		0.00	0.05	t	0.02	—	0.25
MgO	0.99	1.76	0.72	0.24	0.56	0.04	0.23
CaO	0.66	2.50	1.69	1.53	0.38	0.04	1.30
Na <sub>2</sub> O	2.25	2.10	2.45	2.34	2.21	0.63	1.84
K <sub>2</sub> O	2.68	2.80	3.35	6.16	4.32	4.75	4.99
P <sub>2</sub> O <sub>5</sub>		0.10	0.30	—	0.05	—	0.21
SO <sub>3</sub>	0.01						
H <sub>2</sub> O+		1.08	1.06		0.55		0.83
H <sub>2</sub> O-		0.18	0.05	0.30	0.41	1.11	
CO <sub>2</sub>			0.51	0.92	—	—	0.54
Loss on Ig.	2.32						
	102.15	99.51	100.00	100.20	99.68	99.64	100.94

1. Basal arkose of the Goshonoura group (Zone  $\alpha$ =Member Ia); Sp. No. GS 21; color 5 GY 7/2 (grayish yellow green) [Analyst: Mitsuo NAKAMURA].
2. Akaiwa arkose, Tetori group, Lower Cretaceous, Japan (MAEDA, 1960, p. 685).
3. Torridonian arkose (average of three analyses), Precambrian, Scotland (KENNEDY, 1951, p. 258).
4. Lower Old Red Sandstone, Devonian, Scotland (MACKIE, 1901, p. 58).
5. Jotnian arkose, Precambrian, Finland (LOKKA, 1950).
6. Unmetamorphosed sparagmite, Norway (BARTH, 1938, p. 58).
7. Average arkose (PETTIJOHN, 1957, p. 324).

Table 7. Chemical composition of red siltstone.  
(percent)

	1	2	3	4	5	6	7	8	9
SiO <sub>2</sub>	58.44	57.77	68.24	52.89	77.54			54.68	58.10
TiO <sub>2</sub>				1.39	0.79			0.98	0.65
Al <sub>2</sub> O <sub>3</sub>	21.73	16.14	14.79	15.83	7.69			15.83	15.40
Fe <sub>2</sub> O <sub>3</sub>	9.07	15.67	5.69	5.87	1.77	7.97	1.75	7.14	4.02
FeO		1.55				0.19	0.49	1.10	2.45
MnO		0.08						0.07	
MgO	1.42	2.10	3.53	6.39	1.77			2.81	2.44
CaO	0.62	3.39	2.60	3.97	2.61			3.14	3.11
Na <sub>2</sub> O	1.30		1.16	0.72	1.70			1.87	1.30
K <sub>2</sub> O	3.31		0.14	3.23	1.66			4.06	3.24
P <sub>2</sub> O <sub>5</sub>				0.14	0.09			0.41	0.17
SO <sub>3</sub>	0.01		0.01	t	nil			—	0.64
H <sub>2</sub> O+								5.33*	5.00*
H <sub>2</sub> O-									
CO <sub>2</sub>								2.11	2.63
BaO									0.05
C									0.80
Loss on Ig.	4.88	6.52	3.92	9.11	3.67				
	100.78	103.22	100.08	99.54	99.29			99.53	100.00

1. Red siltstone, Lower formation, Goshonoura group; Sp. No. GS Ex. 1; color 5R 3/4 (dusky red) [Analyst: Mitsuo NAKAMURA].
  2. Red siltstone, Upper formation, Mifuné group, Cretaceous; Sp. No. MF. 2056; color 5R 3/4 [Analyst: Yeiko YOSHINAGA].
  3. Green very fine-grained sandstone, Upper formation, Mifuné group; Sp. No. MF. 2064; color 5G 5/2 (grayish green) [Analyst: Mitsuo NAKAMURA].
  4. Red blocky shale, Ninnescah formation, Permian, Kansas (SWINEFORD, 1955, pp. 122-123).
  5. Red sandy siltstone, Salt Plain formation, ditto (SWINEFORD, 1955).
  6. Red specimen, Wind River formation, Eocene, Rocky Mountains region (cited in Van HOUTEN, 1948, p. 2093).
  7. Ditto.
  8. Average red shale, Muhos formation, Finland (SIMONEN *et al.*, 1955, p. 68).
  9. Average of 78 shales (CLARKE, 1924, p. 631).
- \* Reported as H<sub>2</sub>O.

for comparison (Table 6, Anal. 2-7). The chemical composition of the Goshonoura arkose is similar to that of the Cretaceous Akaiwa arkose from the Hida Mountains of central Japan (MAEDA, 1960) and to that of the late Precambrian Torridonian arkose from Scotland (KENNEDY, 1951). An unexpected character of the Goshonoura arkose is its low percentage of K<sub>2</sub>O just as in the Akaiwa arkose, despite its rather high content of orthoclase feldspar. MAEDA (1960) attributed the low K<sub>2</sub>O content of the Akaiwa to the chemical character of its basement rock which is regarded to be comparatively low in K<sub>2</sub>O content. As to the Goshonoura arkose, however, more interpretable chemical data are needed not only on the present arkose itself but also on

the granitic rocks around the Goshonoura area.

A selected representative of the red siltstone is specimen GS Ex. 1, from Member Ia, in which red siltstones are associated with the arkose sandstones. Another sample, MF. 2056, from the Upper formation of the Mifuné group, has been analysed. The color of the samples is dusky red (5R 3/4). The results obtained are presented in Table 7 (Anals. 1, 2) together with several published data of red siltstones and a new datum of green, very fine-grained sandstone from the Mifuné group for comparison. The most remarkable point in the chemical composition of the Goshonoura and Mifuné red siltstones is much higher content of  $\text{Fe}_2\text{O}_3$  than that of other listed data or even than the sum of  $\text{Fe}_2\text{O}_3$  and FeO of them (Table 7). This is more stressed in the Mifuné red siltstone. The closely associated green sediments in the Mifuné group have as much  $\text{Fe}_2\text{O}_3$  content as certain other examples of red siltstones but show much lower  $\text{Fe}_2\text{O}_3$  content than the analysed Mifuné red siltstone (Table 7, Anal. 3). Thus, the remarkably high content of  $\text{Fe}_2\text{O}_3$  seems to be a common character of the Cretaceous red sediments in Goshonoura and Mifuné groups. The percentage of CaO in the Goshonoura is smaller than that of other available data. To give generalized comments on the Cretaceous red beds in Middle Kyushu, more available data are needed.

### III. Petrographic Remarks

#### A. Stratigraphic zonation of the Goshonoura group based on mineral assemblage

Zonal succession is of great significance in stratigraphic classification and correlation. Especially a zone defined by one or more distinctive fossil species is important as a fundamental unit of biostratigraphy. In addition, many other features are used for the identification or discrimination of rock-stratigraphic units. Heavy mineral zones are an instance. Their usefulness in identification and correlation of strata, especially where fossils are rare or lacking, has been repeatedly pointed out with many excellent examples by sedimentary petrologists (REED *et al.*, 1927; EDSON, 1932; COGEN, 1936, 1940; STOW, 1938; ANDERSON *et al.*, 1948; SHUKRI *et al.*, 1954; PETTIJOHN, 1957). The proportion and kind of the major constituents should be also taken into consideration.

On the basis of the major and minor mineralogical constituents of the sandstones, petrographic zones are discriminated in the Cretaceous sequence of Goshonoura Island, each of which has characteristic features clearly different from those of other contiguous zones above and below (Table 8). Of course, such an attempt is effective within a certain tectotope.

In the Cretaceous sandstones of the Goshonoura Island specimens have almost the same petrographic features within a definite stratigraphic subdivision. Thus, averaged features of each subdivision are illustrated in histograms (Text-figs. 7-9, 11). The zones have been determined by the presence of mineral species and other sandstone attributes as well as their relative proportions. Brief notes on each of the proposed

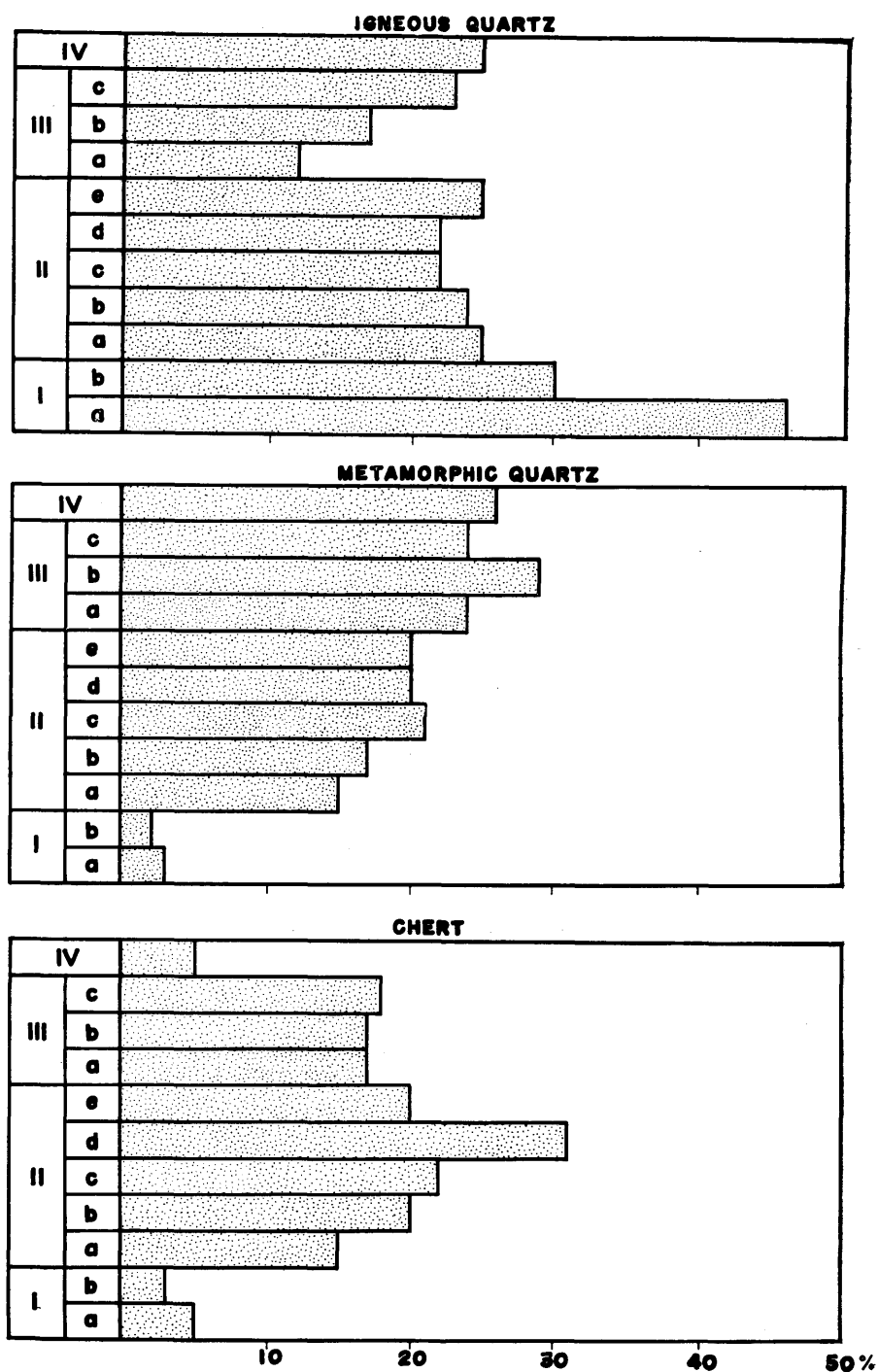


Fig. 7. Vertical variations of major constituents of sandstones from Goshonoura Island (H. OKADA Del.).

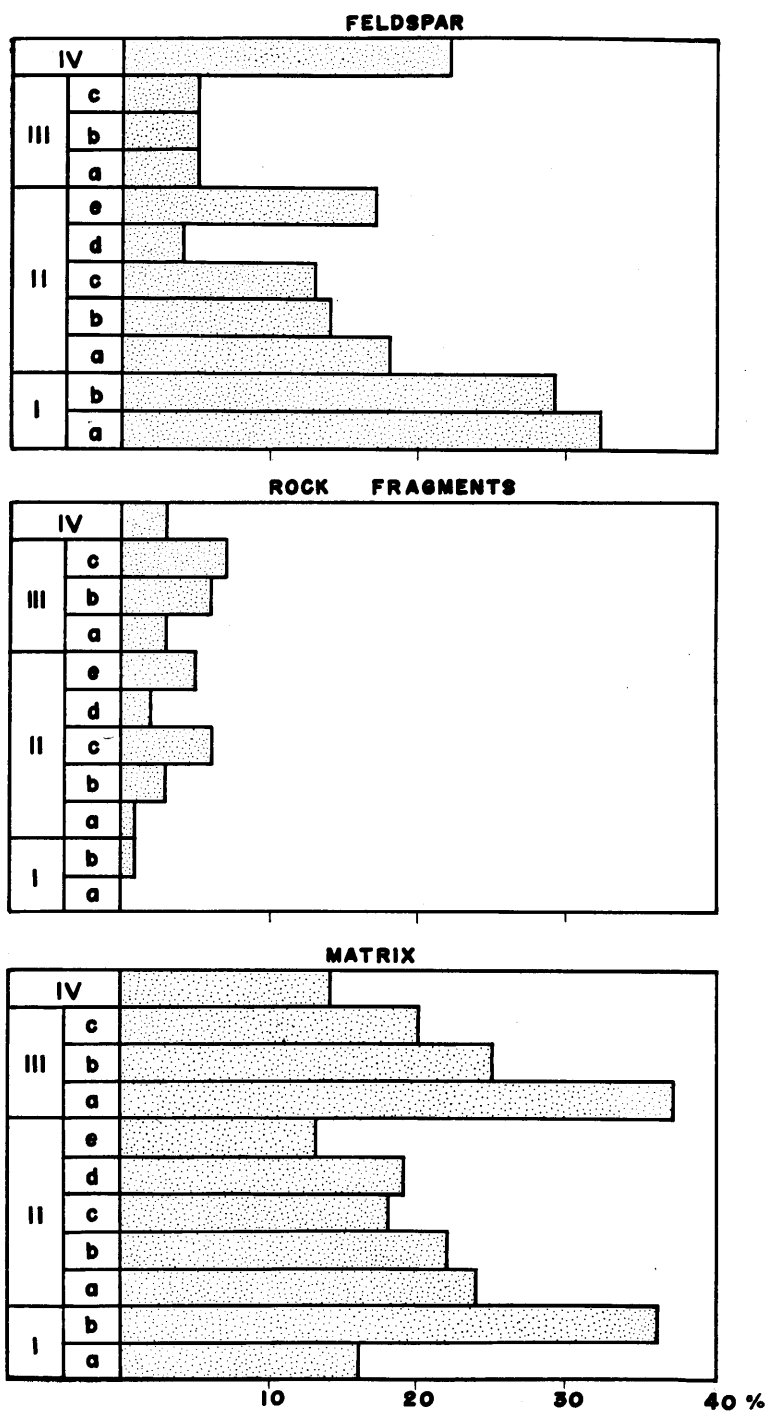


Fig. 7.—(Continued)

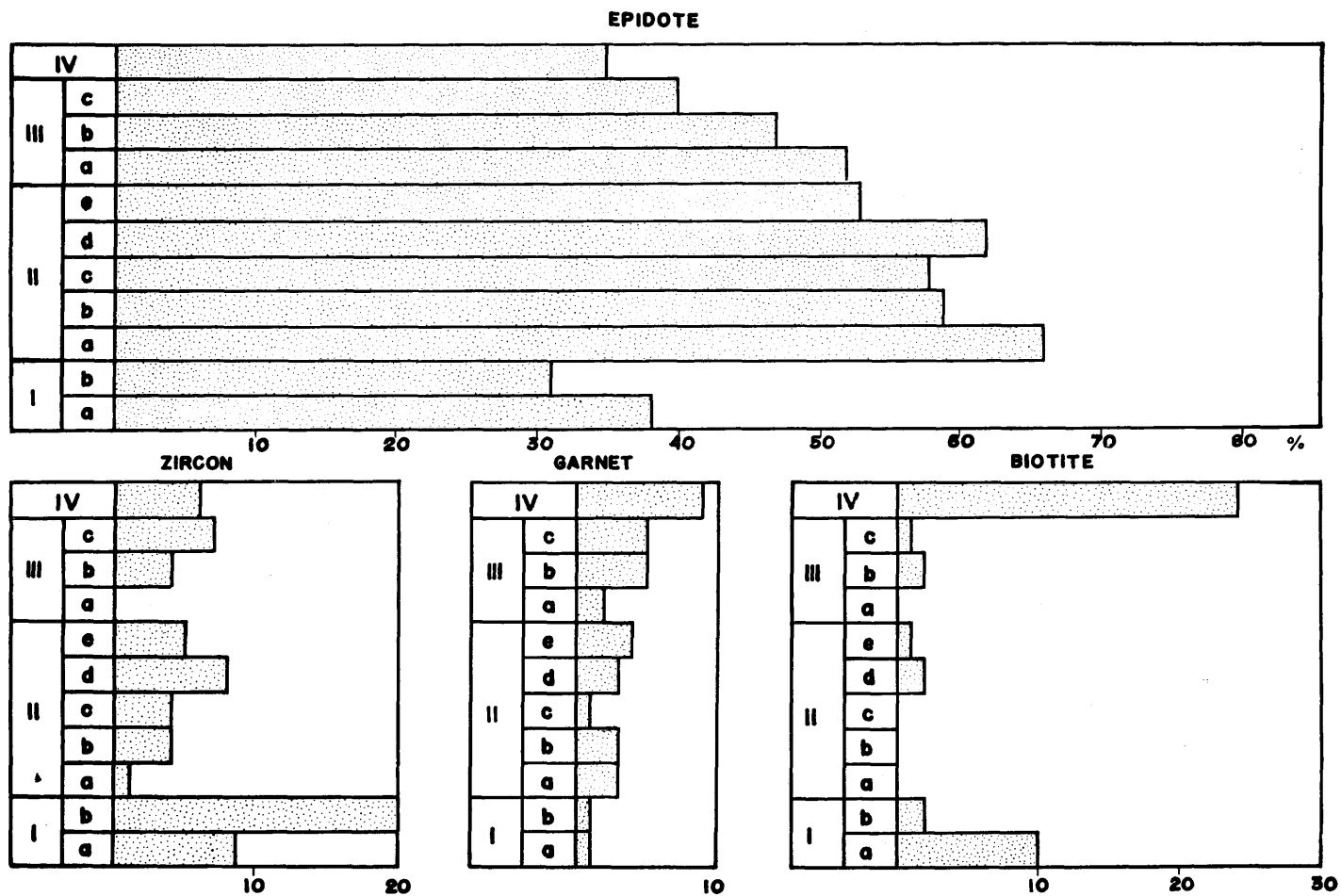


Fig. 8. Vertical variations of selected heavy minerals of sandstones from Goshonoura Island (H. OKADA Del.).



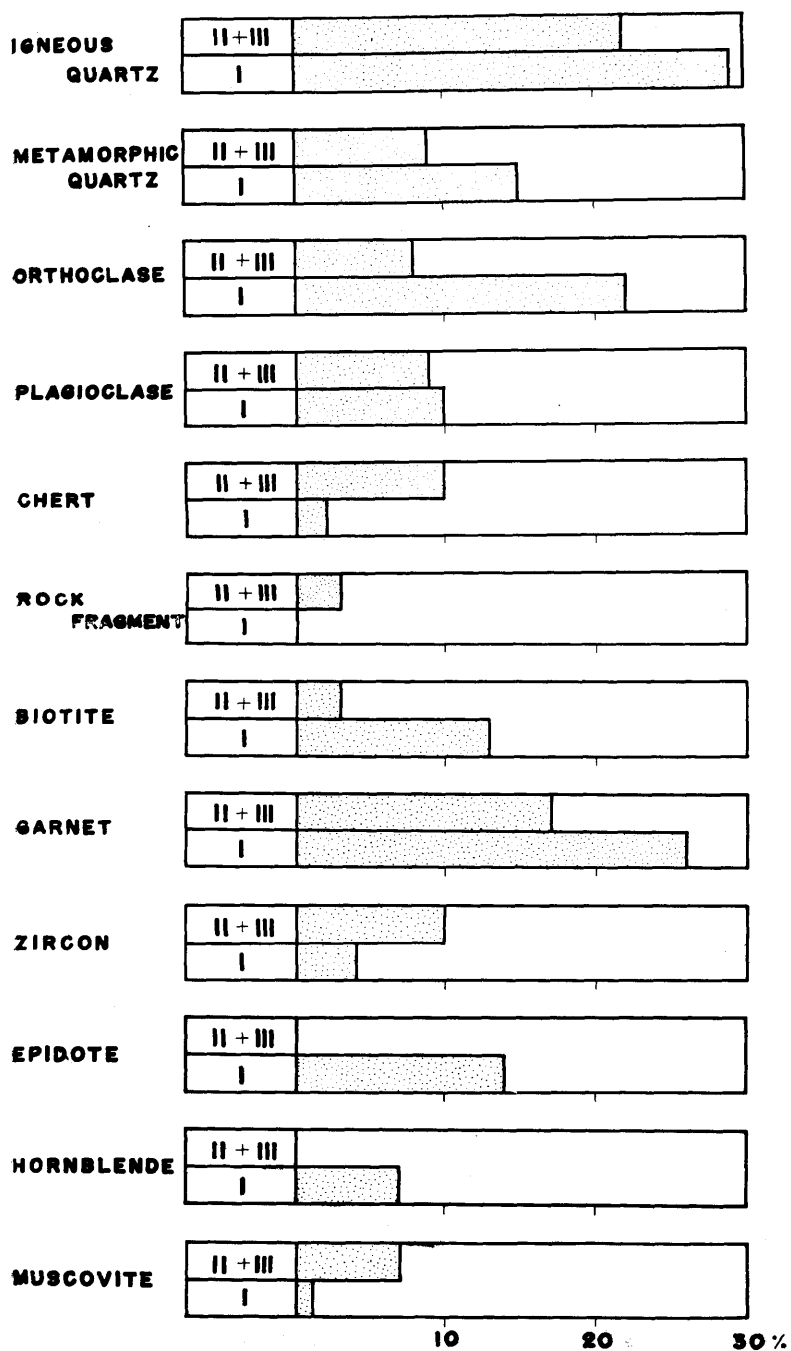


Fig. 9. Vertical variations of selected constituents of sandstones of the Himenoura group in the type section (H. OKADA Del.).

zones are given as follows in the ascending order :

(1) *Zone  $\alpha$* . Zone  $\alpha$  is represented by Member Ia of the Goshonoura group. It is characterized by predominance of feldspar, igneous quartz, biotite, and hornblende, but is almost free from volcanic rock fragments. In this zone, arkose or A<sub>1</sub> type sandstone prevails.

(2) *Zone  $\beta$* . This zone occupies Member Ib. It is distinguished by high proportions of zircon and matrix. In these points it differs from Zone  $\alpha$  below as well as Zone  $\gamma$  above. Feldspar content is still remarkably high in it, as in the underlying zone  $\alpha$ . Feldspathic graywacke of A<sub>2</sub> type is the prevailing sandstones.

(3) *Zone  $\gamma$* . This refers to the intervening part between the readily identified Zone  $\beta$  below and Zone  $\delta$  above, ranging from Member IIa to Member IIc. Mineralogically it has less diagnostic features than other zones, but it can be distinguished by the following points. First, biotite is absent or exceedingly rare in this zone. Secondly, epidote, metamorphic quartz, and chert come out extraordinarily predominant, in that Zone  $\gamma$  is distinctively differentiated from the underlying zone  $\beta$ , but such a tendency is succeeded by Zone  $\delta$  contiguously above. Thirdly, the sandstones are feldspathic graywacke of B<sub>2</sub> type, which is slightly different from B<sub>1</sub> type of Zone  $\beta$  but much so from C type of the succeeding zone  $\delta$ .

(4) *Zone  $\delta$* . This is represented by Member IId. It is characterized by a small amount of feldspar and relatively higher contents of epidote, biotite, zircon, and chert. In these respects, Zone  $\delta$  is clearly distinguished from the overlying zones. Feldspathic graywacke of C type prevails in this zone.

(5) *Zone  $\epsilon$* . Zone  $\epsilon$  is represented by Member IIe. It is characterized by a large percentage of feldspar. With this point it is distinguished from the contiguous zones above and below. Sandstones of Zones  $\alpha$  and  $\theta$  likewise have extremely high content of feldspar but those of Zone  $\epsilon$  mostly show a much larger percentage of matrix, although there is a small amount of arkoses in Zone  $\epsilon$ . The present zone is dominated by feldspathic graywacke of B<sub>1</sub> and B<sub>2</sub> types.

(6) *Zone  $\zeta$* . This occupies the whole part of Member IIIa. The sandstones of this zone are discriminated by high quantity of matrix and negligible amounts of zircon and biotite. Otherwise they are rather similar to those of the superjacent zone  $\eta$ . They are represented by feldspathic graywacke of C type.

(7) *Zone  $\eta$* . This applies to the combined members IIIb and IIIc. It has less diagnostic mineralogical features than others but somewhat dominant rock fragments and reappearance of zircon and biotite may be good criteria to recognize the zone. Especially frequent occurrence of purple zircon in Member IIIc is worthwhile to pay attention. The lithologic pattern of the sandstones in this zone is chiefly lithic graywacke and partly feldspathic graywacke of type C.

Zonation can be extended to the overlying Himenoura group. In this group even a preliminary investigation leads us to discriminate at least the following two zones.

(8) *Zone  $\theta$* . This is represented by the stratigraphic division IV in Goshonoura Island and at the same time by the Lower formation of the Himenoura group in its type area. Zone  $\theta$  is definitely characterized by the abundant and widespread occur-

rence of biotite, garnet, and feldspar. In the type section of the Himenoura group hornblende is an important constituent in addition to the above, and the roundness of grains is exceedingly low.

(9) *Zone  $\iota$* . This is represented by the Middle and Upper formations of the Himenoura group. In this zone epidote is extremely rare. In addition, hornblende, biotite, and feldspar decrease suddenly in their quantities.

Table 8. Scheme of mineral zones in the Goshonoura and Himenoura groups.

STRATIGRAPHIC DIVISION			ZONE
HIMENOURA GR.	III		$\epsilon$
	II		
	I		$\theta$
GOSHONOURA GROUP	III	c	$\eta$
		b	
		a	$\zeta$
	II	e	$\epsilon$
		d	$\delta$
		c	$\gamma$
		b	
		a	
		I	b
	a		$\alpha$

The above described zones are summarized in Table 8, and their geological distribution is illustrated in Text-fig. 10. Incidentally MATSUMOTO (1938) states that in the Middle formation of the Goshonoura group Members IIa and IIc are similar in litho- and bio-facies, as are Members IIb and IIe and also Members IId and Ib. The first two are indeed similar in mineralogic point of view, being included in Zone  $\gamma$ , but the second and the last two can be respectively distinguished from each other by mineral assemblage. Thus, the zones defined by mineral assemblage are useful in stratigraphic correlation within a tectotope of the Goshonoura and Himenoura basins.

### B. Provenance

A close investigation of major constituents of the given sandstones as well as their heavy mineral assemblages is an effectual approach to the interpretation of their source rocks. As guides to provenance have been taken into consideration chiefly the types of quartz (KRYNINE, 1941; BOKMAN, 1952a; WEAVER, 1955; *etc.*) and feldspar (MIZUTANI, 1959), heavy minerals (BOSWELL, 1933; Van ANDEL, 1959), especially their particular suites (PETTIJOHN, 1957; *etc.*), and some minerals diagnostic of a particular type of rocks (KRYNINE, 1946). On the basis of some of these predecessors' works, possible provenance is considered of the Cretaceous deposits investigated.

The following is the comments on provenance that is induced mainly from mineral compositions.

Zone  $\alpha$  or the lowest member Ia gives direct evidence of plutonic—probably granitic source, and also minor evidence of metamorphic and chert-bearing sedimentary sources. Most of the quartz grains are typically of the plutonic type (WEAVER, 1955), being considerably angular in roundness. Feldspar content is highly abundant, in which orthoclase is particularly of significant amount. Its grains present fragmentary and irregular shape of extremely low roundness. Therefore, granitic rocks were no doubt a contributor of detritus in this period of

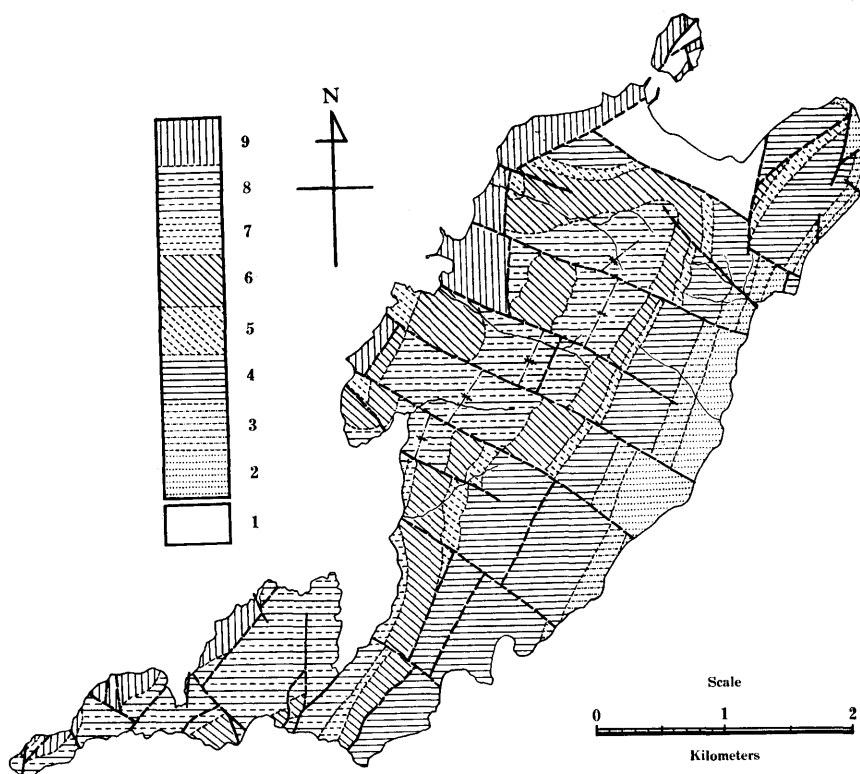


Fig. 10. Geological map showing distribution of mineral zones in Goshonoura Island (H. OKADA Del.).

1: Granite, 2: Zone  $\alpha$ , 3: Zone  $\beta$ , 4: Zone  $\gamma$ , 5: Zone  $\delta$ ,  
6: Zone  $\epsilon$ , 7: Zone  $\zeta$ , 8: Zone  $\eta$ , 9: Zone  $\theta$ .

sedimentation. This is further reinforced by the mineral suite of hornblende and biotite. Moreover, extremely low roundness of grains and their poor sorting lead us to conclude that source area was not in a distance. The granitic rock exposed at the northern corner of Goshonoura Island may represent a portion of the source granite, although its relation to the Goshonoura group is presumed to be in fault contact at present. As to the relation of this granitic basement to the "Miyanojima granite" (MATSUMOTO, 1949; YAMAMOTO, 1935) of the main island of Kyushu further study is needed.

In addition, the presence, although insignificant, of the metamorphic quartz indicates that at least some of the grains owed their source to the metamorphic rocks. Furthermore, fragments of pure chert and clayey or silty chert suggest an older sedimentary source. These auxiliary rocks must have constituted a blanket covering granitic bodies. This blanket for the most part must have been stripped off and the granitic rocks may have been under active erosion.

A problem to be particularly noted is what the provenance of a considerable amount of epidote is. In the contemporaneous Mifuné group I have postulated its origin in metamorphic rocks such as green schists (OKADA, 1960b). The present zone

bears little amount of metamorphic components as stated above, in spite of rather considerable amount of epidote, while pebbles of granitic rocks in the sandstones sometimes bear epidote. In this respect it may pertinently follow that at least during the period of this sedimentation, many, if not all, of the epidote grains have been derived from igneous rocks, especially granitic rocks. In the present state of knowledge, however, I hesitate to give a final conclusion as to its origin, since there are many cases in its formation as reviewed in the foregoing chapter (p. 21).

Member Ib or Zone  $\beta$  follows Member Ia or Zone  $\alpha$  unchangeably in respect to the provenance.

Succeeding that stage, there is a distinct change in mineral compositions between Zone  $\beta$  and Zone  $\gamma$ . The most important change is a drop in the feldspar content from 29 percent in Zone  $\beta$  to 13 to 18 percent in Zone  $\gamma$ . Biotite and hornblende disappear in passing from Zone  $\beta$  to Zone  $\gamma$ , as does igneous quartz. In clear contrast to the above, metamorphic quartz, chert, volcanic rock fragments, and epidote display a remarkable rise in amounts; epidote from 31 to 58 to 66 percent, chert from 3 to 15 to 22 percent, metamorphic quartz from 2 to 15 to 21 percent, and rock fragments from 1 to 2 to 6 percent. These facts imply a vicissitude of provenance. That is to say, integrating the informations stated above, it may be possible to visualize the source area during deposition of Zone  $\gamma$  as consisting of two dominant rocks, *viz.* a large area consisting chiefly of low-rank metamorphic rocks and a series of folded chert-bearing sedimentary rocks as shown by the fractures in chert grains. This inference of a sedimentary terrain is justified by the presence of relatively well rounded individual grains of quartz which show the roundness of 0.7 or more. The source of the angular igneous quartz is not precisely known; it may have come from older angular-grained sandstones, but it is most likely derived from igneous rocks, and less likely from non-strained metamorphics. The presence of orthoclase, microcline, and myrmekite suggests such a plutonic rock as leucocratic granite as one of the sources.

Summarizing the above, during deposition of Zone  $\gamma$  the source area was made up chiefly of extensive low-rank metamorphics together with chert-bearing sedimentaries and subordinately of igneous rocks.

Zone  $\delta$ , succeeding Zone  $\gamma$ , is characterized by a sudden drop in feldspar content and a striking increase of biotite and zircon. Such an apparent change does not always mean a significant vicissitude in back ground of source rocks, but may be explained by a change of a depositional environment (see also the next chapter, p. 36).

In other words, metamorphic and sedimentary terrains were probably a primary source during this period, and some parts of detritus might have been derived secondarily from the previously deposited sequence by current scouring.

In Zone  $\epsilon$ , feldspar recovers its percentage to as much as about 17. It follows that at least to a certain extent granitic rocks took part in contributing detritus. In this connection, arkose sandstone is traced especially on the northwestern coast of the island (Sp. Nos. GS 30, 32, 106; see Text-fig. 2). Therefore, it is summarized that important contributors of detritus were metamorphic *plus* sedimentary terrains

with a local exposure of granitic rocks.

In Zone  $\zeta$  zircon and biotite get obsolete. Similarly feldspar and igneous quartz decrease in amounts. These facts hence mean that metamorphics and sedimentaries played an important role as source rocks in this stage.

Such a major tendency is followed by the overlying zone  $\eta$ . This suggests that the erosion in metamorphic and sedimentary blankets continued throughout this stage. The direct provenance of purple zircon, which is commonly present in Member IIIc, is rather hard to be explained herein at present. It might have something to do with boulder-bearing fanglomeratic deposits comprising boulders and cobbles of gneissose and granitic rocks, which are locally interbedded. Its ultimate source is said to be the Precambrian granite according to TOMITA (1954). Thus, exposure and disintegration of granitic and highly crystallined rocks which supplied voluminous detritus in the next stage may be foreshadowed in this stage.

From Zone  $\eta$  to Zone  $\theta$  a very distinct change occurred in mineral constituents as well as in sandstone types. The most serious change is an abrupt rise in biotite from 1 to 24 percent, garnet from 5 to 9 percent, and feldspar from 5 to 22 percent. In addition, hornblende also suddenly increases in amount. In sharp contrast to the above, chert shows a sudden drop in content from 18 to 5 percent. These facts imply an intense tectonic change in provenance areas. As a result, a vast basement of granitic and highly crystalline rocks was revealed and succeeded by an active erosion, providing the depositional sites with the bulk of granular material during the time of Zone  $\theta$ . Much metamorphic quartz may have mainly inherited from gneissose metamorphics. Ill-sorted and highly angular-grained detritus constituting the arkose must have been brought directly from the basement.

UEDA *et al.* (1960) has reported in detail the unconformable relation between the Himenoura group and the basement, and described that boulders and pebbles in the conglomerates of the Lower formation are made up of granodiorite *plus* dike rocks of porphyrite, quartz-porphyry, and diorite as well as gneiss *plus* limestone, depending on the geology of the basement, which consists of granodiorite and metamorphic rocks. The former is called the "Pre-Himenoura granodiorite" (UEDA *et al.*, 1960) which may be a variety of the "Miyano-hara granodiorite" (YAMAMOTO, 1951, 1952, 1953). The latter comprising gneiss and crystalline limestone, accompanied by serpentinite, is an western extension of the "Higo gneiss" (MATSUMOTO, 1949; YAMAMOTO, 1953).

Shortly, from these direct and indirect evidences, detritus of Zone  $\theta$  is no doubt for the most part derived from this basement composed of granodiorite and gneissose metamorphics.

Zone  $\theta$  is succeeded by the uppermost zone  $\iota$  in the type section of the Himenoura group. The change is characterized not only by the decrease of epidote from 14 percent to almost nil, hornblende from 7 percent to negligible amount, biotite from 13 to 3 percent, and orthoclase from 22 to 8 percent, but also by the increase of chert from 2 to 10 percent and volcanic rock fragments from nearly nil to 3 percent. Thus, it may be postulated that the previous main source of plutonics and metamorphics was diluted by the influx of detritus from sedimentaries with subordinate volcanics.

In conclusion, the deposition of the Goshonoura group began with the influx of the bluk detritus from the granitic basement together with minor supply of low-rank metamorphics and chert-bearing sedimentaries. As the transgression proceeded, it was followed by the culminated supply of low-rank metamorphics and sedimentaries during deposition of the main part of the Goshonoura, with much eliminated source of plutonics, although the last supplied some amount of detritus episodically in a certain stage of this period. On the other hand, volcanic rocks such as andesite and the like were not restricted to the lower stage of the Goshonoura, but increased upwards in amounts throughout the group. Following the period of the Goshonoura characterized chiefly by the metamorphic and sedimentary detritus, this rule was upset by incoming of a vast volume of detritus from plutonics and gneissose rocks, *viz.* the Pre-Himenoura granodiorite and the "Higo gneiss", in the Himenoura group. At the later stage of the Himenoura, the detritals were somewhat diluted by mixing of material from sedimentaries and volcanic rocks.

Changes of the provenance commented above are summarized in Text-fig. 11.

From which direction the detritus of these Cretaceous deposits was brought is hard to be precisely concluded, as far as the available data are concerned. It will be clarified by examining the detritus covering more regional area, more detailed study of selected minerals, and by analysing minor sedimentary structure systematically.

### C. Depositional environments and tectonics

(1) *Zone  $\alpha$  (Arkose suite).* This zone is characterized by the arkose suite, with thin intercalated beds of red siltstones. Thus, the environment of deposition of this stage must have been under a special condition. Similar lithologic suites are reported in the recent sediments of southern Mexico (KRYNINE, 1935), the Triassic Newark series in Connecticut (KRYNINE, 1950; HEALD, 1956b), the Keweenaw deposits in Michigan (WHITE *et al.*, 1954), the Jotnian sandstones in Finland (SIMONEN *et al.*, 1955), the Upper Permian red beds in Kansas (SWINEFORD, 1955), the Cretaceous Yatsushiro formation in Middle Kyushu, Japan (FUJII, 1956; AKATSU, 1959), and so forth.

In reference to the bulk quantity of feldspar in arkose, significance of the detrital feldspar has been a serious controversial matter. One is the theory that certain particular climatic conditions are required to retard chemical decay of feldspar (MACKIE, 1899). The other is the opinion that feldspathic sediments are not always of products under the vigorous climate, as is mentioned in the following.

Recent deposits of arkose, accompanying lateritization, in humid tropics in southern Mexico are reported by KRYNINE (1935), who showed that relief rather than climate is generally the chief factor to determine the feldspar content in sediments. Further, there are many other reports that arkosic sediments can be formed even under warm humid conditions (GOLDMAN, 1915; REED, 1928, 1930). On the other hand, REED, (1924, 1928) called attention to the difficulties of inferring from mineralogic data the ancient climates in his studies of the Californian material. Regarding the Goshonoura arkose, its occurrence reminds us of such arkose deposits as being at present generated in southern Mexico (KRYNINE, 1935). Interbedded red siltstones of the Goshonoura arkose

suite are a characteristic feature. Further, some of the arkose sandstones themselves appear moderately red in that hematitic matter coats the constituent grains. On the other hand, light pinkish appearance of some of them is due to the color of orthoclase, the bulk of components of the arkose. The coexistence of fresh feldspar and severely decayed materials from feldspar may indicate the rapid deposition in stream channels or lakes on land under rather warm humid climate where a kind of lateritization proceeded. Hence coating of some feldspar and quartz grains with red-pigment remained unremoved. In this connection, red siltstones also may have been to some extent inherited from the blankets of red soils produced by terrestrial, highly oxidizing condition or lateritization on the granitic upland as postulated above. The debris disintegrated from the highly relieved source was selectively deposited, to form coarse-grained arkose beds, on the one hand, and siltstone, on the other hand, both of which do not indicate any clear boundary of stratification. Extensive cross-bedding, lenticular shape of the strata, and lack of fossils are favorable for concluding the terrestrial deposition.

In some parts of the arkose of Zone  $\alpha$  feldspar content is exceptionally low. This is presumably due to the same reason as in the disintegrated granites in Texas where the percentage of quartz and rock fragments increases with increasing grain size whereas that of the feldspars and heavy minerals decreases (McEwen *et al.*, 1959).

(2) *Zone  $\beta$  (Feldspathic graywacke suite).* Zone  $\beta$  succeeding to the arkose suite is represented by feldspathic graywacke. This lithologic change only reflects the fluctuation of depositional environments. From faunal assemblage and sedimentary structure, MATSUMOTO (1938, p. 32) has deduced that this is the deposits in a shallow sea or brackish environment and partly in a marshy land near the coast. As is understood from the poor textural maturity (as much as on the average 36 percent clay matrix), the condition must have been in general under a low energy so that the poorly sorted, angular-grained, clay-rich sandstones were produced.

(3) *Zone  $\gamma$  (Feldspathic graywacke suite).* This zone constituting the main part of the Middle formation is again characterized by feldspathic graywacke. In certain mineralogical features it is dissimilar to the foregoing zone, but stratigraphically and palaeontologically the two zones are of successive and gradational relation with each other. Such a lithologic change hence seems to be not so serious as to reflect a major tectonic event, but is due merely to the gradual shift of the principal source area from the plutonics to the metamorphics *plus* sedimentaries.

The interbedded rocks showing variability in grain size, textural maturity, and mineral compositions lead us to imagine that they must be the deposits in two or more environments that were adjoining and rapidly fluctuating from one to another. I agree with MATSUMOTO (1938, pp. 37-38) in that Members IIa and IIc containing fossils of shallow-sea element are the deposits in a high-energy condition to cause a sporadic better sorting of sand particles. They are intervened by Member IIb with large proportions of fine-grained sediments, which must have been laid down offshore in the environment of rather calm-currents, as is also supported by fossils of open-sea element.

(4) *Zone  $\delta$  (Feldspathic graywacke suite).* It is a remarkable fact that less durable



constituents such as feldspar and rock fragments are very scarce throughout this zone. Regarding heavy minerals their assemblage is rather simple, consisting prevalently of more persistent minerals like zircon, garnet, and epidote. Equally noteworthy is that diastem or penecontemporaneous erosion is commonly recognized as a sedimentary feature (MATSUMOTO, 1938, p. 37; reconfirmed by observations of MATSUMOTO, OGURI, and myself on the survey trip, Jan. 9, 1960). In addition, thin red sediments are sometimes interbedded. The diminution of feldspar, rock fragments, and other less durable matters therefore may have been caused mechanically and chemically by an abrasion of high potent current action and subaerial erosion. The littoral environment must have prevailed. On the other hand, source area potency remained unchanged, judging from the mineral composition.

(5) *Zone  $\epsilon$  (Feldspathic graywacke suite)*. The main part of this zone is predominated by massive, fine-grained, or muddy deposits containing abundant fossils of open-sea element, as does Member IIb within Zone  $\gamma$ . Texturally sandstones are well-sorted and better rounded, which are prevalent especially in both upper and lower portions. They may be the deposits by potent energy near the coast. Thus, its depositional environment is similar to that of Member IIb commented above. It is noted that arkosic character is locally recognized in the northwestern part. This local feature seems to locate the granitic uplands to northwest with a considerable distance.

(6) *Zones  $\zeta$ - $\eta$  (Feldspathic and lithic graywacke suites)*. In these serial zones red sediments are characteristically intercalated. Particularly Zone  $\zeta$  must represent depositions in two or more environments which were rapidly fluctuating, as judged from much heterogeneous lithologic characters comprising interbedded mudstone and coarse-grained sediments. A low-energy environment resulted in depositing ill-sorted sandstones with large quantity of clay matrix, which is the prevailing nature in this zone. In passing upwards the red bed occurs remarkably, which is a key to Member IIIb or lower part of Zone  $\eta$ . Thus the environment may be almost similar to that of Zone  $\alpha$  and a part of Zone  $\delta$  in terrestrial or near-coast deposits. Especially noteworthy is the intercalation of fanglomeratic deposits consisting mainly of boulders of granitic and gneissose rocks. As to their geological significance, further study is urgently needed. In spite of the influx of these granitic materials, the averaged content of feldspar is considerably low. It may be primarily because these fanglomeratic deposits were too local in occurrence to be dispersed widely. In addition, the environment of deposition was presumably less favorable for feldspar to survive for ubiquitous distribution, if detritus of feldspar were brought.

(7) *Zone  $\theta$  (Arkose suite)*. The present zone, which represents the lower part of the Himenoura group, is characterized by feldspar in flood. From this and other evidences it is inferred that granitic and gneissose rocks were seriously disintegrated on the exposures of striking relief in and near the coastal region. Sandstones of this zone show consistent textural features irrespective of their geographic distribution. This implies a simple environment of deposition. This arkose suite consists to a great extent of residual and less transported deposits, as judged from the texture.

*Zone  $\iota$  (Feldspathic graywacke)*. As granitic *plus* metamorphic upland became lower in its relief, sedimentaries and volcanics participated in supplying more debris

into this depositional site. There, at least two environments are recognized. One is of low energy to form matrix-rich graywacke and another is of high energy giving rise to well-sorted, matrix-deficient sandstones, although the latter is uncommon in occurrence.

To sum up, the basal arkose of the Goshonoura group is probably the products under moist and rather high temperature climatic condition and in terrestrial and coastal environments. The rest of the Goshonoura begun with deposition in brackish or shallow-sea environment, was followed by the culminated supply of metamorphic and sedimentary detritus into the shallow-sea or sometimes open-sea environments, and at the closing stage a near-coast environment prevailed again. It may be said that subsidence in depositional sites was as a whole in harmony with the upheaval in the provenance, although in minor details depositional environments were rapidly fluctuating.

At the first stage of the Himenoura group, granitic and gneissose rock terrains were intensely uplifted, which were succeeded by exposures of sedimentaries and volcanics. The whole of the Himenoura group was deposited in a marine area which was directly connected with open sea, as is clearly shown by its fauna.

As to the volcanic activity during the deposition of the Goshonoura group, any additional evidences were not obtained, although MATSUMOTO (1938) reported pebbles of volcanic rocks in conglomerate. Now that some twelve beds of tuffaceous rocks are recognized in the adjacent basin of the contemporaneous Mifuné group (MATSUMOTO, 1939a; OKADA, 1960b), their absence in the Goshonoura basin seems to imply that an unstableness of fluctuating sites of deposition was unfavorable for preservation of ash and other volcanic ejecta.

#### **D. A few comments on the Goshonoura graywacke**

Graywackes are characterized by certain attributes and associations, being indicative of special tectonic environment, as is ubiquitously believed. First of all, graded bedding is most characteristic of graywackes. BAILEY (1930, 1936) concluded that current-bedded sandstones belong to relatively shallow water, and graded-bedded sandstones belong to relatively deep water. On the other hand, KUENEN *et al.* (1950) have experimentally proved that graded bedding is the product of submarine-generated turbidity currents. This idea has been cited and advanced by KUENEN (1951) himself and other authors (PETTIJOHN, 1950; *etc.*).

In the case of the Goshonoura group the grading is too poorly developed for its graywacke to be regarded as the deposits of the turbidity flows, and, instead, cross-lamination is rather a common feature. Further some parts are characterized even by an admixture with a large number of pebbles or cobbles. With regard to such an abnormal type of deposition, some examples are reported in the Bentura basin, California (NATLAND *et al.*, 1951), the Stanley graywacke, Arkansas (BOKMAN, 1952b), the Mifuné graywacke, Kyushu, Japan (OKADA, 1960b), recent deep sea deposits in the Hudson Canyon, off New York (ERICSON *et al.*, 1951), *etc.* On the other hand,

KUENEN *et al.* (1952) reviewed the abnormal type of graded bedding and attempted to explain a mechanism of its formation.

Judging from the gross lithologic features, the Goshonoura graywacke was for the most part deposited in the environments within a reach of normal current or wave action. The environments gave rise to no or poor turbidity flows even in the deeper part of the basin, as is represented by the Mifuné graywacke. Therefore, this does not seem to belong to such a special case as the abnormal type of graded bedding explained by KUENEN *et al.* (1952) and as the Stanley graywacke interpreted by BOKMAN (1952b).

Integrating all these facts, the Goshonoura graywacke hence is not of typical geosynclinal deposits which should be as a rule characterized by the graded graywacke.

In addition, another to be especially commented on the Goshonoura graywacke is the content of feldspar which shows a rhythmic variation in the stratigraphic distribution, depending on the degree of influence of granitic and its related rocks in the source area. However, the feldspar content of the Goshonoura graywacke is not so high, as compared with that of the domestic and foreign graywackes (FUJII, 1956, 1958; MIZUTANI, 1957; KIMURA, 1957; KRYNINE, 1937; HELMBOLD, 1952; Van HOUTEN, 1958; *etc.*), although the Goshonoura graywacke abounds in feldspar more than the neighbouring Mifuné. This seems to be merely attributed to the influence of feldspar-bearing rocks of the source area. Furthermore, in the Goshonoura, orthoclase surpasses plagioclase in almost all the examined specimens, as does the K-feldspar of many sandstones (MARTENS, 1931; PETTIJOHN, 1957, p. 125). Consequently, strictly speaking, K-feldspar in the Goshonoura intensely reflects the granitic source, just as in the Jurassic and Cretaceous graywacke in California (BAILEY *et al.*, 1959).

#### **E. Relationship between the Goshonoura group and the Himenoura group**

The very contact between the Goshonoura group and the Himenoura group is observable only at a few localities in the southwestern part of Goshonoura Island. They border each other at present along a presumed high-angled fault in the north-western part of the island. A consecutive relation is only observed in the south-western tip, where the Goshonoura group is apparently conformably followed by the Himenoura group. In other places, as in Maeshima at the northern corner of Goshonoura and in the type area to the northeast the Himenoura rests on granitic rocks with a distinct unconformity.

Heretofore, hence, it had been regarded that the relation between the two groups is conformable with transitional beds (MATSUMOTO, 1938, 1954). Recently a discovery of ammonite species of *Graysonites* cf. *fountaini* YOUNG together with *Desmoceras kossmati* MATSUMOTO from the uppermost member IIc of the Middle Goshonoura has made conclusive the Lower Cenomanian age of that part, casting a question that there might be a stratigraphic gap between the Goshonoura and Himenoura groups or the time range of the deposition of the whole Upper formation of the Goshonoura

group might be relatively long as compared with the Middle Goshonoura (MATSUMOTO, 1960). A resolution of this problem from a petrographical respect is attempted herein. The result of my study may be summarized as follows:

First of all, a lithologic change is very distinct from the lithic graywacke of the Upper Goshonoura to the typical arkose of the Himenoura. It is equally significant that some of the major constituents and accessory minerals exhibit a sudden rise or drop in quantity in passing upwards from the Goshonoura to the Himenoura. Especially, biotite, garnet, hornblende, and feldspar are the examples of a much striking increase, while chert and epidote *vice versa* (see Text-fig. 11).

Taking all these and other stratigraphic facts into consideration, a significant change of tectonics must have taken place not only in the source rock areas but also in the sites of sedimentation. As is remarked by BOSWELL (1916, p. 164), an unconformity is usually emphasized by the changes in mineral composition. This is commented by MILNER (1952, pp. 164-165) with agreement. Consequently, I am inclined to believe that there should be a significant stratigraphic gap between the Goshonoura and Himenoura groups.

Even if we take into consideration the possibility of considerable length of sedimentation period of the Upper Goshonoura (AMANO *et al.* in MATSUMOTO, 1960), the above mentioned gap between the two groups becomes by no means insignificant.

#### IV. Concluding Remarks

##### A. Summary of the petrographical analyses

The petrographical analyses of the Cretaceous sandstones in Goshonoura Island are summarized in Text-fig. 11.

##### B. Regional paleotectonic environments of sedimentation

###### 1. Comparison with the contemporaneous Mifuné group

The Mifuné group of moderate thickness of about 1,500 meters, presenting a cycle of sedimentation, is represented by the graywacke suite of lithologically uniform character throughout the group, except for a greater proportion of red sediments. The Mifuné graywacke is characterized by a considerably high amount of clay matrix and low content of feldspar, containing accessory heavy mineral assemblage of metamorphic rocks. Thus, this graywacke does reflect very strongly metamorphic sources. The main provenances are traceable both to the north and to the south. Another special feature is that the Mifuné graywacke shows no or very poorly developed graded-lamination. Further detailed descriptions of the Mifuné have already been given in another paper (OKADA, 1960b).

The Goshonoura group, on the other hand, is characterized by the arkose suite at the base and by the graywacke suite mostly referable to the feldspathic graywacke in the main part. In particular a rhythmic variance of feldspar content is a remarkable feature. The Goshonoura graywacke is devoid of normal grading as in the

STRATIGRAPHIC DIVISION		ZONE	LITHOLOGIC PATTERNS		CHANGE OF SELECTED CONSTITUENTS											CHANGE OF PROVENANCE			
					IGNEOUS QUARTZ	METAMORPHIC QUARTZ	CHERT	FELDSPAR	MATRIX	ROCK FRAGMENTS	ZIRCON	GARNET	EPIDOTE	BIOTITE	HORNBLende	SEDIMENTARIES	PLUTONICS	METAMORPHICS	VOLCANICS
GOSHONOURA GROUP	HIMENOURA	III		FELDSPATHIC GRAYWACKE															
		II																	
		I																	
	GOSHONOURA GROUP	c	$\eta$	LITHIC GRAYWACKE FELDSPATHIC GRAYWACKE															
		b																	
		a																	
		e	$\epsilon$	B <sub>1</sub> + B <sub>2</sub>	FELDSPATHIC GRAYWACKE ARKOSE SUBERAYWACKE														
		d	$\delta$	C	FELDSPATHIC GRAYWACKE SUBERAYWACKE														
		c	$\gamma$	B <sub>2</sub>	FELDSPATHIC GRAYWACKE														
		b																	
		a																	
		b	$\beta$	A <sub>2</sub>															
		a	$\alpha$	A <sub>1</sub>	ARKOSE														

Fig. 11. Summarized chart showing petrographic characters of sandstones examined (H. OKADA Del.).

Mifuné graywacke. The heavy mineral assemblage indicates partly granitic and partly sedimentary-metamorphic sources.

In conclusion the essential features controlling the lithotope are common to the two groups, while the major difference between them is primarily attributed to the heterogeneous distribution of rocks in the source areas as well as in the basement.

## 2. Regional paleotectonics

A conclusion regarding tectonism in source areas, from a petrographic study of the Goshonoura and Mifuné groups, is that at the incipient stage of their sedimentation the source areas presented a conspicuous relief, which may be referred to the Sakawa orogeny of KOBAYASHI (1941, 1951), and were subjected to rather an epeirogenic upheaval with some local mild orogenic episodes.

In this and following stages the basin-making depression which took place within the mobile belts kept continued subsidence, although negligibly local cease of the subsidence is recorded at certain horizons of the Goshonoura. To the depressions within the deformed belts, KAY (1951) presented definitions of taphrogeosyncline and epieugeosyncline, of which the former is bounded by faults on one or both sides and the latter is a sinking area without faulting. The Mifuné basin characterized by red sediments is partly bounded by faults which seem to be in part contemporaneous with the sedimentation. Thus, the Mifuné has been compared to the taphrogeosynclinal Triassic Newark series in the Appalachians (OKADA, 1960b). Anyway, its sedimentation seems to be related with the tectonic activity along the Median tectonic line, as MATSUMOTO (1939b) remarked. The Goshonoura basin, however, shows no sign of faulting and smaller amount of red beds. Thus, it may be rather epieugeosynclinal.

Although the graywacke suite is typical of many geosynclines and presents the flysch facies to them, an abnormal type of the Goshonoura and Mifuné graywackes cannot be considered at all to represent the flysch facies. Nevertheless their suite cannot either be precisely defined as the molasse facies, although some authors regarded the Cretaceous deposits in Middle Kyushu as the post-orogenic molasse facies resulted from the Sakawa orogenic cycle (KOBAYASHI, 1941, 1951; TOKUYAMA, 1958, 1959). As a matter of fact, basal coarse-grained arkose and conglomerate comprising cobbles and boulders derived from the underlying deformed basement, which are respectively accompanied by red beds may exhibit to be post-orogenic in a broad sense, as reviewed by DUNBAR *et al.* (1957, pp. 315-316). Moreover, the whole area of the Goshonoura and Mifuné groups was subjected to a certain degree of deformation after the deposition. Typical tectonic sediments, however, should be inherited monogenetically from one side, whereas the detritus of these basins now in question is derived polygenetically and in the case of the Mifuné two side sources are evident. Several heterogeneously combined factors furnish the present basins with a peculiar lithotope. Thus I hesitate to call these deposits precisely a molasse facies. They are a variety of the rock associations in post-orogenic basins described by DUNBAR *et al.* (1957).

## References Cited

- AKATSU, Ken (1951): A sedimentological study of the Cretaceous Yatsushiro formation (in Japanese with English résumé). *Unpub. Master's thesis, Kyushu University*.
- AMANO, Masahisa, OGATA, Shinsuke, and NIRE, Naomichi (1958a): On the *Tendagurium* from the lower bed of the Goshonoura group in Shishi-jima, Kagoshima Prefecture, Kyushu, Japan. *Kumamoto J. Sci., Ser. B, Sec. 1, Geol.*, **3**, (1), 17-20, pl. 1.
- AMANO, Masahisa and FURUZAWA, Wakatsu (1958b): On the *Dreissensia* cfr. *lanceolata* (SOWERBY) occurred from the Cretaceous bed in Shishi-jima, Kyushu, Japan. *Ibid.*, 21-26, figs. 1-2.
- ANDERSON, J. L. *et al.* (1948): Cretaceous and Tertiary subsurface geology. *Maryland Dept. Geol. Mines Water Resources Bull.* **2**, 1-113.
- BAILEY, E. B. (1930): New light on sedimentation and tectonics. *Geol. Mag.*, **67**, (2), 77-92, figs. 1-4, pl. 1.
- (1936): Sedimentation in relation to tectonics. *Bull. Geol. Soc. Am.*, **47**, (11), 1713-1725, figs. 1-3.
- BAILEY, Edgar H. and IRWIN, William P. (1959): K-feldspar content of Jurassic and Cretaceous graywackes of northern Coast Ranges and Sacramento Valley, California. *Bull. Am. Assoc. Petrol. Geol.*, **43**, (12), 2797-2809, figs. 1-4.
- BARTH, T. F. W. (1938): Progressive metamorphism of sparagmite rocks of southern Norway. *Norsk Geol. Tidsskr.*, **18**, 54-65.
- BARTON, D. C. (1916): The geological significance and genetic classification of arkose deposits. *J. Geol.*, **24**, (5), 417-449, figs. 1-4, tables 1-3.
- BOKMAN, John W. (1952a): Clastic quartz particles as indices of provenance. *J. Sed. Petr.*, **22**, (1), 17-24, figs. 1-2, tables 1-3.
- (1952b): Lithology and petrology of the Stanley and Jackfork formations. *J. Geol.*, **61**, (4), 152-169, figs. 1-5, tables 1-3, pl. 1.
- 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.
- (1933): On the mineralogy of sedimentary rocks. *Thomas Murby, London*.
- CAROZZI, Albert V. (1960): Microscopic sedimentary petrography. i-viii, 1-485, figs. 1-88, *John Wiley & Sons, Inc., New York and London*.
- CLARKE, F. W. (1924): The data of geochemistry. *U. S. G. S. Bull.* **770**, 1-841.
- COGEN, William M. (1936): Heavy mineral zones in the Modelo formation of the Santa Monica Mountains, California. *J. Sed. Petr.*, **6**, (1), 3-15, figs. 1-11.
- (1940): Heavy mineral zones of Louisiana and Texas Gulf Coast sediments. *Bull. Am. Assoc. Petrol. Geol.*, **24**, (12), 2069-2101, figs. 1-22, table 1.
- DRYDEN, A. L., Jr. (1931): Accuracy in percentage representation of heavy mineral frequencies. *Nat. Acad. Sci., Proc.*, **17**, (5), 223-238.
- DRYDEN, L. (1935): A statistical method for comparison of heavy mineral suites. *Am. J. Sci.*, **29**, (173), 393-408, fig. 1, tables 1-5.
- DUNBAR, Carl O. and RODGERS, John (1957): Principles of stratigraphy. i-xii, 1-356, figs. 1-123, tables 1-11, *John Wiley & Sons, Inc., N. Y.*
- EDSON, F. C. (1932): Heavy minerals as a guide in stratigraphic studies. *Am. Min.*, **17**, (9), 429-436.
- ERICSON, D. B., EWING, M. and HEEZEN, B. C. (1951): Deep-sea sands and submarine canyons. *Bull. Geol. Soc. Am.*, **62**, (8), 961-966.
- FUJII, Koji (1956): Sandstones of the Mesozoic formations in the Yatsushiro district, Kumamoto Prefecture, Kyushu, Japan (in Japanese with English résumé). *J. Geol. Soc. Japan*, **62**, (727), 193-211, figs. 1-10, tables 1-8, pl. 3.
- (1958): Petrography of the Cretaceous sandstones of Hokkaido, Japan. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **6**, (3), 129-152, figs. 1-7, tables 1-7, pl. 23.
- GODDARD, E. N. [Chairman] (1951): Rock-color chart. 2nd print. *Rock-color chart Committee*,

- Geol. Soc. Am., N. Y.*
- GOLDMAN, Marcus I. (1915): Petrographic evidence on the origin of the Catahoula sandstone of Texas. *Am. J. Sci., 4th Ser.*, **39**, (231), 261-287, figs. 1-10.
- HEALD, M. T. (1956a): Cementation of Simpson and St. Peter sandstones in parts of Oklahoma, Arkansas and Missouri. *J. Geol.*, **64**, (1), 16-30, figs. 1-3, tables 1-2.
- (1956b): Cementation of Triassic arkoses in Connecticut and Massachusetts. *Bull. Geol. Soc. Am.*, **67**, (9), 1133-1154, figs. 1-4, tables 1-6, pls. 1-3.
- HELMBOLD, Reinhard (1952): Beitrag zur Petrographie der Tanner Grauwacken. *Heiderberger Beitr. Min. Petr.*, **3**, 253-288.
- IJIMA, Azuma (1959): On relationship between the provenances and the depositional basins, considered from the heavy mineral associations of the Upper Cretaceous and Tertiary formations in central and southeastern Hokkaido, Japan. *J. Fac. Sci., Univ. Tokyo, Sec. II*, (4), 339-385, figs. 1-25, tables 1-35, pls. 21-23.
- KARAKIDA, Yoshifumi (1954): The presence of "Zircon Zone" along a Cretaceous granodiorite-granite contact in North Kyushu (in Japanese with English résumé). *J. Geol. Soc. Japan*, **60**, (711), 517-532, figs. 1-10, tables 1-3.
- KAY, Marshall (1951): North American geosynclines. *Geol. Soc. Am. Mem.* **48**, i-ix, 1-143, figs. 1-20, table 1, pls. 1-16.
- KENNEDY, W. Q. (1951): Sedimentary differentiation as a factor in Moine-Torridonian correlation. *Geol. Mag.*, **88**, (4), 257-266, figs. 1-2, tables 1-4.
- KIMURA, Toshio (1957): The geologic structure and the sedimentary facies of the Chichibu group in the eastern Kii Peninsula: A contribution to the geotectonic study of Southwest Japan. *Sci. Papers Coll. Gen. Educ., Univ. Tokyo*, **7**, (2), 243-272, figs. 1-11, table 1.
- KOBAYASHI, Teiichi (1941): The Sakawa orogenic cycle and its bearing on the origin of the Japanese islands. *J. Fac. Sci., Imp. Univ. Tokyo, Sec. II*, **5**, (7), 219-578, figs. 1-55, pls. 1-4.
- (1954): The origin of the Japanese islands and the Sakawa orogenic cycle—An introduction to the regional geology of Japan (in Japanese) [3rd Ed.], i-xv, 1-352, figs. 1-68, tables 1-17, pls. 1-4, *Asakura Book Co., Tokyo*.
- KRUMBEIN, W. C. (1941): Measurement and geological significance of shape and roundness of sedimentary particles. *J. Sed. Petr.*, **11**, (2), 64-72, figs. 1-2, tables 1-4, pl. 1.
- KRYNINE, Paul D. (1935): Arkose deposits in the humid tropics. A study of sedimentation in southern Mexico. *Am. J. Sci., 5th Ser.*, **29**, (172), 353-363, figs. 1-2.
- (1940): Petrology and genesis of the Third Bradford sand. *Pa. St. Coll. Miner. Indus. Expt. St. Bull.* **29**, 1-134.
- (1946): The tourmaline group in sediments. *J. Geol.*, **54**, (2), 65-87, figs. 1-17, tables 1-3.
- (1950): Petrology, stratigraphy, and origin of the Triassic sedimentary rocks of Connecticut. *Conn. State Geol. Nat. Hist. Survey Bull.* **73**.
- KUENEN, Ph. H. (1951): Properties of turbidity currents of high density. *Soc. Econ. Geol. Paleon., Special Publ.* **2**, 14-33.
- KUENEN, Ph. H. and MIGLIORINI, C. I. (1950): Turbidity currents as a cause of graded bedding. *J. Geol.*, **58**, (2), 91-127, figs. 1-7, tables 1-3, pls. 1-5.
- KUENEN, Ph. H. and MENARD, Henry W. (1952): Turbidity currents, graded and non-graded deposits. *J. Sed. Petr.*, **22**, (2), 83-96, figs. 1-6.
- LOKKA, Lauri (1950): Chemical analyses of Finnish rocks. *Bull. Comm. Géol. Finlande*, (151).
- MC EWEN, Michael C., FESSENDEN, Franklin W., and ROGERS, John J. W. (1959): Texture and composition of some weathered granites and slightly transported arkosic sands. *J. Sed. Petr.*, **29**, (4), 477-492, figs. 1-19, tables 1-7.
- MACKIE, Wm. (1899): The feldspars present in sedimentary rocks as indicators of contemporaneous climates. *Trans. Edinburgh Geol. Soc.*, **7**, 443-468.
- (1901): Seventy chemical analyses of rocks. *Ibid.*, **8**.
- MAEDA, Shiro (1960): Note on the chemical composition of a sandstone from the Tetori group (in Japanese). *J. Geol. Soc. Japan*, **66**, (781), 685-686, figs. 1-2.



- MARTENS, James H. C. (1931): Persistence of feldspars in beach sand. *Am. Min.*, **16**, (11), 526-531, fig. 1, table 1.
- MATSUMOTO, Tatsuro (1938): Geology of the Goshonoura islands, Amakusa, with special reference to the Cretaceous stratigraphy (in Japanese with English appendix). *J. Geol. Soc. Japan*, **45**, (532), figs. 1-12, tables 1-7, pls. 1-4.
- (1939a): Geology of the Mifuné district, Kumamoto Prefecture, Kyushu, with special reference to the Cretaceous system (in Japanese with English résumé). *Ibid.*, **46**, (544), 1-12, figs. 1-2, table 1, pl. 1.
- (1939b): Some geological problems concerning the Central Zone of Kyushu (the "Nagasaki Dreiecke") (in Japanese with English résumé). *Ibid.*, **46**, (550), 366-382.
- (1949): Geology of the Higo-gneiss area (abstract) (in Japanese). *Ibid.*, **55**, (648-649), 122.
- [Editor] (1954): The Cretaceous system in the Japanese islands. i-xiv, 1-324, figs. 1-77, tables 1-2, pls. 1-20. *Japan. Soc. Prom. Sci. Res.*, Tokyo.
- (1960): *Graysonites* (Cretaceous ammonites) from Kyushu, with *Notes on Stratigraphy* by Masahisa AMANO, Tatsuro MATSUMOTO, Hakuyu OKADA, and Hisakazu OGURI. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **10**, (1), 41-58, figs. 1-11, pls. 6 [1]-8 [3].
- MILNER, Henry B. (1952): Sedimentary petrography [3rd Ed.]. i-xix, 1-666, figs. 1-100, pls. 1-52, *Thomas Murby, London*.
- MIZUTANI, Shinjiro (1957): Permian sandstones in the Mugi area, Gifu Prefecture, Japan. *J. Earth Sci., Nagoya Univ.*, **5**, (2), 135-151, figs. 1-8, tables 1-2, pl. 1.
- (1959): Clastic plagioclase in Permian graywacke from the Mugi area, Gifu Prefecture, central Japan. *Ibid.*, **7**, (2), 108-136, figs. 1-11, tables 1-3, pl. 1.
- NATLAND, M. L. and KUENEN, Ph. H. (1951): Sedimentary history of Ventura Basin, California and the action of turbidity currents. *Soc. Econ. Paleon. Miner., Special Publ.* **2**, 76-107.
- OKADA, Hakuyu (1957): On the heavy mineral composition of the Cretaceous Mifuné group, Kyushu (in Japanese). *Synthetic Study of the Late Mesozoic of Japan [Mimeograph]*, (7), 161-165, table 1.
- (1960a): Sandstones of the Paleogene Ikushumbetsu coal-bearing formation, Hokkaido, Japan. *Japan. J. Geol. Geogr.*, **31**, (2-4), 149-164, figs. 1-2, tables 1-3, pl. 11.
- (1960b): Sandstones of the Cretaceous Mifuné group, Kyushu, Japan. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **10**, (1), 1-40, figs. 1-16, tables 1-7, pls. 1-5.
- OKADA, Hakuyu and OGURI, Hisakazu (1960): Sandstones of the Cretaceous Goshonoura group, Kyushu (abstract) (in Japanese). *J. Geol. Soc. Japan*, **66**, (778), 466-467.
- OTA, Yoshihisa (1959): *Trigonioides* and its classification. *Trans. Proc. Palaeont. Soc. Japan*, [N. S.], (34), 97-104, figs. 1-3, table 1, pl. 10.
- PETTJOHN, F. J. (1950): Turbidity currents and graywacke: A discussion. *J. Geol.*, **58**, 169-171.
- (1957): Sedimentary rocks [2nd Ed.], i-xvi, 1-718, figs. 1-173, tables 1-119, pls. 1-40, *Harper & Brothers, N. Y.*
- PUSTOWALOFF, L. W. (1955): Über sekundäre Veränderungen der Sedimentgesteine. *Geol. Rund.*, **43**, 535-550.
- REED, R. D. (1924): Role of the heavy minerals in the Coalinga Tertiary formation. *Econ. Geol.*, **19**, (8), 730-749, figs. 71-72, tables 1-3.
- (1928): The occurrence of feldspar in California sandstones (discussion). *Bull. Am. Assoc. Petrol. Geol.*, **12**, Pt. 2, (10), 1023-1024.
- (1930): Recent sands of California. *J. Geol.*, **38**, (3), 223-245, figs. 1-15.
- REED, R. D. and BAILEY, J. P. (1927): Subsurface correlation by means of heavy minerals. *Bull. Am. Assoc. Petrol. Geol.*, **11**, (4), 359-368.
- SHIROZU, Haruo (1956): Green minerals in sandstones of the Kishima group (in Japanese). *J. Geol. Soc. Japan*, **62**, (728), 280-281.
- (1959): Chlorite (in Japanese). *Miner. J.*, **4**, (1-2), 82-99, figs. 1-3, table 1.

- SHIROZU, Haruo and TANAKA, Bungo (1958): On green sandstones of the Kishima group in the Karatsu coal field, with special reference to green minerals (in Japanese with English résumé). *J. Mining. Inst. Kyushu*, 27, (3), 130-134, figs. 1-2, tables 1-4.
- SHUKRI, M. N. and EL-AYOUTY, M. K. (1954): The mineralogy of Eocene and later sediments in the Anquabia area—Cairo-Suez district. *Bull. Fac. Sci., Cairo Univ.*, (32), 47-61.
- SIMONEN, Ahti and KOUVO, Olavi (1955): Sandstones in Finland. *Bull. Comm. Géol. Finlande*, 28, (168), 57-87, figs. 1-15, tables 1-9, pls. 1-4.
- SMITHSON, Frank (1941): The alteration of detrital minerals in the Mesozoic rocks of Yorkshire. *Geol. Mag.*, 78, (2), 97-112, figs. 1-7.
- STOW, M. H. (1938): Dating Cretaceous-Eocene tectonic movements in Big Horn basins by heavy minerals. *Bull. Geol. Soc. Am.*, 49, (5), 731-762, figs. 1-3, tables 1-4.
- SWINEFORD, Ada (1955): Petrography of Upper Permian rocks in South-central Kansas. *State Geol. Surv. Kansas Bull.* 111, 1-179, figs. 1-13, tables 1-7, pls. 1-24.
- TOKUYAMA, Akira (1958): Die obertriadische Molasse im Mine-Gebiet, Westjapans. 2 Teil Ablagerungseigenschaften und Bodenbewegungen (in Japanese with German résumé). *J. Geol. Soc. Japan*, 64, (757), 537-550, figs. 1-6.
- (1959): Postorogenic sediments (in Japanese with English résumé). *J. Geogr.*, 68, (4), 175 (13)-189 (27), figs. 1-2.
- TOMITA, Tōru (1954): Geologic significance of the color of granite zircon, and the discovery of the Pre-Cambrian in Japan. *Mem. Fac. Sci., Kyushu Univ., Ser. D. Geol.*, 4, (2), 135-161.
- UEDA, Yoshiro and FURUKAWA, Nobutsune (1960): On the Himenoura group of the Amakusa-Kamishima and adjacent islets, Kumamoto Prefecture (in Japanese with English résumé). *Sci. Rpt. Fac. Sci., Kyushu Univ., Geol.*, 5 (1), 14-35, figs. 1-8, tables 1-2.
- VAN ANDEL, Tj. H. (1959): Reflections on the interpretation of heavy mineral analyses. *J. Sed. Petr.*, 29, (2), 153-163, figs. 1-3, table 1.
- VAN HOUTEN, F. B. (1948): The origin of red-banded early Cenozoic deposits in Rocky Mountain region. *Bull. Am. Assoc. Petrol. Geol.*, 32, (11), 2083-2126, figs. 1-3, tables 1-3.
- [Translator] (1958): Contribution to the petrography of the Tanner graywacke. *Bull. Geol. Soc. Am.*, 69, (3), 301-314, figs. 1-5, tables 1-6.
- WEAVER, Charles E. (1955): Mineralogy and petrology of the rocks near the Quadrant-Phosphoria boundary in southwest Montana. *J. Sed. Petr.*, 25, (3), 163-192, figs. 1-11, tables 1-4.
- WHITE, W. S. and WRIGHT, J. C. (1954): The White Pine copper deposit, Ontonagon County, Michigan. *Econ. Geol.*, 49, (7), 675-716, figs. 1-11, tables 1-4.
- YAMAMOTO, Hirosato (1951): On the occurrence of the Miyanojima granitic rocks, Kumamoto Prefecture (abstract) (in Japanese). *J. Geol. Soc. Japan*, 57, (670), 312-313.
- (1952): On the relationship between the Miyanojima granite and the Higo gneiss. (abstract) (in Japanese). *Ibid.*, 58, (682), 277.
- (1953): Metamorphic geology of the Higo gneiss area, Kumamoto Prefecture, with special reference to TOMITA's "Zircon method" (in Japanese with English résumé). *Sci. Rpt. Fac. Sci., Kyushu Univ., Geol.*, 4, (2), 81-93, figs. 1-3, tables 1-9, pls. 1-2.

## Appendix

Romanized geographical names in the Goshonoura and Himenoura areas described in this paper are followed by a corresponding Japanese name. Letters in square brackets [ ] stand for an abbreviated local name used in Text-fig. 2.

Akasé [As]	赤瀬 (御所浦島)	Kurosaki [Kr]	黒崎 (御所浦島)
Akazaki	赤崎 (天草上島)	Kuroso [Ks]	クロソ ( " )
Akutan [Ak]	アクタン (御所浦島)	Kwannon-iwa [Kn]	観音岩 ( " )
Aradachi	アラダチ ( " )	Kyodomari [Kd]	京泊 ( " )
Arakuchi [Ar]	嵐口 ( " )	Maeshima [Ms]	前島
Arakuchizaki [Az]	嵐口崎 ( " )	Momonokisako [Mm]	桃木迫 (御所浦島)
Bonzu Islet	坊主島	Motoshima [Mt]	元島 ( " )
Dadeku [Dd]	ダデク (御所浦島)	Motoura [Mu]	元浦 ( " )
Daisakuyama	大作山 (天草上島)	Nagahama [Nh]	長浜 ( " )
Enokuchi [En]	江ノ口 (御所浦島)	Naruko [Nr]	鳴子 ( " )
Furukamiyo	古神代 (天草上島)	Nishiura	西浦 (天草上島)
Furuyashiki [Hr]	古屋敷 (御所浦島)	Nosaba-zaki [Ns]	ノサバ崎 (御所浦島)
Gannohana [Gh]	ガンノハナ ( " )	Okinohana	沖ノ鼻
Goshonoura	御所浦 = 熊本県天草郡 御所浦村	(or Hokigahana)	[ホウキゲ鼻] ( " )
Higashiura	東浦 (天草上島)	Okubo [Ok]	大久保 ( " )
Himenoura	姫浦 ( " ) = 天草郡姫戸村	Ozé	大瀬 ( " )
Hinoshima Islet	樋ノ島	Oura [Ou]	大浦 ( " )
Hobashira-ishi [H]	帆柱石 (御所浦島)	Owubayama [Oy]	オウバヤマ ( " )
Hongo [Hg]	本郷 ( " )	Senohana [Sh]	瀬ノ鼻 ( " )
Judan [Jd]	十段 ( " )	Shitanuki	下貫 (天草上島)
Kakuchi-bana [Kb]	カクチバナ ( " )	Sunota [Sn]	スノタ (御所浦島)
Kamishima	天草上島	Tanoshiri [Ts]	田ノ尻 ( " )
Kamiyo	神代 (天草上島)	Tomari-buraku [Tb]	泊部落 ( " )
Karakizaki [KK]	唐木崎 (御所浦島)	Umedo [Ud]	梅戸 ( " )
Karasu-togé [Kt]	烏峠 ( " )	Umeki [Uk]	梅木 ( " )
Kobunenosako [Ko]	小舟ノ迫 ( " )	Usomichi [Um]	ウソミチ ( " )
Kokubi [Kk]	小首 ( " )	Wadanohana	和田ノ鼻 (天草上島)
Koyeji [Kz]	越地 ( " )	Wakiura	脇浦 ( " )
Kugu-shima Islet	櫛島	Yokoura Islet	横浦島

Hakuyu OKADA

Cretaceous sandstones of Goshonoura Island, Kyushu.

**Plates 1–2.**

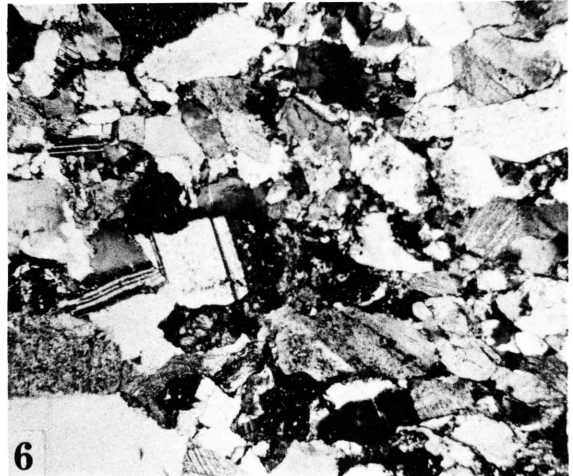
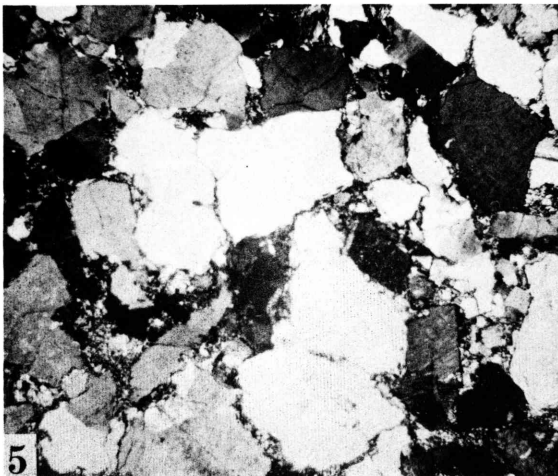
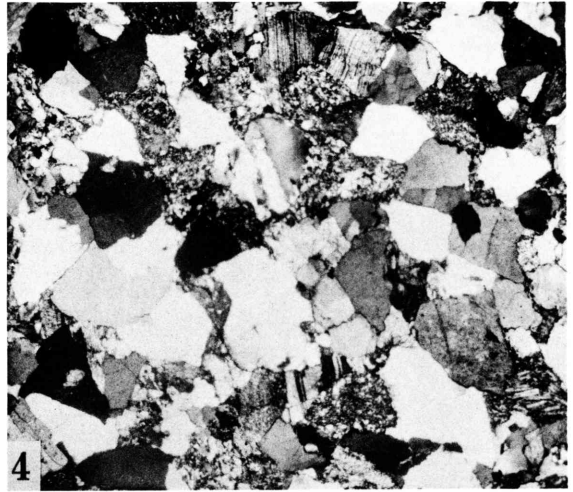
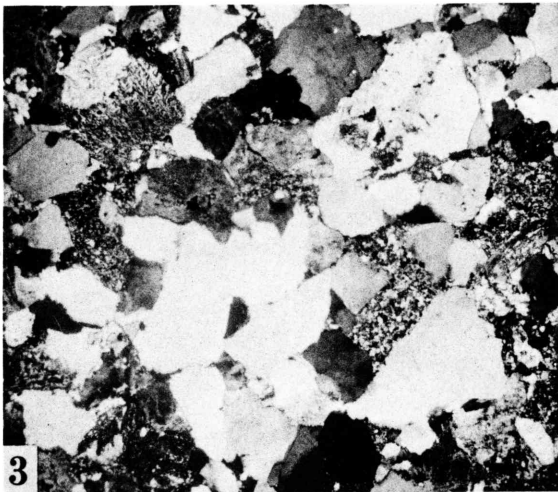
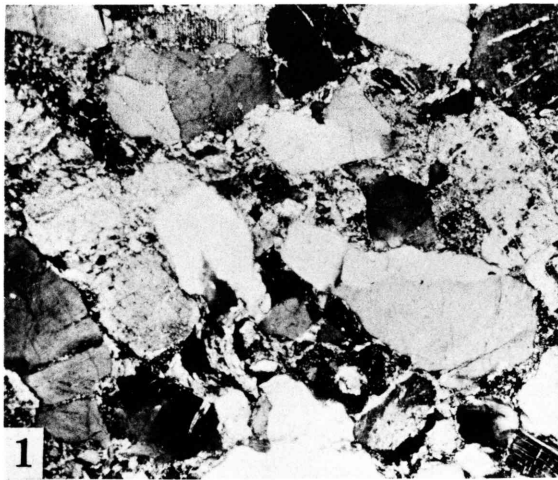
## Plate 1

### Explanation of Plate 1

Figs. 1-6. Photomicrographs of arkose. Crossed nicols;  $\times 30$ , unless otherwise mentioned.

1.  $A_1$  type; GS 21, Member Ia (Zone  $\alpha$ ) of the Lower formation, Goshonoura group, Goshonoura Island;  $\times 40$  (H. OKADA Coll.).
2.  $A_1$  type; GS Ex. 8, Member Ia (Zone  $\alpha$ ) of the Lower formation, Goshonoura group, Goshonoura Island (H. OGURI Coll.).
3.  $B_1$  type; GS 30, Member IIe (Zone  $\epsilon$ ) of the Middle formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
4.  $B_1$  type; GS 32, Member IIe (Zone  $\epsilon$ ) of the Middle formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
5. GS 92, Member IVa (Zone  $\theta$ ) of the Himenoura group, Maeshima Islet (H. OKADA Coll.).
6. Hm K-2, Lower formation of the Himenoura group (Zone  $\theta$ ), Hinoshima Islet, Amakusa-Kamishima (Y. UEDA Coll.).

Photos by H. OKADA.



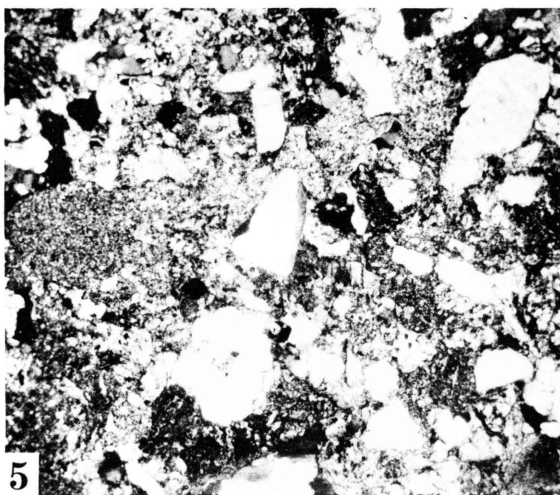
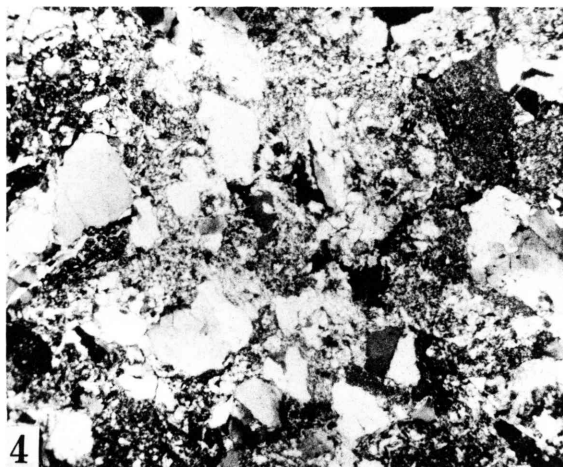
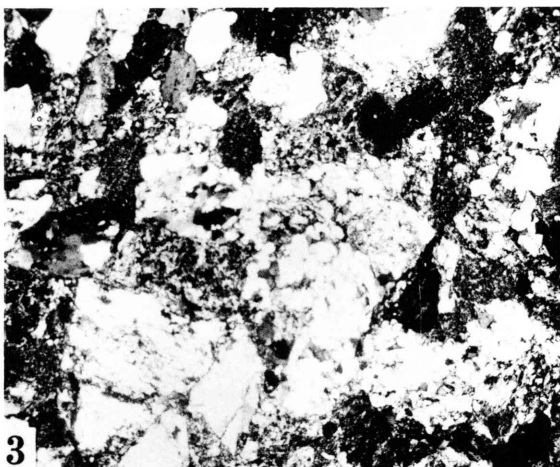
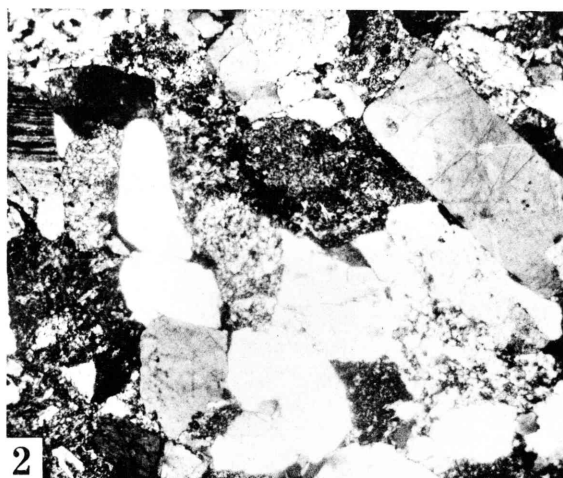
## Plate 2



### Explanation of Plate 2

- Figs. 1, 2. Photomicrographs of feldspathic graywacke. Crossed nicols,  $\times 30$ .
1.  $A_2$  type, GS 13, Member Ia (Zone  $\alpha$ ) of the Lower formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
  2. GS 46, Member IIb (Zone  $\gamma$ ) of the Middle formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
- Figs. 3-5. Photomicrographs of lithic graywacke. Crossed nicols,  $\times 30$ .
3. C type, GS 69, Member IIIa (Zone  $\zeta$ ) of the Upper formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
  4. C type, GS 113, Member IIIc (Zone  $\eta$ ) of the Upper formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
  5. C type, GS 115, Member IIIc (Zone  $\eta$ ) of the Upper formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).
- Fig. 6. Photomicrograph of subgraywacke. Crossed nicols,  $\times 30$ .
- $B_2$  type, GS 131, Member IIb (Zone  $\gamma$ ) of the Middle formation, Goshonoura group, Goshonoura Island (H. OKADA Coll.).

Photos by H. OKADA.



H. OKADA : Cretaceous Sandstones of Goshonoura Island