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GEOLOGICAL SURVEY OF JAPAN

HEAVY MINERAL COMPOSITION OF THE RECENT MARINE SEDIMENTS IN THREE DIFFERENT ENVIRONMENT

By

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GEOLOGICAL SURVEY OF JAPAN

Hisamoto, Takatsu-ku, Kawasaki-shi, Japan

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Isamu KOBAYASHI, Director

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Part III Heavy Mineral Composition of Marine Sediments in Beppu Bay, Kyushu, Japan

Preface

Recently, special attention has been given to the marine geology and geophysics of the continental shelves, slopes, and deeper parts. The Geological Survey of Japan has been promoting several special projects concerning "Investigations on Marine Geotectonics Around the Japanese Islands," "Investigations on the Mineral Resources on and in the Continental Shelf Areas," "Sea Bottom Geological Investigations," and "Basic Investigations for Exploration of Deep Sea Mineral Resources in the Northwest Pacific."

The writer has been studying heavy minerals in sandstones and Recent sediments. The study of heavy minerals in modern sediments plays an important role in the field of sedimentology. It affords information on the provenance or source area of detrital materials and on the cause of lateral variation of mineral compositions. With the progress of the marine investigation projects he had a chance to examine samples of Recent sediments from three different marine environments, inland bay, continental shelf, and deep sea. The writer joined the cruise of the deep sea mineral resource investigations and got samples. Samples for the study of the continental shelf and the inland bay deposits were provided by the Marine Geology Section of the Geological Survey.

The results are presented here in three separate parts: Part I, Heavy Mineral Composition of the Marine Sediments on the Continental Shelf, Western Offshore Areas of Kyushu, Japan; Part II, Heavy Mineral Composition of Some Deep Sea Sediments near the Mariana Islands, Northwest Pacific Ocean; and Part III, Heavy Mineral Composition of Marine Sediments in Beppu Bay, Kyushu, Japan.

The writer would like to express his sincere thanks to Drs. A. MIZUNO, E. INOUE and Mr. S. NAKAO for their kind suggestions, assistances, and provided data.

Taisuke SUZUKI

Part I Heavy Mineral Composition of the Marine Sediments on the Continental Shelf, Western Offshore Areas of Kyushu, Japan

Taisuke SUZUKI*

Abstract

The Geological Survey of Japan carried out a marine geological investigation in the western offshore areas of Kyushu in 1969 and 1970.

This report is a part of the studies of the bottom sediments in this area. Heavy mineral analysis was done on 59 samples taken by dredging. Mainly non-opaque heavy minerals have been treated in the study. Among the opaque minerals, the writer recorded only the quantitative ratio(weight percent) of magnetite.

The result of analyses shows that the heavy mineral assemblage in this region can be classified into the following three types; East China Sea, Amakusa Sea and Yatsushiro Bay types, from the characteristics of heavy minerals.

The composition of the East China Sea type is characterized by abundant green hornblende, then followed by epidote, garnet, zoisite, zircon, brown hornblende, tourmaline, and a lesser amount of staurolite, Kyanite, sillimanite, anatase, diopside, biotite, glaucophane, etc.

The Yatsushiro Bay type is characterized by abundant hypersthene, followed by brown hornblende and augite. Epidote, green hornblende, tourmaline, garnet, zircon, oxyhornblende, apatite, etc. are present as a minor constituent.

The Amakusa Sea type has both hypersthene and green hornblende as main constituents, while brown hornblende, augite, zircon, garnet, tourmaline, epidote, zoisite, diopside, biotite are minor associations.

The East China Sea type contains a large amount of minerals which would be derived from the highly metamorphosed rocks and acidic igneous rocks. Among those minerals, staurolite, kyanite and sillimanite are seldom found in the Tertiary System of Japan on land. It might be reasonable to conclude that a part of the marine sediments in the region has been derived from the northern continental land area (North, Middle China and Korea) where the metamorphic rocks of Pre-Cambrian age are widely distributed.

The origin of the Yatsushiro Bay type sediments might be volcanic rocks, and it is believed that most of the sediments might have come from the land area of western Kyushu.

The Amakusa Sea type, located in between the former two areas, has the heavy mineral composition of a mixture type of the above two ones.

In the future, it would be very much necessary to collect data from neighbouring land areas and to consider the mechanism of sedimentation by means of the specific gravity difference of each heavy mineral.

I. Introduction

The Geological Survey of Japan carried out a marine geological investigation of the

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western offshore areas of Kyushu in 1969 and 1970 in cooperation with the Faculty of Oceanography of Tokai University.

The survey was done mainly around the Danjo Islands in the northeastern margin of the East China Sea with a range of 300 km east to west, and 70–80 km north to south. The purpose of the investigation was to establish and examine a system on marine geological survey technique including preparation of a marine geological map in the area. Several research reports have been published already by the Technical Group of the Sea Bottom Geological Investigation (1970-A, 1970-B, 1970-C, 1970-D) and MIZUNO *et al.* (1971).

This is a report on the result of heavy mineral analysis of marine sediments taken by dredging method (Fig.1).

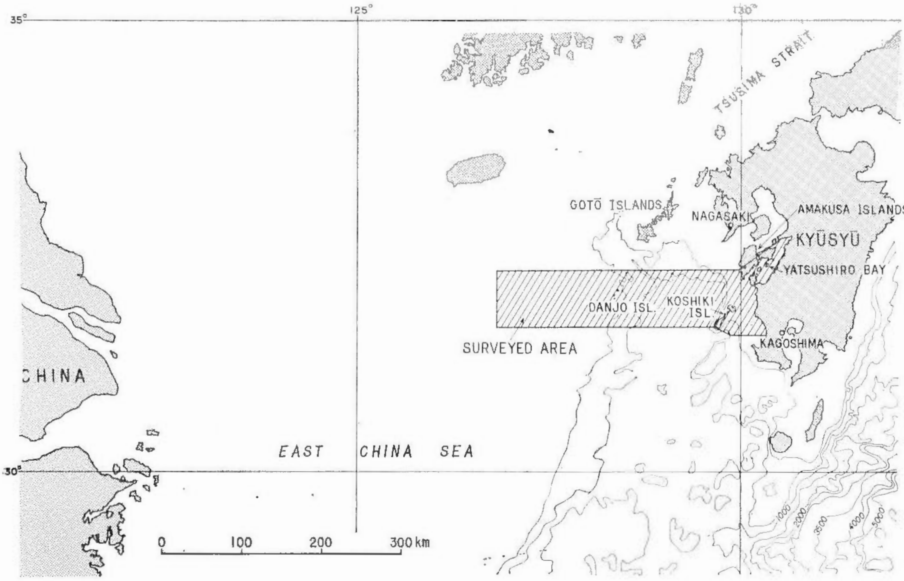

Fig. 1 Location of area surveyed, shown on the regional bathymetric chart

The bottom sediment samples for analysis were provided by the Technical Group of the Sea Bottom Geological Investigation and the rock and beach sand samples from the nearby islands in the investigated area were provided by Eiji INOUE and Seizo NAKAO of the Geological Survey of Japan.

II. Samples and Study Methods

II. 1 Samples

59 samples, excluding silty and muddy sediments, were chosen for heavy mineral analysis from about 230 dredged samples which were collected between latitudes 31° 30' N and 32° 30' N, and between longitudes 126°40' E and 130° 30' E.

In order to examine the relationship with the above-mentioned bottom sediment samples, the writer also carried out analyses on four beach sand samples from Nakadōri Island and Fukue Island of Goto Archipelago, and Kamikoshiki Island of the Koshiki Islands and on the granodiorite samples from Kamikoshiki Island and Shimokoshiki Island besides the bottom sediment samples (Fig.2).

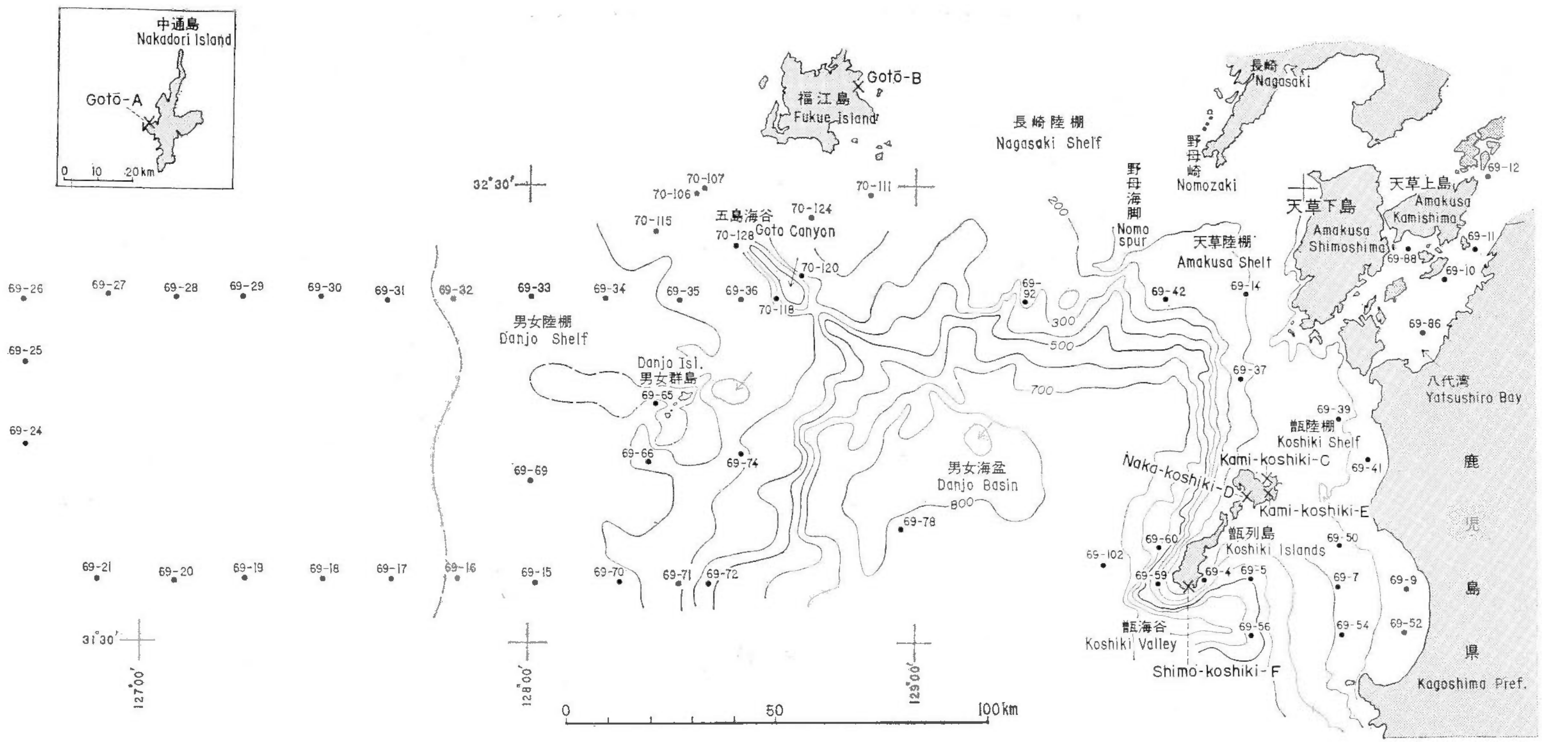

Fig. 2 Map showing sample localities

Bottom sediment samples were collected by a ST-II type, small sampler (Technical Group of the Sea Bottom Geological Investigation, 1970-A; Magoshichi SATO and others, 1970). The behavior and movement of the backet of the sampler during sampling operation are important, but the detail has not been known thoroughly. In some cases, there might be occurred mixing of recent and old sediments in the backet.

II. 2 Study methods

The method of the heavy mineral analysis is as follows; all the samples were screened through the sieve with opening size of 60 mesh in order to make uniform the grains of the samples (the rock samples crushed by a crusher), and then heated gradually with dilute hydrochloric acid. The sample is then washed in water several times, dried, and weighed.

5 grams of cleaned samples of sand fraction were taken from each one. Heavy minerals were separated from the light ones using acetylene tetrabromide (S.G. about 2.9). The heavy mineral grains were mounted on a micro slide glass with synthetic resin (SATO, 1966). There were 12 samples which did not weigh as much as 5 grams. Each one of those 12 samples, which weighed at least more than 1 gram, was put on the separation together.

The writer counted several hundreds of non-opaque heavy minerals on an average under a petrographic microscope for every sample and calculated percentage and ratio to 1,000 as to each non-opaque heavy mineral.

Magnetite, a constituent of opaque heavy minerals, was separated with a horseshoe magnet after the separation of heavy minerals, in order to make easier to see non-opaque minerals, and the weight per cent of magnetite to the heavy residue was recorded as one of the environmental indicators.

III. Heavy Minerals

III. 1 Description

The non-opaque heavy minerals found in the surveyed area are zircon, tourmaline, garnet, amphiboles, pyroxenes, epidote, zoisite, rutile, anatase, titanite, monazite, apatite, kyanite, sillimanite, staurolite, glaucophane and micas (Table 1).

Among those minerals amphiboles and pyroxenes are the most abundant, then followed by epidote, garnet, zoisite, tourmaline and zircon in decreasing order. Other minerals are very few in quantity.

Zircon: Colorless, pink, brown. The colorless one is mostly in short prismatic shape, but sometimes long prismatic crystals are found (length breadth ratio, 1:7). The sample No. 69–11 contains colorless zircon in long prismatic shape, which suggests that the origin might be volcanic rocks. Pink and brown zircons are often rounded.

Tourmaline: In general, the crystal is subangular and seldom has an euhedral prismatic shape. The color ranges from light-brown and brown to green and blue. The light-brown tourmaline is the most common, followed by the brown one.

Garnet: The colorless one is the most abundant. Light-brown or brown, light pink or pale purple ones are present.

Amphiboles: There are bluish-green hornblende, brown hornblende, oxyhornblende and glaucophane.

Bluish-green hornblende: The most abundant mineral. It was found at 14 points where the bluish-green hornblende occupied more than 50% out of the total heavy mineral content (excluding magnetite), and in the case of the sample No. 69–70 it occupies as 79%. Generally, the crystal is fibrous, prismatic with an extinction angle less than 10°.

Common hornblende: Extinction angle is about 15°. Brown and green-brown hornblende are included in this category.

Oxyhornblende: Prismatic, nearly euhedral grains are frequently found near shore areas of Kyushu Island. The crystal becomes fragmentary off the Island.

Glaucophane: Mostly fibrous. The size is smaller than that of other heavy minerals (*Plate 2*, Fig.12).

Pyroxenes: Augite, hypersthene and diopside are included.

Hypersthene: The shape is usually euhedral. Larger sizes show the following dimensions, 0.67mm ×0.16mm, 0.64mm×0.08mm, 0.53mm×0.21mm, 0.56mm×0.1mm, etc. In general, the shapes are short or long prismatic and subangular. However, the short prismatic shapes are abundant in most cases.

Augite: Mostly short prismatic, showing green color. It shows slight pleochroism.

Diopside: Colorless, but sometimes light green.

Epidote: Mostly shows light yellowish-green, but rarely it shows a dark yellowish green, which does not have a perfect extinction (*Plate 3*, Fig. 16). Sometimes the mineral consists of aggregates of fine crystals.

Zoisite: Colorless or light yellow, and it often shows a peculiar deep blue interference color (*Plate 2*, Figs. 9 and 10).

Rutile: Mostly golden yellow.

Anatase: Mostly euhedral or almost euhedral single crystal (*Plate 2*, Fig. 11).

Titanite: Light yellow or light yellowish-brown. Subangular.

Monazite: Dirty light-brown color. Rounded.

Apatite: White or milk-white, short prismatic and subrounded.

Kyanite: Elongated prismatic crystals are often found because of the development of right-angled cleavage. Such extremely elongated prismatic crystals can sometimes be found. Their dimensions: 0.32mm×0.09mm (Sample No. 69–25), 0.28mm×0.16mm (Sample No. 69–28), 0.6mm×0.08mm (Sample No. 69–74), etc. (*Plate 2*, Fig. 7, *Plate 3*, Figs. 17 and 18).

Sillimanite: Irregular, prismatic (*Plate 2*, Fig. 8, *Plate 3*, Fig. 13).

Staurolite: Irregular grains with conchoidal fracture (*Plate 1*, Figs. 1–6).

Micas: Muscovite and biotite are present. Because the specific gravity of micas is around 2.9, which is almost equal to the specific gravity of the heavy liquid (2.9), the separation was not complete. Then the amount of micas in the table may be in some error. Both muscovite and biotite have various sizes taking platy rounded shape. Sometimes inclusion can be seen in muscovite. Biotite is brown, sometimes green. The green one almost always has inclusion. Some green varieties may have a possibility of chlorite, but the writer has included the one on the category of biotite for convenience.

Magnetite: The weight percentage of magnetite in the whole heavy minerals has been recorded as a tentative environmental indicator. It seems that the points where high content of magnetite is recorded are relatively close to the land. Sample No. 69–36 contains more than 80% of magnetite in the total heavy minerals, in other words, the weight percentage of magnetite reaches as much as 48% to the whole sample, the highest content of magnetite in this region.

In comparison with the heavy minerals in the Japanese Tertiary System, there are many common heavy minerals in this area. However, staurolite, kyanite and sillimanite are peculiar ones in this region.

According to SATO (1971), it is pointed out that those minerals are particularly found in the metamorphic rocks, but those are rarely found in the Tertiary formations in Japan except in the Okinawa Islands (OHARA, 1964; SUZUKI, 1970). Considering the origin of

Table 1 Heavy mineral composition of the marine sediments in the western offshore areas of Kyushu

Minerals / Sample No.	Zircon colorless	Zircon pink light	Zircon brown	Tourmaline	Garnet colorless	Garnet brown	Rutile red	Rutile yellow	Anatase	Titanite	Monazite	Apatite	Epidote	Zoisite	Hornblende green	Hornblende brown	Oxyhornblende	Hypersthene	Augite	Diopside	Kyanite	Sillimanite	Staurolite	Glaucophane	Biotite brown	Biotite green	Muscovite	Reaction to Hcl	Magnetite	Weight % of heavy residue	Type
69 - 12	2														2	43		51	2									○	○	8.40	Yatsushiro Bay
〃 88	5		1	3	1−	+				1		1−	3	1−	2	19	+	53	10									◎	○	1.94	
〃 11	1−			1−	1−	+							2		1	3	+	86	5									○	○	4.72	
〃 10	+			1−									3		3	12	1	67	13									○	○	3.10	
〃 86	1			4	1−		+				1−		4		2	2	1	75	9									○	+	3.77	
〃 39	+	+		3	+								5		4	16	3	62	8									○	○	8.42	
〃 41				+	+								6		3	34	2	43	12									○	+	6.72	
〃 9				1									3		3	9		78	6									○	◎	11.88	
〃 52	+		+										4		7	16	+	65	6									○	◎	10.52	
〃 50	+			3									2		1	11	4	69	9									○	+	7.18	
〃 7	1−			1									2		3	17	2	65	9									○	○	4.10	
〃 54	1−			2									2	+	1	12	1	71	10									○	◎	29.00	
〃 5	+			1−								+	3		7	21	2	59	7									○	◎	17.60	
〃 56	1−			1								1	4		20	12	1	51	9						+			◎	◎	2.14	
69 - 4	3	+		1	+	1−			+		1−		4	1	67	7	1	10	2	1−	1−	+						○	+	3.33	Amakusa Sea
〃 59	+			2									1		55	13	1	24	4	+								○	◎	15.48	
〃 14	+			2									3	2	7	22	2	45	16									○	○	12.70	
〃 37				4	1−								1	+	3	22	1	57	10	1−								○	○	9.72	
〃 60	1−			3	1−					+		1−	3	+	79	5	+	5	1	1								○	+	7.90	
〃 42				5	1−							1−			7	22	1	47	15	+								○	○	29.48	
〃 3	2			3	1						+	1−	1	2	20	17	5	37	9	2								○	○	6.65	
〃 102	3			4	+					1		1−	3	2	52	8	1−	18	6	1								○	○	7.48	
〃 92	1−			4							+	1−	1	+	22	9	3	42	16	1−						+		◎	○	0.52	
〃 78	1−			2	4	+				1−	+		5	5	47	5		18	8	2					+			○	○	4.04	
70-111	5		2	7	4	+				1−	+	1−	14	11	37	3	2	8	4	1−					+			○	○	2.50	
〃 124	5	1−	1	6	4	1−	+	+					19	12	31	2	2	9	6	1−				+	+	+		○	◎	6.57	
〃 120	4		1−	4	3	1		+		+	+	3	13	11	41	2	+	8	6	1			+		+	1−		◎	◎	5.82	
〃 118	3	+	2	5	4	2	+	+	+	1−		+	15	11	49	1		4	1	1					1−	+		○	○	3.86	
〃 128	1−		2	5	7	+				1−	1−		10	7	53	3		5	2	2			+			+		◎	+	2.32	
69 - 36	2		+	10	11	1				+	1−		6	5	14	1−		33	15	+								○	◎	59.83	
〃 74	5	+	1	7	19	+		+		+	2		10	10	39	2		+	1−		1−		1−					○	+	4.60	
〃 72	3		+	9	7			+		1		+	6	8	50	+		5	1−	1					2	2	1−	○	+	1.02	

	a	a	a	b	b	b	c	d	d	d	d	e	e	f	f	f	g	g	g	h	h	h	h	i	i	i	j	k	l	m
〃 71	1−		2	4	3	+			+			8	5	64	4		4	1	+	+		1−		1	1		○	+	0.58	East China Sea
70-107	+	+	1−	3	6	+				1	1−	9	3	56	9		7	2	2								○	+	2.16	
〃 106	3		+	5	13	1−		+	1−	+		12	9	42	4	+	6	2	+		+		+	+			○	+	3.28	
〃 115	4	+		6	4	+	+		+	+	+	8	12	59	1−		3	1	1								○	+	2.60	
69-35	1	+	2	3	12	1			1	1−	1−	11	12	43	3	+	4	3	1−			1−					○	+	3.22	
〃 65	1			4	2							14	8	50	2	+	9	6				2		2	+		◎	◎	1.84	
〃 66			1−	1−	2				1−			15	8	59	4		6	3				1−					○	+	2.54	
〃 70	1		+	1	8	2	+			2		11	7	48	9		4	4	+			1					○	+	3.34	
〃 34	5	+		6	14		+			1	2	16	7	39	2	+	4	2				+				+	○	+	4.04	
〃 33	7	1		6	15	2	+		1−	1	1	11	10	37	4		3	1				1−		+			◎	+	2.68	
〃 69	3		+	4	7	1−			+	+	1	8	4	47	10		8	3	2		+	2		+			○	+	3.46	
〃 15	1		+	2	6	+					1−	8	3	67	4		3	3	1			+					○	+	3.28	
〃 32	+		+	7	4	2				2		15	7	48	9		5	1−				+					○	+	2.92	
〃 16	2			3	9	1				1−	1−	14	8	46	5	+	3	2	+	+		3	+				○	+	5.64	
〃 31	2	1		8	11	2				2		14	9	43	4		4	1				+		+			◎	+	3.38	
〃 17	1			5	6	4				+		13	6	51	7		5	1				1−					○	+	6.12	
〃 30	5	1		4	14	1				1		17	6	41	4		2	1		1−		1−	+			+	○	+	3.88	
〃 18	3	+		9	9					1		17	8	47	2		2	1				1−					○	+	3.74	
〃 29	10		2	5	11	1−		1−		2		12	10	43	1	1−	+	+				1					○	+	3.86	
〃 19	5		+	1	10	1		+		2		16	8	46	4	1−	3	1				1				+	○	+	5.62	
〃 28	1		1−	6	7	2				2		17	9	47	2	+	4	2		+		1		+			○	+	5.26	
〃 20	11		2	6	19	1−				1		11	10	34	1		1	+				1−					○	+	4.46	
〃 27	7		1−	4	11	2	+			5		15	14	34	3		1	1		+		1					○	+	4.80	
〃 21	6	+	2	7	9	1	1−	1−		1		17	10	43	1		1−										○	+	2.83	
〃 26	6	1		5	7	1				3		7	6	51	5		3	2	1			1		1−			○	+	5.22	
〃 25	12			5	10	1−				3		8	11	44	1		1	1		1−		1		+			○	+	3.98	
〃 24	12			6	9	1−		+		3		5	12	45	4	+	1	+		+		1−	+				+	+	3.00	
Goto-A Beach sand	3		1	3	5	+			1−			47	16	+	2		18	4									+	+	0.37	Surrounding isles area
Goto-B Beach sand	7	+	3	1	1	+						44	31	1−	1−	+	9	2									○	○	0.91	
Kami-Koshiki-C Beach sand						+						75	10	1−	4		3	7	+						+		◎	+	9.00	
Naka-Koshiki-D Beach sand	1			3					1−		1−	23	2	1−	3		25	16	9						15		◎	−	1.06	
Kami-Koshiki-E Diorite	3		+									+		40	57												○	+	16.06	
Shimo-Koshiki-F Granodiorite	3			2								5			79									11			○	◎	2.52	

+ : rare, ○ : common, ◎ : abundant, 1− : less than 1%

Reaction to cold dilute Hcl { + : weak effervescence; ○ : moderate 〃; ◎ : strong 〃 }

the sediments, it is very important and noticeable that there are the above minerals everywhere in the surveyed area, though the amount is only a few. Moreover, diopside, which is uncommon in the Tertiary formations on land, is another characteristic heavy mineral in the area.

III. 2 Composition

The heavy mineral association in this area can be divided into the following three types, namely, Yatsushiro Bay, Amakusa Sea and East China Sea types (Fig.3), from the composition and the distribution of heavy minerals in the samples.

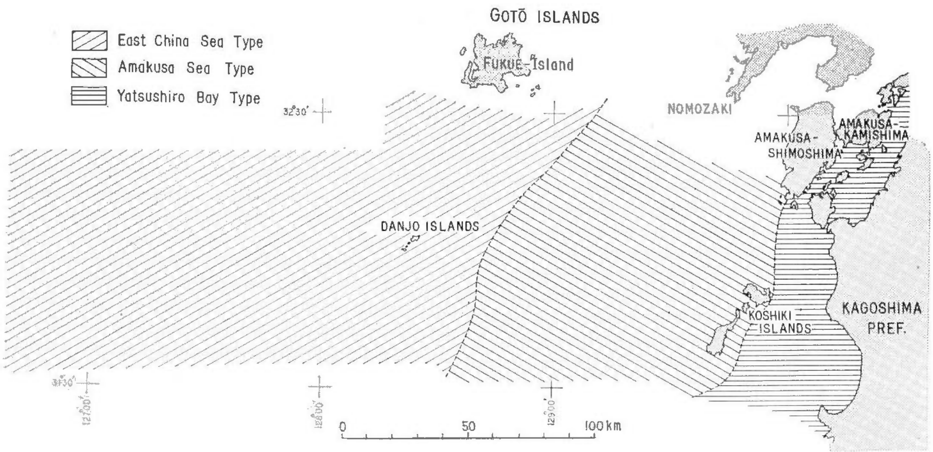

Fig. 3 Distribution of the three patterns of heavy mineral composition

III. 2. 1 Yatsushiro Bay Type

This type distributes in the sea area from Yatsushiro Bay to Koshiki Shelf. Hypersthene is the most abundant heavy minerals in this type and occupies 50–80%, then brown hornblende 5–40%, augite 5–10%. As to minor constituent minerals, epidote, bluish-green hornblende, tourmaline, garnet, zircon and oxyhornblende are found (Fig.4).

Zircon is colorless and has a long prismatic shape. It is a distinctive feature for this type that volcanic glasses attached to opaque heavy minerals are often present. One mineralized fossil foraminifer (Sample No. 69–88) was distinguished (*Plate 3,* Fig. 15).

III. 2. 2 East China Sea Type

This type is distributed along the eastern tip of the East China Sea to Danjo Shelf and Goto Canyon.

The heavy minerals contained in this type are bluish-green hornblende 40–60%, epidote 10–20%, garnet and zoisite ±10% each, zircon, tourmaline and brown hornblende 2–10%.

Anatase, monazite, apatite, diopside, green or brown biotite, titanite, oxyhornblende, glaucophane, staurolite, kyanite and sillimanite are minor minerals (Fig.5). This type contains more mineral species than other types, especially than the Yatsushiro Bay Type.

III. 2. 3 Amakusa Sea Type

This type can be seen around Danjo Basin, the southern tip of Nagasaki Shelf and a part of Koshiki Valley.

Hypersthene and bluish-green hornblende, 10–50% each, occupy most part of the heavy minerals in the area, and then followed by brown hornblende 5–20% and augite

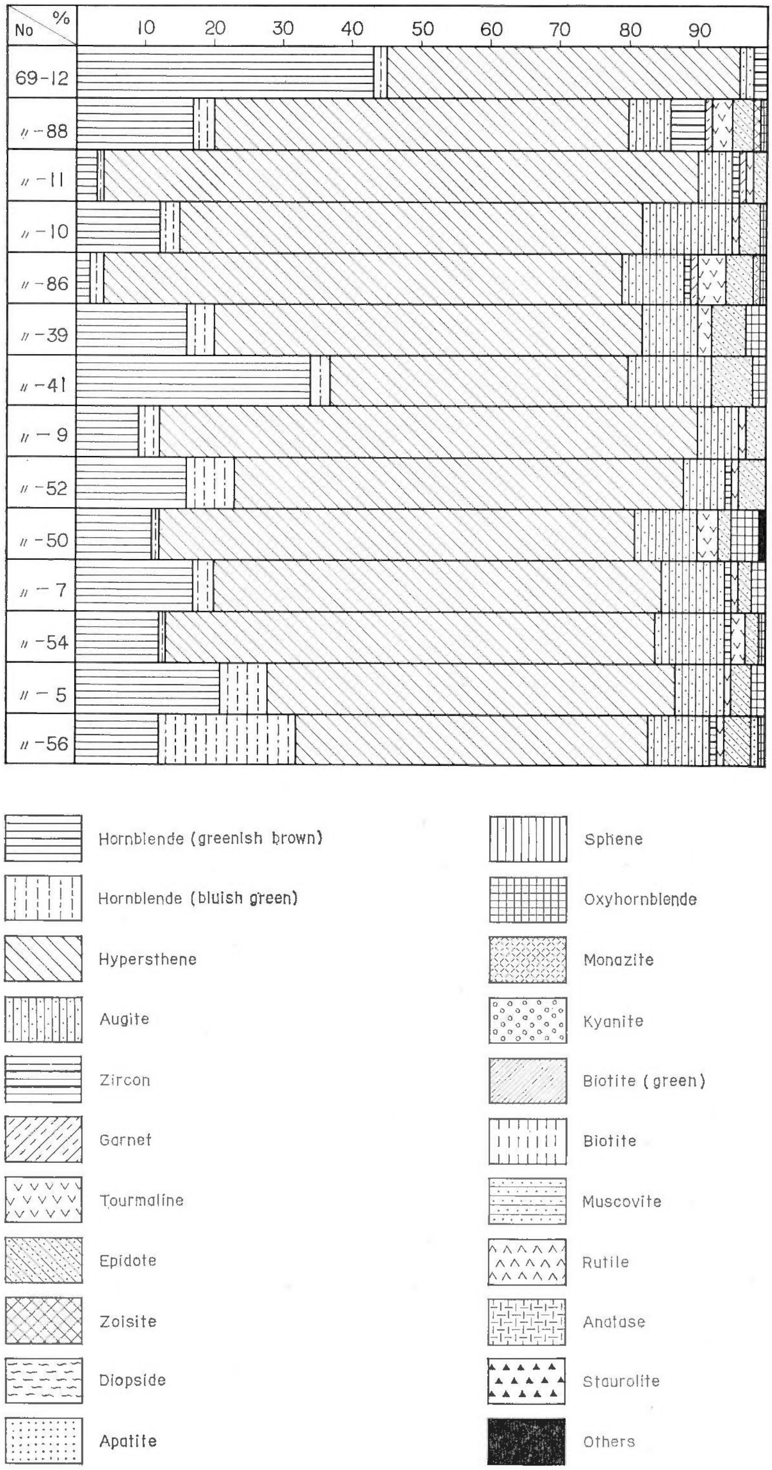

Fig. 4 Figure showing heavy mineral composition of Yatsushiro Bay Type (%)

±10%. Small amounts of zircon, garnet, tourmaline, epidote, zoisite, diopside, apatite and micas are also contained (Fig. 6).

This type is situated in between the distribution areas of the Yatsushiro Bay Type and the East China Sea Type. The heavy mineral composition of this type is a mixture of the minerals of the other two types.

III. 3 Heavy minerals in the beach sands and rock samples from surrounding islands

The results of analyses of five samples collected from the islands in the surveyed area are shown in Table 1 and Fig.7. It is clear from the table and figure that the beach sands of Goto Islands (samples Goto-A and Goto-B) contain 40–75% of epidote, the highest amount, and then followed by zoisite 10–30% and hypersthene 10–20%. Zircon, garnet, tourmaline, augite, brown or bluish-green hornblende are minor constituents.

The beach sand sample of Kamikoshiki Island (Kamikoshiki-C) contains large amounts of epidote and zoisite, but zircon, garnet and tourmaline are lacking.

The beach sand sample of Nakakoshiki Island (Nakakoshiki-D) has diopside, apatite, titanite and biotite besides those minerals found in the above-mentioned three samples.

Kamikoshiki-E is a sample of diorite which crops out in the eastern part of Kamikoshiki Island. The diorite consists of

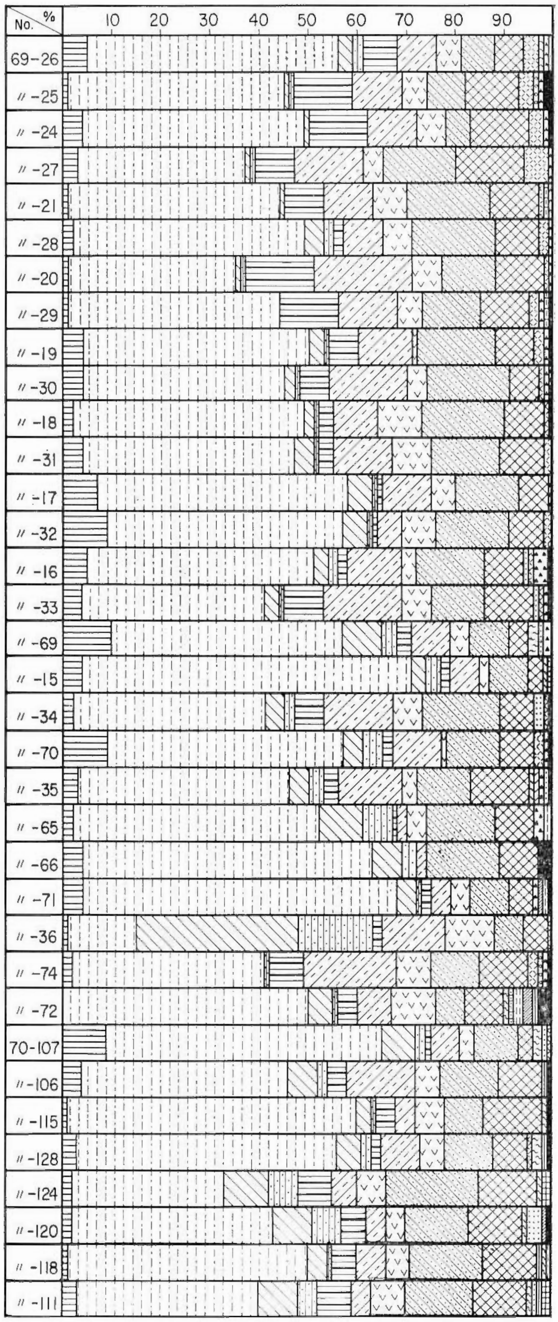

Fig. 5 Figure showing heavy mineral composition of East China Sea Type (%)

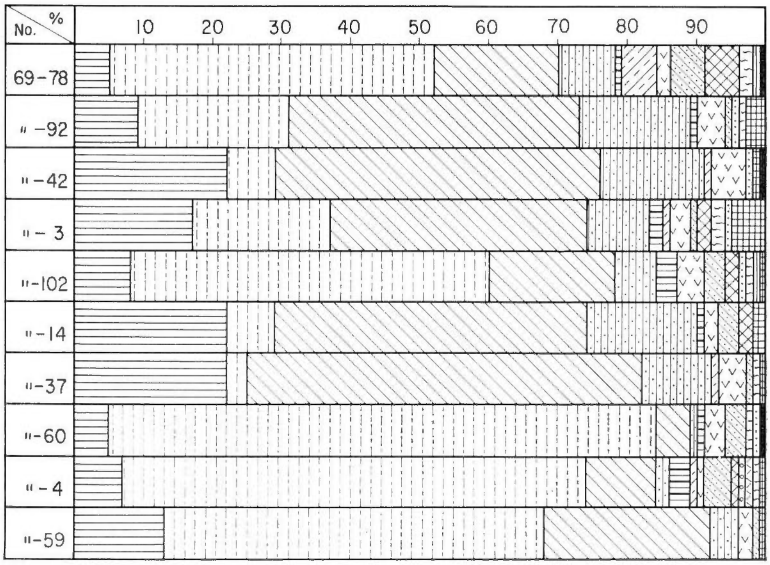

Fig. 6 Figure showing heavy mineral composition of Amakusa Sea Type (%)

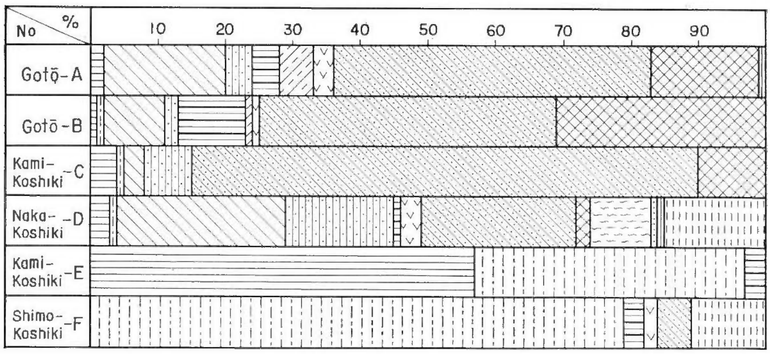

Fig. 7 Figure showing heavy mineral composition of connected area (%)

over 50% of brown hornblende, 40% of bluish-green hornblende and several per cent of zircon in the heavy residue part. Hornblende is the dominant heavy mineral (*Plate 3*, Fig. 14).

The sample Shimokoshiki-F is granodiorite which crops out in the western part of Teuchi village of southern Shimokoshiki Island. The sample contains 80% of bluish-green hornblende, zircon, tourmaline, epidote and biotite.

According to TAKAI *et al.* (unpublished data), the heavy minerals in the Himenoura Group (Cretaceous) and the Akasaki Group (Paleogene) in Kamikoshiki Island include zircon, tourmaline, garnet, epidote, allanite, titanite, zoisite, apatite, monazite, bluish-green hornblende and hypersthene. In general, epidote is overwhelmingly abundant in those Groups. In some cases, it happens to show that epidote is the only constituent of non-opaque heavy minerals.

IV. Origin of the Sediments

The writer discusses the origin of the sediments with the above-mentioned compositional and individual characteristics of the heavy minerals.

It is considered that the origin of the Yatsushiro Bay Type sediments would be mostly intermediate to basic volcanic rocks, since there exists an abundant hypersthene, brown hornblende, augite and volcanic glass. A small amount of zircon, garnet and tourmaline indicates that some parts of the sediments were derived from acidic igneous and sedimentary rocks.

It seems that large amount of pyroclastic material may have been brought from the southeastern land area where andesitic rocks are widely distributed.

The reasons are, (1) "Shirasu," which is pumice flows and has been developed widely in the southern part of Kyushu, is rich in hypersthene, then followed by augite and a small amount of common hornblende (FUKUTA *et al.*, 1971), and this composition is quite similar to that of the Yatsushiro Bay Type, (2) intermediate and basic volcanic rocks of Neogene Tertiary to Quaternary in age have been distributed widely on the land area of west Kyushu, (3) the Yatsushiro Bay area has a suitable geographical position for deposition of the detritus of "Shirasu" and volcanic rocks mentioned above, and (4) the heavy minerals identified are very angular or euhedral grains. So it can be concluded that those minerals have not been transported for a long distance.

There are two possibilities about the introduction of a large amount of volcanic material into the sea area; one is that the above-mentioned rocks may have been transported from the land after weathering and deposited in this area, and the other is that they may have been brought in this bay area directly as pyroclastic flows.

The heavy mineral compositions of the Amakusa Sea Type and the East China Sea Type are quite similar to that of the granodiorite in Shimokoshiki Island; that is, relatively high content of bluish-green hornblende and low content of zircon, epidote, tourmaline and biotite. From the distribution of bluish-green hornblende in Fig. 8, you can see very large amount of bluish-green hornblende, more than 500‰ (per mil), in the areas from the southwestern part of the Koshiki Islands to the southern part off the Danjo Islands, the southwestern part of Fukue Island and the northwestern tip of the surveyed area. Quite recently the existence of "Magoshichi Hill" has been known, which consists of granitic rocks in the surveyed area, southwest off the Koshiki Islands (MIZUNO *et al.*, 1971). Granodiorite containing bluish-green hornblende is also found in Shimokoshiki Island. Judging from these evidences, it might be able to interpret that the bluish-green hornblende in the bottom sediments in the surveyed area from the environs of Shimokoshiki Island to around "Magoshichi Hill" would be derived from those granitic rocks.

A similar relation as above is observed in the southwestern area to Fukue Island, too. This area is situated on a connection line between Goto Archipelago and Torinoshima. Granitic rocks crop out in several places in Goto Archipelago in the direction from NE to SW (Fig.9), Torinoshima, which also consists of granitic rocks (MATSUI, 1969), is located on the extension line of the above direction, i.e., NE-SW. From the above-mentioned reasons, it is possible to say that there were granitic rocks distributed around the Danjo Islands and the northwestern tip of the surveyed area.

So far the writer has discussed about the relation between the hornblende and granitic rocks. However, it is also necessary to examine another possibility of derivation that bluish-green hornblende might be derived from other than granitic rocks, as the mineral is said to be found in low to medium grade metamorphic rocks.

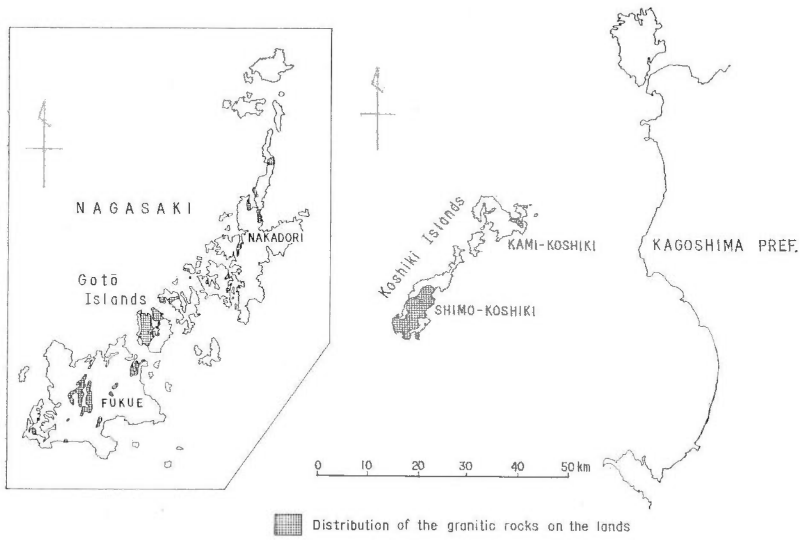

Fig. 9 Map showing the distribution of granitic rocks, from the geological map of Kagoshima (1954) by the Geological Survey of Japan

Also, it can not be overlooked that the content of diopside is correlative to that of bluish-green hornblende.

In the East China Sea Type, there are staurolite, kyanite, sillimanite, epidote and zoisite which are very common in metamorphic rocks besides bluish-green hornblende (Figs. 10, 11, 12).

Because of lacking of samples of original rocks and geological data, it is difficult to estimate the origin of those minerals. However, the writer tries to discuss the origin of those minerals. First of all, it is necessary to know the relation between such characteristic minerals as staurolite, kyanite and sillimanite and the distribution of Paleozoic-Mesozoic metamorphic rocks (Fig.13), namely "Sangun," "Sambagawa" and "Ryoke," on the land area around the surveyed area.

According to the Regional Geology of Japan, "Kyushu" (1962), sillimanite has been found in the "Higo" metamorphic rocks. The "Higo" metamorphic rocks correlated to the "Ryoke" metamorphic rocks (Geological map of Japan, 1971) distribute in the land area east to northeast of Yatsushiro Bay. The "Higo" metamorphic rocks have been divided into three zones according to the metamorphic grades, namely low (I), medium (II) and high (III). Sillimanite is contained in the II and III zones. Though sillimanite in the "Higo" metamorphic rocks can be transported at most as far as Yatsushiro Bay or Ariake Sea, it would be geographically difficult to consider that it has been transported up to the East China Sea. Sillimanite found in the Koshiki Valley may have come from the west.

Next, let us see whether staurolite, kyanite and sillimanite are contained in the younger sedimentary rocks which overlie the above-mentioned Paleozoic-Mesozoic metamorphic rocks directly or indirectly.

According to OHARA (1961, 1964), less than one per cent of staurolite has been seen at one locality in a sandstone of the Ainoura formation of Sasebo Group (Miocene in age), in the Sakito Coal Field, Nagasaki Prefecture. There are none of those three heavy minerals in the Paleogene formation which crop out in both Fukuoka and Kumamoto Prefectures.

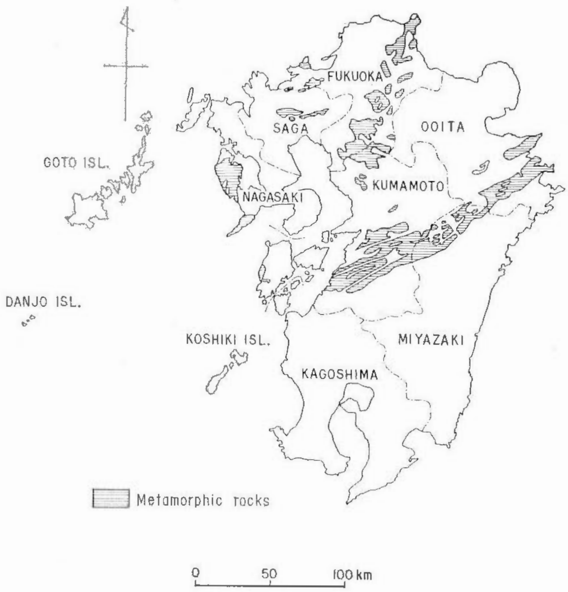

Fig. 13 Figure showing the distribution of the metamorphic rocks, from the Geological Map of Japan, Fourth Edition (1971)

Those minerals are not found either in the Paleogene formations of Shimo-shima Island of Amakusa, Kumamoto Prefecture or those of Nishisonogi Peninsula, Nagasaki Prefecture (SATO, 1961, 1966).

On the other hand, staurolite, kyanite and sillimanite are often recorded as important constituent heavy minerals in sedimentary rocks in America and Europe. SATO (1971) reported that the origin of those heavy minerals in Paleogene formations in Wyoming and Colorado, U.S.A., would be the Pre-Cambrian metamorphic rocks in the Rocky Mountain region.

As already mentioned, there have been found no such kind of metamorphic rocks containing those three heavy minerals around the surveyed area. However, Pre-Cambrian metamorphic rocks which contain staurolite, kyanite and sillimanite are widely developed in the mainland, China and Korean Peninsula, to the north of the surveyed area (MIYASHIRO, 1951). So, it may be concluded that the source of the above three heavy minerals in the sediments could be sought in the northern continental area.

Most samples of the bottom sediments belonging to the East China Sea Type are sand or muddy sand. Mud or sandy mud, however, can be seen at the southwestern extremity of the surveyed area (MIZUNO, 1971). EMERY *et al.* (1969) recognized a cool lower-chrolinity current which flows southward in the middle of the Yellow Sea and the East China Sea. The water in the western half of the East China Sea contains fairly abundant fine detrital materials (silt and clay). In contrast, the warm saline water that flows northward in the eastern half contains a little amount of suspended materials. According to NIINO and FMERY (1961), Recent fine sediments are spread in a form of the tongue from the central part of the Yellow Sea to Tunghai Shelf, to which the finer sediments at the southwestern tip of the surveyed area would belong.

V. Heavy Minerals in the Relict Sediments

Among sand or muddy sand sediments which belong to the East China Sea Type, some of them that dredged from the southwestern part to Goto Islands coincide with the so-called relict sediments reported by EMERY (1968) and EMERY *et al.* (1969). It is said that the sediments would be deposited in or near the ancient coastal area because they contain molluscan remains of brackish to shallow marine water types and those of cold water element.

Ten samples, dredged from the area connecting four sampling points, namely No. 69–30, No. 69–16, No. 69–34 and No.69–70, have been confirmed as the relict sediments. The area is about 300m in depth and located west of Danjo Shelf. At the time of sampling, there might be an intermixture of Recent sediments with the relict sediments.

It is hard to see the difference of heavy mineral species or composition among the confirmed relict, possible relict and Recent sediments in the East China Sea Type. There is a slight change in the amount of heavy minerals among them, but it seems that the difference is within a range of analytical errors.

It is inferable that the most heavy minerals in the East China Sea Type would be derived constantly from northern continental areas through the time of deposition of relict and the Recent sediments, even if there might have occurred crustal movements during the Pleistocene age, or any change of the sea level in the Glacial age.

VI. Conclusion

The writer has deduced that the origin of the characteristic heavy minerals like staurolite, kyanite, sillimanite, etc. in the marine sediments in the surveyed area would be the Pre-Cambrian metamorphic rocks in the North, Middle China and Korea. As mentioned above, those minerals are also found in the Neogene Tertiary formations of Okinawa Prefecture and of northern Kyushu. On the other hand, there have never been found those minerals in the Cretaceous and Paleogene formations on land around the surveyed area. This may suggest that the supply of metamorphic materials from western or northern continental area started since the Neogene time.

It is necessary for us to continue a further survey and study because the area surveyed is quite limited and we lack in necessary materials for studying original rocks.

In the future we should study the bay-type sediments which likely to have more simple sedimentary feature, and also investigate the compositional change due to a specific gravity difference of heavy minerals, the effects of tidal and ocean currents to sediments, and the relationship between heavy mineral composition of marine sediments and that of various kinds of rocks around the land areas concerned.

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I. 九州西方海域堆積物中の重鉱物組成

鈴 木 泰 輔

要 旨

1969年と1970年に地質調査所は，九州西方海域における海底地質調査を実施した。本報告はこの研究の一部をなすものである。ドレッジ法によって採取された試料のうち，59個について重鉱物分析を行なった。同定には主として透明鉱物のみを扱い，不透明鉱物については磁鉄鉱の量比のみを記録した。

解析の結果，この地域における重鉱物は組成上の特徴と分布などから東支那海型，天草灘型，八代湾型の３型に大別された。

東支那海型の組成は，緑色角閃石がきわめて多く，次いで緑れん石，ざくろ石，ゆうれん石，ジルコン，褐色角閃石，電気石などで代表され，十字石，らん晶石，珪線石，鋭錐石，透輝石，黒雲母およびらんせん石などの少数鉱物からなっている。

八代湾型の組成は圧倒的に紫蘇輝石が多く，次いで褐色角閃石，普通輝石の順で代表され，少数鉱物として緑れん石，緑色角閃石，電気石，ざくろ石，ジルコン，酸化角閃石および燐灰石などから構成されている。

天草灘型の組成は，紫蘇輝石と緑色角閃石が大半を占め，褐色角閃石，普通輝石，ジルコン，ざくろ石，電気石，緑れん石，ゆうれん石，透輝石，黒雲母などからなる。

次に各組成におけるおおよその起源について述べると，

東支那海型は，高変成度の岩石を含む変成岩源と酸性火成岩源の鉱物がほとんどを占めているが，とくにわが国の第三系堆積岩中にはまれな存在となっている十字石，らん晶石および珪線石などの特徴的鉱物種が含まれることから，先カンブリア紀の変成岩類が広く分布する北方大陸から一部分の堆積物が由来するものと考えられる。

八代湾型は大部分が火山岩源と思われ，堆積物の主なものはおそらく東方陸域部からもたらされたものであろう。

天草灘型は前述の２つの型の分布地域に挟まれた位置にあたり，重鉱物種が両者の混合型となっている。

今後はさらに周辺陸域部との関連性ならびに鉱物の比重差などによる堆積機構を解明することが必要である。

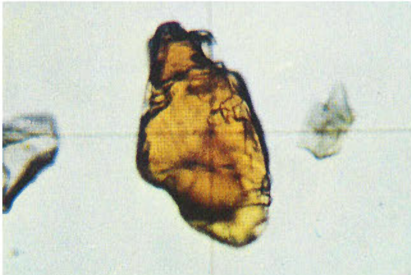

Fig. 1

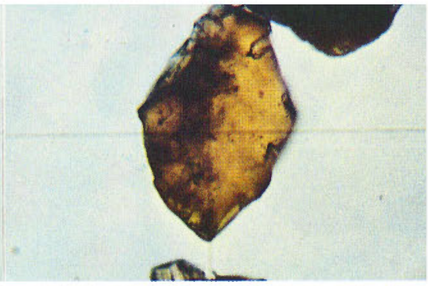

Fig. 2

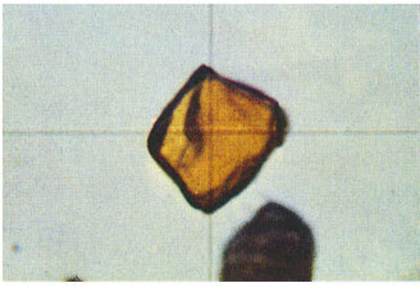

Fig. 3

Fig. 4

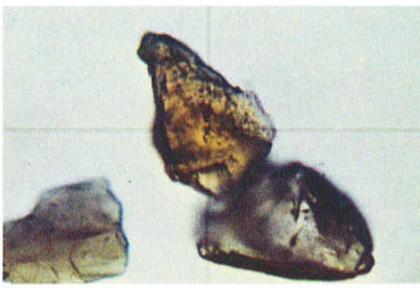

Fig. 5

Fig. 6

Figs. 1 – 6 Staurolite in the sediments of East China Sea Type.

Fig. 1	Sample	No. 69–29	0.33 mm × 0.17 mm
Fig. 2	〃	No. 69–16(A)	0.35 mm × 0.21 mm
Fig. 3	〃	No. 69–74	0.21 mm × 0.13 mm
Fig. 4	〃	No. 69–16(B)	0.32 mm × 0.22 mm
Fig. 5	〃	No. 69–30	0.26 mm × 0.16 mm
Fig. 6	〃	No. 69–70	0.24 mm × 0.20 mm

Fig. 7

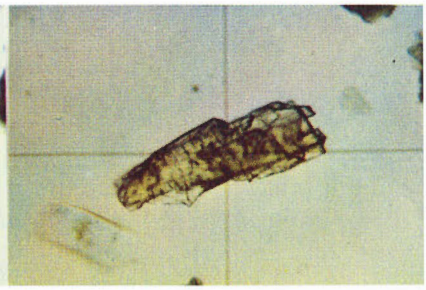

Fig. 8

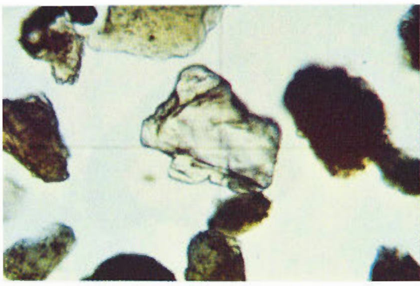

Fig. 9

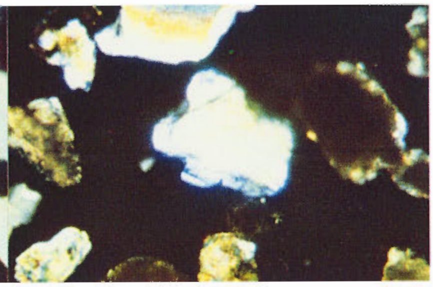

Fig. 10

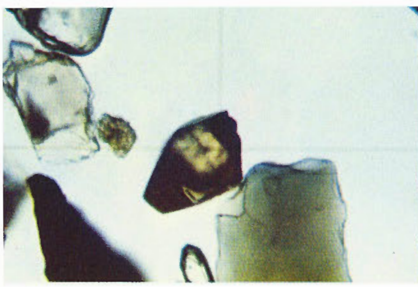

Fig. 11

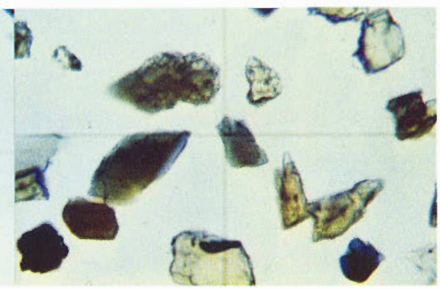

Fig. 12

Fig. 7 Kyanite in the sediments of East China Sea Type.
Sample No. 69－25 0.32 mm×0.09 mm

Fig. 8 Sillimanite in the sediments of Amakusa Sea Type.
Sample No. 69－4 0.30 mm×0.08 mm

Figs. 9,10 Zoisite in the sediments of East China Sea Type.
Sample No. 70－115 0.21 mm×0.16 mm
Fig. 9 Parallel nicols
Fig. 10 Crossed nicols

Fig. 11 Anatase in the sediments of East China Sea Type.
Sample No. 70－106 0.18 mm×0.12 mm

Fig. 12 Glaucophane in the sediments of East China Sea Type.
Sample No. 70－124 0.08 mm×0.05 mm

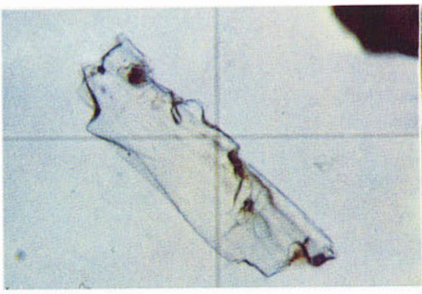

Fig. 13

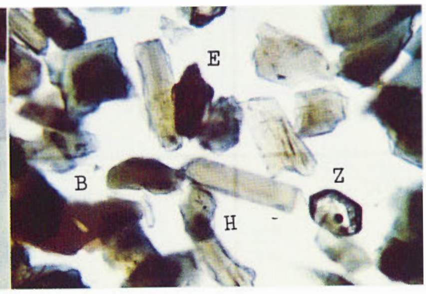

Fig. 14

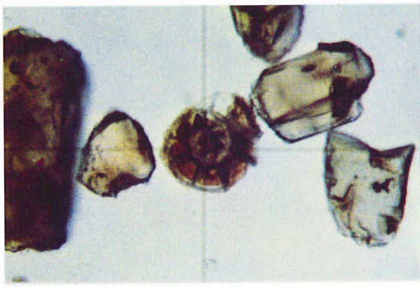

Fig. 15

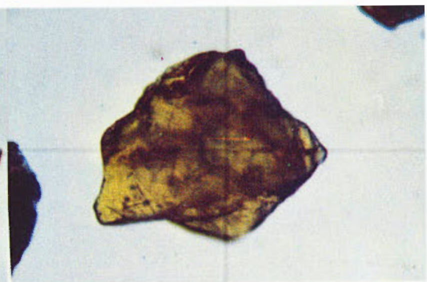

Fig. 16

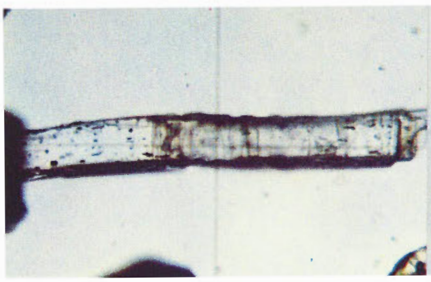

Fig. 17

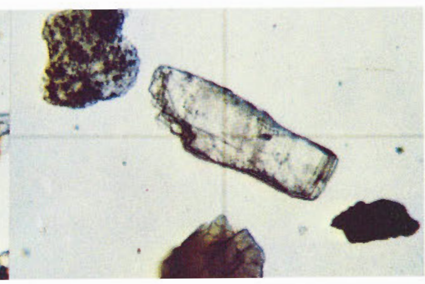

Fig. 18

Fig. 13 Sillimanite in the sediments of East China Sea Type.
Sample No. 69−69 0.13 mm×0.45 mm

Fig. 14 Biotite, epidote, hornblende and zircon in the granodiorite, at the south of Shimo-koshiki Island, Kagoshima Pref.
B : Biotite 0.21 mm×0.10 mm
E : Epidote 0.11 mm×0.06 mm
Z : Zircon 0.05 mm×0.08 mm
Others : Hornblende

Fig. 15 A fossil of mineralized foraminifera in the sediments of Yatsushiro Bay Type.
Sample No. 69−88 0.14 mm×0.13 mm

Fig. 16 Epidote in the sediments of East China Sea Type.
Sample No. 69−17 0.32 mm×0.24 mm

Fig. 17 Kyanite in the sediments of East China Sea Type.
Sample No. 69−74 0.60 mm×0.08 mm

Fig. 18 Kyanite in the sediments of East China Sea Type.
Sample No. 69−71 0.28 mm×0.09 mm

Part II Heavy Mineral Composition of Some Deep Sea Sediments near the Mariana Islands, Northwest Pacific Ocean

Taisuke SUZUKI*

Abstract

The writer joined a marine research survey for exploration of deep-sea mineral resources in the sea areas of Bonin, Mariana, and Caroline Islands, northwest Pacific Ocean, in 1972 and had a chance to study heavy mineral assemblage of ocean bottom sediments.

Fifteen samples, of which twelve were collected from the ocean bottom and three from the shore, have been analysed.

The result of the analyses shows that pyroxenes are the most abundant heavy minerals attaining about 80 to 90 per cent in quantity, then followed by several per cent of amphiboles. Both minerals can be seen in almost every sample. Olivine is present in 9 samples. Epidote and rutile are only found in the southern part of the surveyed area.

Judging from the heavy mineral composition, it is inferred that the source of the sediments in this area is mainly intermediate to basic volcanic rocks, in general, but in the southern are a small part of the sediments may have derived from metamorphosed rocks.

I. Introduction

The Geological Survey of Japan and the National Research Institute for Pollution and Resources carried out a joint research for bottom topography and submarine geology in the sea areas of the Bonin, Maliana and Caroline Islands, northwest Pacific Ocean during November and December, 1972.

The purpose of this survey is to make the basic research for the exploration of the mineral resources that are considered to exist in the deep-sea bottom of this area.

The writer went aboard the vessel and was allotted the sedimentary petrographic study of bottom sediments as a member of the research group.

This is a report of the heavy mineral analysis of bottom sediments and rock fragment samples taken by dredgers.

Period of cruise	From November 9, 1972
	To December 11, 1972
Surveyed area	From 8° 46′ N. to 28° 01′ N.
	From 141° 14′ E. to 158° 41′ E.
Research vessel	Bosei-maru, 1,100 tons, of Tokai University

II. Samples and Study Method

Samples studied are mainly dredged from the sea bottom, but three are taken from islands.

Bottom samples which are collected from the area between latitudes 8°46.5′N and 28°

* Fuel Department

01. 7′ N, and between longitudes 141° 14.2′ E and 158° 41.9′ E are brown clay, foraminiferal ooze, radiolarian ooze, sandy silt and rock fragments.

Each dredged point has a range, because the vessel stops the engine and drifts for hours of the dredging operation. So it is common that there exists a location difference between the beginning and the end of operation. Therefore, the writer puts the locations of samples in this report as two ways, that is, the ship position when the dredger hits the bottom and the position when the winch starts to rewind the cable (Table 1).

Three samples from the shore are basalt and beach sands of Guam, Mariana Islands, and of Ponape, Caroline Islands (Fig. 1).

To get sand fraction for heavy mineral analysis, mud in clay or ooze samples have been removed by elutriation. Rock samples have been crushed under 60 mesh by a stamp-

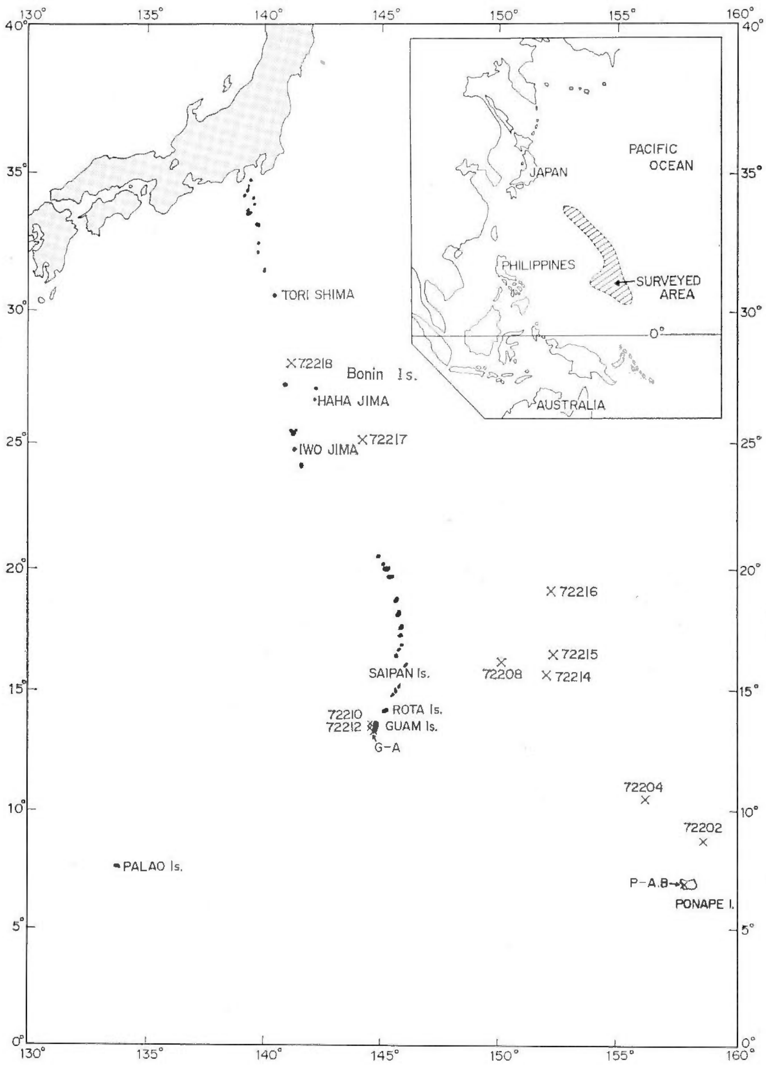

Fig. 1 Map showing sample localities and surveyed area

Table 1 Heavy mineral composition of Some Ocean Sediments near the Mariana Islands, Northwest Pacific Ocean

Location No. (Sample Number)	Location N. Lat.	Location E. Long.	Depth (m)	General Description of Samples	Olivine	Hornblende	Oxyhornblende	Hypersthene	Augite	Epidote	Zoisite	Rutile	Titanite	Grain Size (mm) 0.5 ~1.0	0.25~0.5	0.12~0.25	0.06~0.12
72202	8°48.9′~ 8°46.5′	158°41.9′~ 158°39.1′	5,160	red clay		7		19	74	+					c	a	
〃	〃 〃	〃 〃	〃	rock fragment		3		69	24				4		r	a	
72208	16°05.0′~ 16°08.0′	150°06.5′~ 150°04.0′	5,710	red clay		2	+	52	42	3		1			r	r	a
〃	〃 〃	〃 〃	〃	rock fragment		3		72	25					c	a	c	
72210	13°37.7′	144°37.4′	1,770	red clay	5	2	1	8	83			1				r	a
72212	13°36.1′~ 13°36.6′	144°35.9′~ 144°35.5′	2,040	foraminiferal ooze	2	5	4	26	63	+		+			r	r	a
72214	15°41.0′~ 15°40.0′	152°06.0′~ 152°05.0′	1,470	〃		4	2	17	77			+			r	r	a
72215	16°23.8′~ 16°29.8′	152°18.0′~ 152°16.2′	5,820	red clay	2	3		65	27	3	+	+			r	r	a
72216	19°02.0′~ 19°05.0′	152°19.2′~ 152°15.1′	5,520	〃		4	+	29	63	4						r	a
72217	25°07.5′	144°19.3′~ 144°18.3′	3,810	radiolarian ooze	20	1	+	9	70						r	a	
〃	〃	〃 〃	〃	rock fragment	1	1		6	92						c	a	
72218	28°01.7′~ 28°02.5′	141°14.2′~ 141°12.6′	4,145	sandy silt	17	3		10	70						r	c	a
P - A	Nan Madol, Ponape Islands		—	beach sand	64	4		3	28	1					c	a	
P - B	〃		—	basalat	54			25	21						c	a	
G - A	Umatac, Guam Islands		—	beach sand	1	5	2	3	82	6		1			r	a	

+: 0.5 per cent under, r: rare, c: common, a: abundant

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mill and mud fraction has been removed. The following steps are usual way, as described in Part I.

The writer treated 15 bottom sediment samples but omitted a description of 3 samples because of their very small quantity of heavy minerals or their very small size (less than 0.06mm).

III. Heavy Minerals

III. 1 Description

The non-opaque heavy minerals in the surveyed area are olivine, amphiboles, pyroxenes, epidote, zoisite, rutile and titanite (Table 1).

Among those minerals, pyroxenes are the most abundant, occupying 80 per cent to more than 90 per cent in quantity, then followed by several per cent of amphiboles. Olivine content varies from place to place such as zero to 20 per cent. Small amounts of epidote (less than 6 per cent) and rutile (less than one per cent) are observed in some locations. Titanite is only found in rock fragments.

Heavy mineral assemblage in the beach sand samples is the same as that of the bottom sediment samples.

Olivine: Almost colorless. Most are in irregular shape and ellipsoidal grains (*Plate 1*, Fig.1).

Pyroxenes: Consist of augite and hypersthene. Augite is abundant and ubiquitous. Grains are mostly in irregular shape and seldom in prismatic shape. The latter is seen in some cases in the volcanic glass (*Plate 1*, Fig.2). In general, augite from the southern area is rounded and small in size, whereas one from the northern area is larger and has angular shape. Hypersthene is angular and prismatic grain. Irregular, fragmentary one is generally small.

Amphiboles: Composed of hornblende and oxyhornblende. Hornblende is brown ~greenish brown (*Plate 1*, Fig.3). Smaller grains are common except grains in the rock fragment samples.

Epidote: Ordinally, grains are smaller in size than other minerals (*Plate 1*, Fig.4).

Zoisite: Only found in one location, and less than one per cent in quantity (*Plate 1*, Fig.5).

Rutile: Found in red clay and ooze in a small quantity. Grains are small (*Plate1*, Fig.6).

Titanite: Occurred in the rock fragment of bottom sediment samples. Light yellow. Dispersion phenomenon is seen in some samples.

III. 2 Composition and origin

The heavy mineral composition in red clay, foraminiferal ooze, radiolarian ooze and sandy silt in this region is, on the whole, characterized by abundant augite, then followed by hypersthene, olivine, hornblende.

Oxyhornblende, epidote, rutile and zoisite are present as a minor constituent (Fig.2).

Heavy mineral assemblage at two localities in the northern part (72217 and 72218), though the distance between them is about 250 km is much the same, showing 70 per cent of augite, about 20 per cent of olivine, 10 per cent or so of hypersthene. It is considered that these minerals are derived from basic volcanic rocks such as augite-olivine trachy-andesite, or olivine-bearing two pyroxenes andesite in the Bonin Islands and Iwo Island which lie along the west side of the Bonin Trench in the north-south direction.

Heavy mineral association of each point in the southern area contains a large amount of augite, hypersthene, and a few per cent of hornblende, olivine and oxyhornblende. The

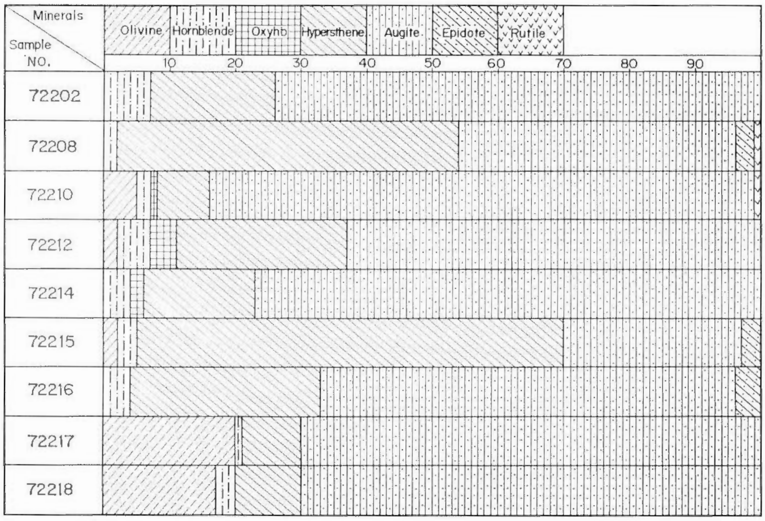

Fig. 2 Figure showing composition of heavy minerals

sediments in this area are also derived from the same kind of volcanic rocks as above, because they are also predominantly distributed in this region. Moreover, those samples include epidote, zoisite and rutile as a minor constituent, which indicate that a part of the sediments might come from metamorphosed rocks.

Among samples in the southern area, hypersthene content is somewhat rich at two localities, 72208 and 72215. Topographically, these points lie in the trough of the Magellan Sea Mounts.

It is interesting that the heavy mineral composition of the sample 72214 collected from the top of a sea mount in the Magellan Sea Mounts does not show much difference from another samples in this region. This may suggest that the area has supplied materials uniformly after the formation of sea mounts and their subsidence (Fig.3).

Both the shore samples from Ponape and Guam islands show considerable difference in heavy mineral composition. The beach sand sample from Ponape has abundant, more than 60 per cent, olivine, about 30 per cent of pyroxenes, several per cent of amphiboles, which is quite similar to the mineral composition of basalt that crops out in the Ponape island. While the beach sand sample from Guam has rather similar heavy mineral composition to that of the bottom sediment samples. The shore samples for analysis in this case are one each from both islands, so it is necessary to gather more samples and informations to discuss further.

IV. Summary

Heavy mineral assemblage of the deep sea sediments near the Bonin, Mariana, and Caroline Islands, northwest Pacific Ocean, has been studied.

Though sample locations are quite limited as compared with a vast surveyed area, heavy mineral composition is rather uniform. We may safely say for general discussion that those samples are representative of ocean bottom sediments in this area.

From the point of heavy mineral assemblage, it is assumed that intermediate to basic volcanic rocks are the main source of the bottom sediments in the whole surveyed area and metamorphosed rocks play a little role as a source material in the southern area.

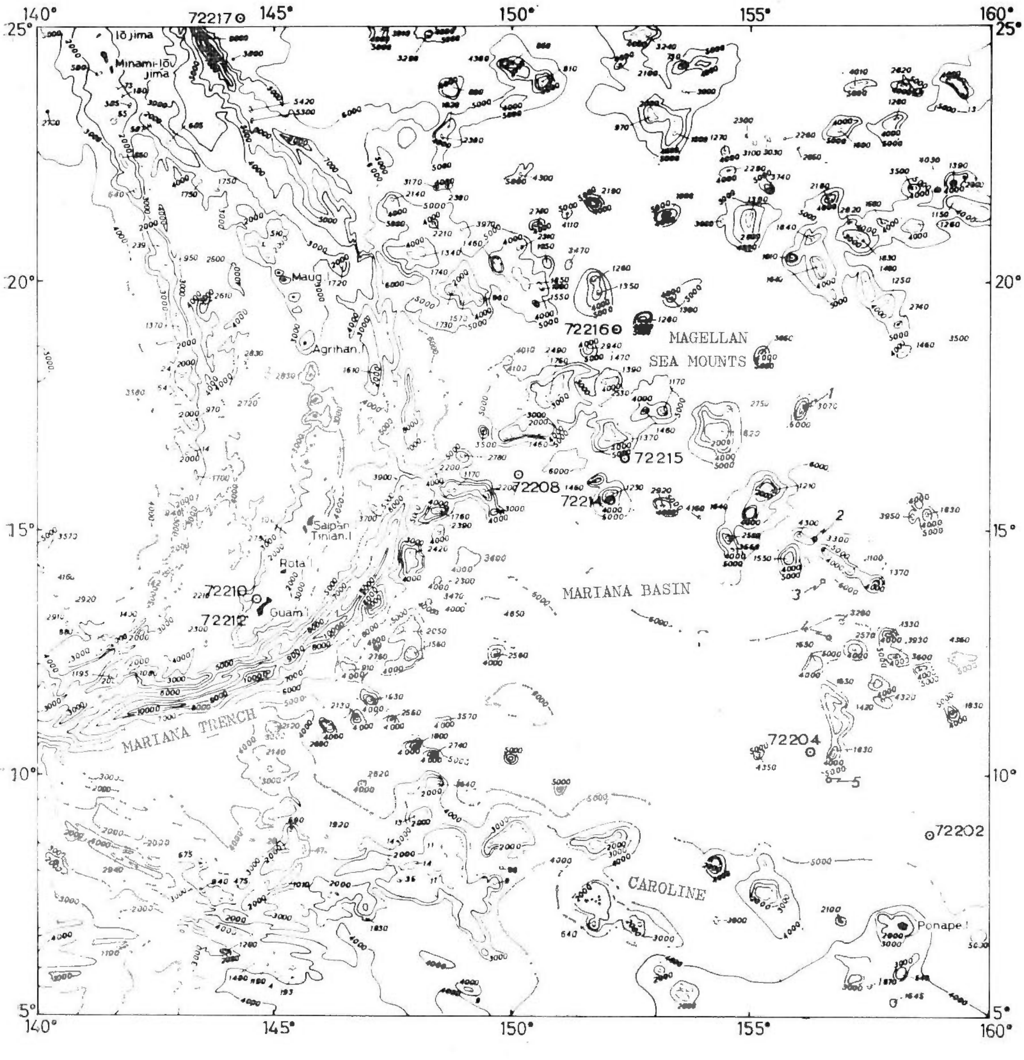

Fig. 3 Map showing bathymetric chart on region
72201……Sample locality

II. 北西太平洋マリアナ諸島付近の若干の堆積物中の重鉱物組成

鈴 木 泰 輔

要　旨

1972年に北西太平洋地域で実施した海洋調査に参加し，海底堆積物中の重鉱物分析を行なった。試料は海域のもの12個，陸域のもの3個である。

分析の結果，次のことが判明した。輝石類が量的にもっとも多く80%から90%に達する。次いで数%の角閃石類が普遍的に分布する。かんらん石は場所によっては産出せず，緑れん石および金紅

石が調査海域の南部にわずかに散見される。

重鉱物分析の結果から本海域の堆積物の供給源岩を推定すると，全般を通じて中性ないし塩基性の火山岩からもたらされたものを主体とすることが考えられるほか，調査海域の南部では変成岩から由来した鉱物が少量含まれることが想定される。

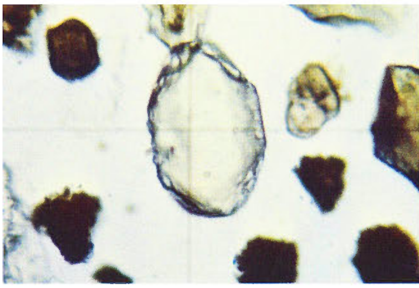

Fig. 1

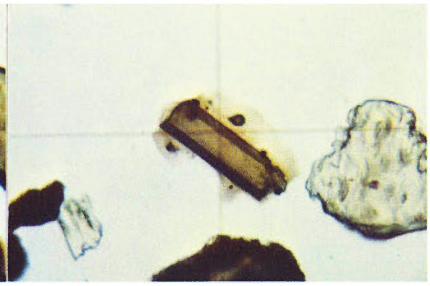

Fig. 2

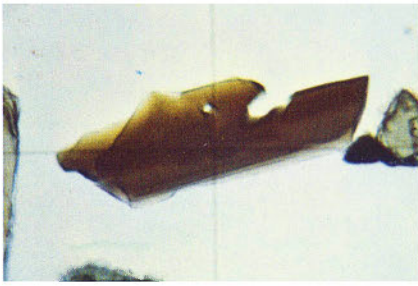

Fig. 3

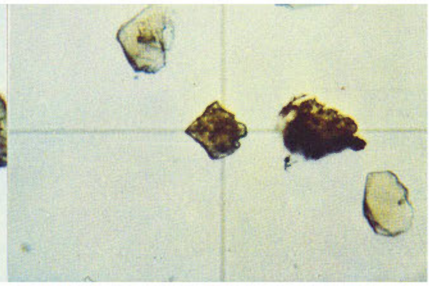

Fig. 4

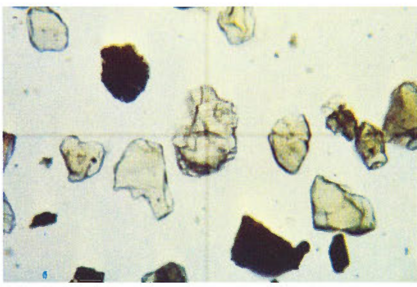

Fig. 5

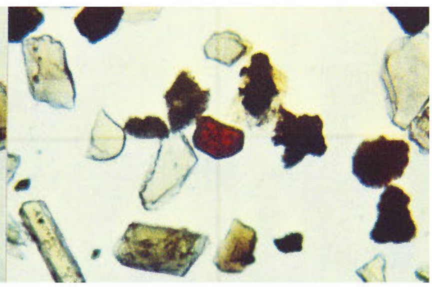

Fig. 6

Fig. 1	Olivine	Sample No. 72217 0.16 mm × 0.25 mm	Depth 3,810 m
Fig. 2	Augite	Sample No. 72217 0.21 mm × 0.05 mm	Depth 3,810 m
Fig. 3	Hornblende	Sample No. 72208 0.45 mm × 0.16 mm	Depth 5,710 m
Fig. 4	Epidote	Sample No. 72216 0.06 mm × 0.06 mm	Depth 5,520 m
Fig. 5	Zoisite	Sample No. 72215 0.13 mm × 0.10 mm	Depth 5,820 m
Fig. 6	Rutile	Sample No. 72208 0.06 mm × 0.05 mm	Depth 5,710 m

Part III Heavy Mineral Composition of Marine Sediments in Beppu Bay, Kyushu, Japan

Taisuke SUZUKI*

Abstract

I pursued my studies of the heavy mineral assemblage of marine sediments in Beppu Bay, northeastern part of middle Kyushu.

The results of the heavy mineral analysis show that amphiboles and pyroxenes are the most abundant, then followed by epidote. Olivine, zircon, tourmaline, garnet, zoisite, clinozoisite, monazite, titanite, rutile, anatase and micas are present as a minor element.

Frequency distribution of each heavy mineral does not show a uniform trend. This is due to the difference of the geological and geographical features of the hinterland and that of the condition of the tidal currents in the surveyed area. Greenish brown hornblende, oxyhornblende and tourmaline are accumulated around the mouth of small rivers. Hypersthene and augite are found both in the mouth of rivers and offshore areas where the minerals were shifted from other marine areas by the tidal currents. Epidote, zoisite, glaucophane and bluish green hornblende, which originate from the older rocks in the south, are mostly transported to the present site of deposition by the tidal currents.

Source rocks and their exposed areas on land of nine species out of twenty are deduced in this study.

Behavior of heavy minerals in Recent sediments in this area is known in the same degree by this study.

I. Introduction

Geological Survey of Japan carried out the investigation on bottom sediments and

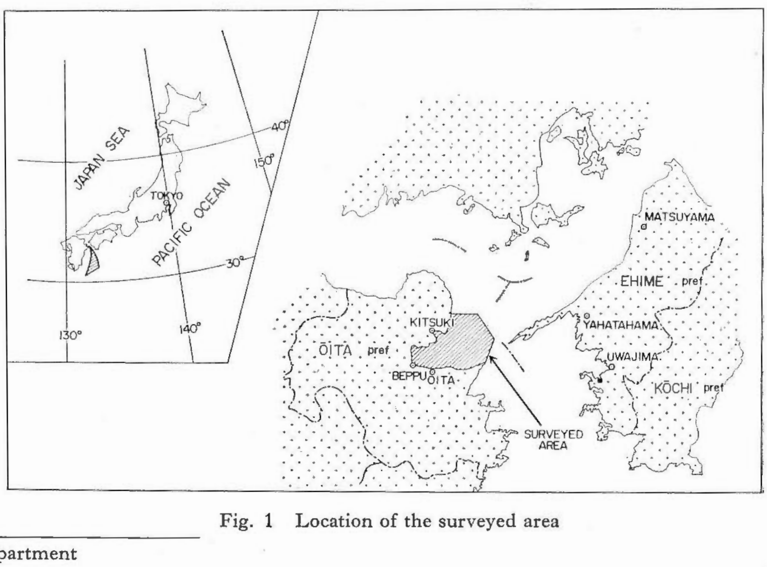

Fig. 1 Location of the surveyed area

* Fuel Department

Table 1 Heavy mineral composition of the marine sediments in Beppu Bay, Kyushu, Japan

Minerals % / Sample No.	Hornblende bluish green	Hornblende greenish brown	Oxyhornblende	Glaucophane	Olivine	Augite	Hypersthene	Diopside	Zircon	Tourmaline	Garnet	Epidote	Zoisite Clinozoisite	Monazite	Titanite	Rutile	Anatase	Biotite Muscovite	Weight % of heavy residue	Magnetite/Total H.M. (wt. %)
Beppu - 2		32	20			8	36		1	+		2			+				0.2	25.0
〃 3		30	40			10	17		1		+	+							1.2	25.0
〃 8		29	24			13	31		+		1	2							1.2	25.0
〃 9		20	13			20	47					+							4.0	50.0
〃 12		17	19			30	32		2										0.4	15.0
〃 14		45	19			4	31		+		+	+							0.1	90.0
〃 18		28	40			17	13					2							11.4	20.2
〃 19	+	18	9			15	54		2			2						+	9.5	21.0
〃 26	2	36	15			4	40	1	+		+			+					0.07	66.6
〃 28		16	4			30	50												14.8	20.2
〃 34	3	34	22			4	34		1		+	2							1.4	10.1
〃 35	2	34	22	+		3	32		1		+	6			+				0.4	15.8
〃 123	4	35	25			3	27		2	+	+	1			1				0.07	33.3
〃 124	3	27	3	1		18	44		1	1		2							0.05	50.0
〃 125	1	35	4	+		13	39		1	1	+	3			+			+	0.1	28.5
〃 126	4	44	25			1	21		1	+	+	2	1		+				11.8	6.7
〃 127	3	44	22			5	18		1		+	5	1						7.2	5.5
〃 128	2	39	20	1		3	24		2	+	1	7	+		1				1.8	9.3
〃 129	3	34	19			8	29		1	1	+	2	1		2				0.2	10.0
〃 50	2	38	18	1		3	27		2	1		5	1		+		+	+	0.5	13.6
〃 130	4	32	7			18	30		1	2	+	2	1		2			+	0.2	20.0
〃 131	1	17	3			14	56	+	1	2	2	3	+		1				2.2	20.5
〃 55	1	54	11			5	27		+		+	1			+				30.7	21.2
〃 57	4	47	19			4	20		1		1	3	1		+				12.6	6.9
〃 58		42	20	1		3	26		1		+	3	1		2			1	6.1	6.9
〃 59	1	46	18	1		5	22		1		+	4	1		1	+			5.7	12.6
〃 60	3	41	22	1		2	13		1	+	1	12	3					+	0.7	7.1
〃 61	1	37	8	+		10	31		1	1	1	9	1		+				0.4	11.1
〃 62	1	25	2	+		14	47		1	1	1	5	2		1		+		2.8	15.7
〃 63	2	23	1			13	43		1	1	1	11	3		1	+			3.1	12.9
〃 65	+	44	4			14	36		1			1							34.5	29.0
〃 66	1	52	10			5	31					1							38.8	22.1
〃 67	1	44	8			8	36		1		1	1							37.1	36.4
〃 68	2	50	9			6	30		1		+	1	+		+				17.6	14.3
〃 69	2	41	12			6	34		1		+	3			1				13.8	10.9
〃 70	2	42	14			4	25		1		+	8	3		1				10.5	8.3
〃 71	3	42	14	+		4	25		1		+	9	1		1			+	3.9	9.1
〃 73	3	38	12	1		5	13		1	1	1	22	3						1.7	9.3

Table 1-2

Sample No.	Hornblende bluish green	Hornblende greenish brown	Oxyhornblende	Glaucophane	Olivine	Augite	Hypersthene	Diopside	Zircon	Tourmaline	Garnet	Epidote	Zoisite	Clinozoisite	Monazite	Titanite	Rutile	Anatase	Biotite	Muscovite	Weight % of heavy residue	Magnetite/Total H.M. (wt. %)
Beppu 74	2	34	9	1		3	21		1	1	1	18	8			1				+	1.3	10.4
〃 75	2	29	6	1		4	31	+	1	1	1	21	2			1					0.4	13.6
〃 78	1	39	10			8	39		1		+	2	+								42.6	31.7
〃 79	1	38	9			12	37				1	2				+					53.0	41.2
〃 80		46	7		+	10	35			+	+	1				1					37.4	35.0
〃 81	1	37	12			9	30	1	2	+	1	5	1			1	+				21.0	18.1
〃 82	1	31	7	1		9	43		1		1	5	1			+					20.4	20.9
〃 83	1	34	6			8	42	1	1		1	4	1			1					10.0	13.3
〃 84	2	37	6	1		8	35		1		1	7	1			1			+		9.7	12.2
〃 85	2	28	6	1		3	39	+	1	+	1	15	2			+			+		7.9	11.2
〃 86	3	28	11	1		5	25		+		+	22	3			1	+		+		5.1	10.2
〃 87	4	31	7			5	23		2	+	+	21	5						+		5.7	11.8
〃 89	2	27	2			19	43	1			+	4	2								14.8	13.6
〃 92	1	34	2			12	48	+			+	2									30.2	41.9
〃 93	+	24	2		+	9	55		1		1	6	1			1					24.8	40.0
〃 95	1	28	3			13	42		1		1	8	2	1		+					56.1	3.8
〃 96	2	21	5	+	1	10	39	+	1		1	16	3			1			+		10.5	16.3
〃 97	1	24	2	+		12	42	+	2		1	14	1			1					12.8	13.6
〃 98	3	29	3	+	1	10	42	1	+		1	9	1			+			+		12.6	16.9
〃 99	1	28	3			19	40				1	7	1			+					10.6	10.3
〃 100	3	32	2			13	44				1	4	1			+					13.6	18.7
〃 101		45	+			16	35	1				2	1			+					20.0	19.8
〃 102	1	22	3	+	+	12	59	+	+		+	3									37.4	29.2
〃 103	1	19	3			20	55		1			1									39.0	29.6
〃 105	1	22	3			20	49		+			5	+								29.8	21.2
〃 109	1	29	4			14	50	+			+	2									44.5	49.4
〃 110	+	22	1		1	13	57		+		+	5									41.6	34.9
〃 111	+	15	1			13	69				1	1									47.2	27.7
〃 113	1	26	3		1	16	50				1	2	+								52.2	42.4
〃 114	+	21	2		1	23	51	+			+	1	1								59.1	44.8
〃 115	+	19	1			20	57					1	+								35.9	23.9

suspended materials in the sea water in and around Beppu Bay (Fig. 1).

This survey is a part of the program named "THE JOINT RESEARCH PROGRAM OF DETAILED OCEANOGRAPHICAL OBSERVATION IN THE BUNGO STRAIT AREA", and this is done and still going on by the AGENCY OF SCIENCE AND TECHNOLOGY. I took up a study of the heavy mineral analysis of bottom samples which were taken in the summer of 1972 by members of the Marine Geology Section of the Survey who participated in this survey.

II. Samples

Sixty-nine samples have been analyzed (Fig.2). The procedure of sample treatment and determination of heavy minerals were the same method as stated in the Part I and Part II of this report.

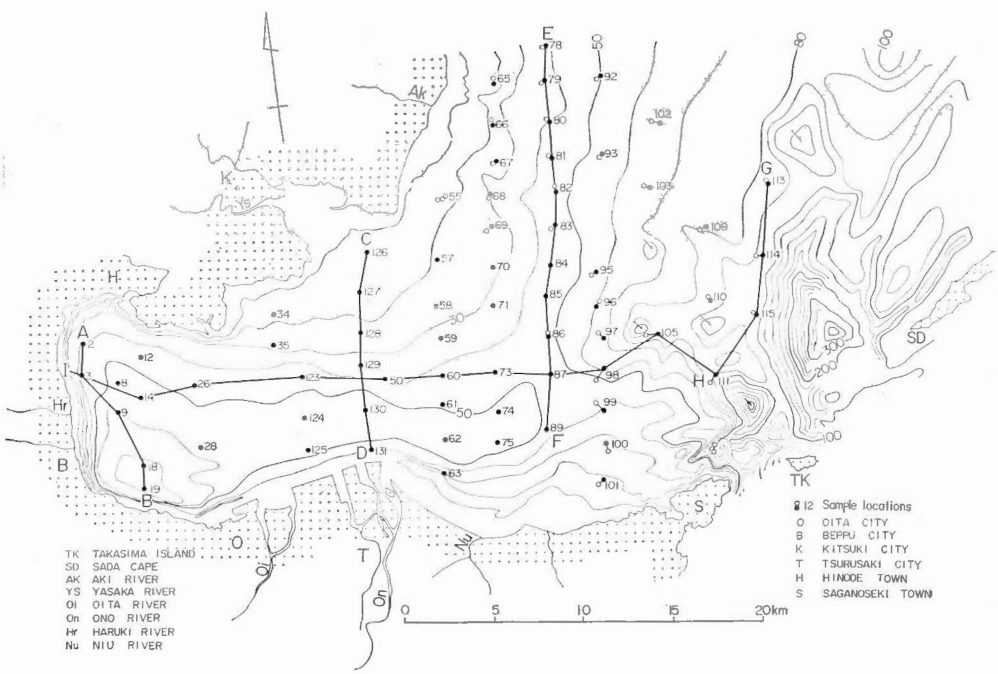

Fig. 2 Map showing sample localities and bathymetry of the area
Tracks A–B, C–D, E–F, G–H and I–H correspond to variation diagrams Fig. 3~6 respectively

III. Heavy Minerals

III. 1 Description

Heavy minerals found in the surveyed area are amphiboles, olivine, zoisite, clinozoisite, monazite, rutile, anatase and micas (Table 1).

Among these minerals, amphiboles and pyroxenes are the most abundant, occupying 70% to more than 90% altogether, and then followed by epidote with maximum amount of 22%. The other minerals are less than several percent.

Amphiboles: Hornblende, oxyhornblende and glaucophane are observed. Hornblende consists of greenish brown and bluish green ones. Greenish brown one is abundant, prismatic in shape, and larger than other heavy minerals in size, showing the dimension of, 1.16 ×0.2mm (sample No. 97), 0.98×0.24mm (sample No.111), and 0.08×0.2mm (sample No. 109).

Bluish green hornblende makes up a few percent of the total heavy mineral. Few yellow greenish ones, mostly fibrous, having pleochroism of light and shade are found. This mineral might be actinolite, but, in this report, it is treated as bluish green hornblende. Oxyhornblende is usually subangular, but sometimes it takes short or long prismatic shape. Glaucophane is also subangular, smaller than other minerals in size, and most of them show pleochroism from blue to clear purple (*Plate 1*, Fig.1).

Olivine: Colourless to slightly yellowish, ellipsoidal grains.

Pyroxenes: Augite, hypersthene and diopside are included. Augite is mostly subangular, prismatic, but some of them are rounded. Hypersthene is short or long prismatic in most cases. Abrased one is almost ellipsoidal. Diopside is white to slightly light green.

Zircon: Almost colourless, seldom pink or light brown. Short prismatic shape is common, but rarely occurs long prismatic one (0.67×0.08mm in sample No. 102, *Plate 1*, Figs.2,3,4).

Tourmaline: Small and subangular (*Plate 1*, Fig.4).

Garnet: Colourless and light brown ones are abundant. Brown and yellow ones are rare. Subangular.

Epidote: Consists of clear yellowish green grains and light yellow ones. The former is subangular and a single crystal, but the latter is mostly composed of aggregate of fine crystals.

Zoisite: Colourless or light yellow.

Clinozoisite: Light yellow, short prismatic.

Monazite: Light yellow, rounded (*Plate 1*, Fig.5).

Titanite: Colourless or light yellow, subangular.

Rutile: Red brown, brownish yellow, and brown in colour.

Anatase: Tip of crystals is broken off (*Plate 1*, Fig.6).

Micas: Biotite, reddish brown biotite and muscovite are present. But reddish brown biotite and muscovite are found only from one station each.

III. 2 Composition

The heavy mineral composition in this region is, on the whole, represented by abundant greenish brown hornblende and hypersthene, and common occurrence of oxyhornblende, augite, and epidote. The amount of each species is variable from place to place, though some areal uniformity is found (Figs. 2,3,4,5,6).

Greenish brown hornblende is rich (about 50%) at the stations near the mouth of the Aki river in the northwestern part of this area, and decreases its amount in the southeast direction (Fig. 7).

Twenty to forty per cent of oxyhornblende distribute both at the mouth of the Haruki and the Yasaka rivulets which pour into the bay at the west and northwest respectively, and the amount diminishes gradually toward the east (Fig.8).

Quantity of hypersthene shows almost reverse interrelation with that of greenish brown hornblende. Hypersthene distributes at the stations along the Bungo Strait in the eastern part of this area, and near the mouth of the Oita and the Ono rivers in the southern part, comprising 51 to 69%. Hypersthene distributing near the mouth of the above rivers diminishes its quantity in the northwest direction (Fig.12).

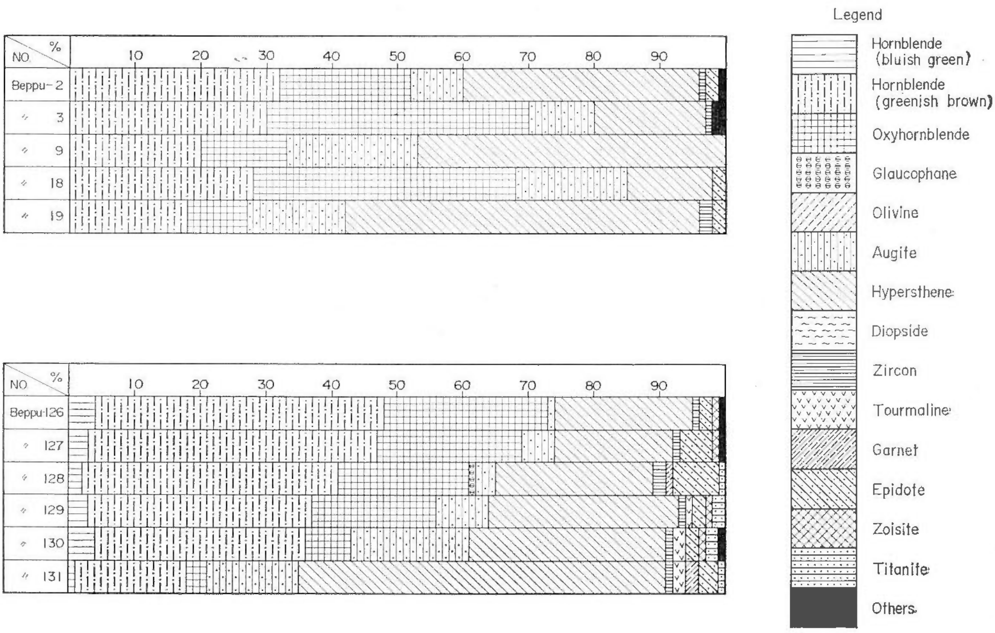

Fig. 3 Variation of heavy mineral composition along A–B and C–D lines

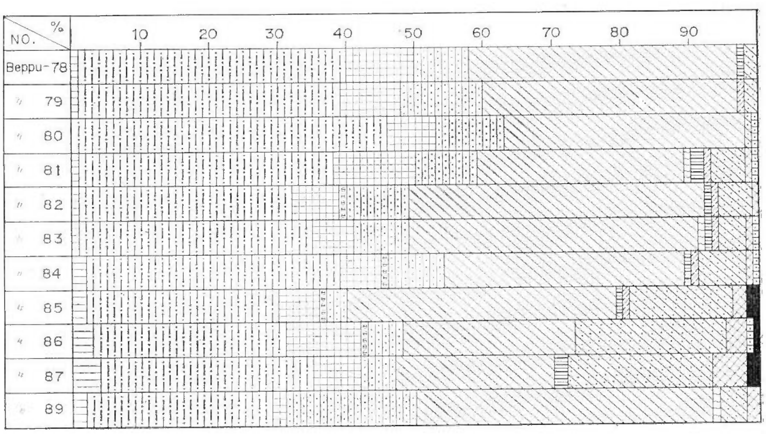

Fig. 4 Variation of heavy mineral composition along E–F line

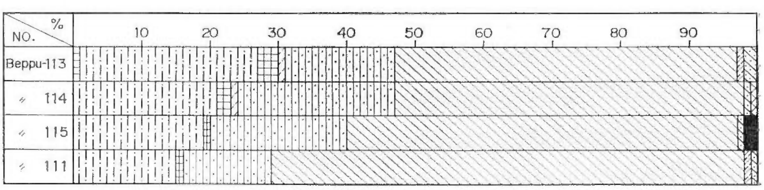

Fig. 5 Variation of heavy mineral composition along G–H line

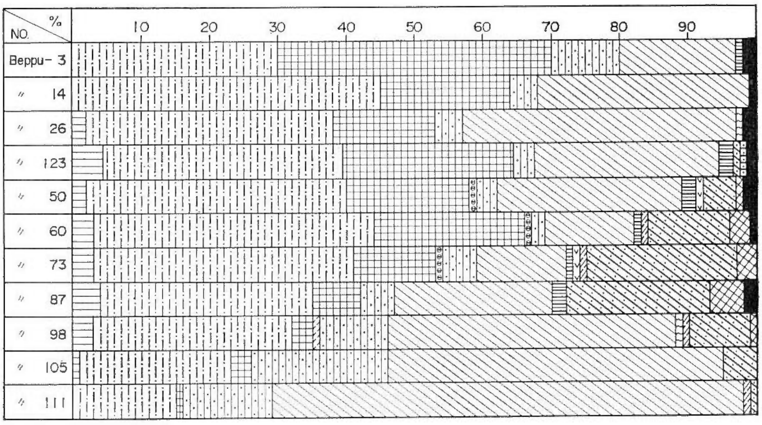

Fig. 6 Variation of heavy mineral composition along I-H line

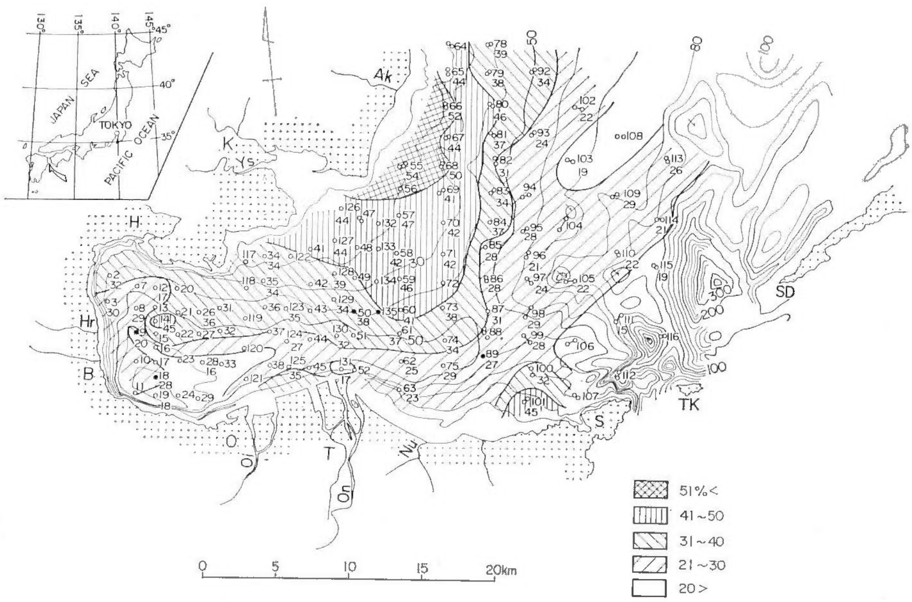

Fig. 7 Map showing distribution of greenish brown hornblende
For abbreviated river, city and town names, see Figure 2

Augite has almost plus correlation with hypersthene in its amount (Fig. 13).

Epidote is composed of about 20–22% and distributes in the small area a little southeast of the central part in the region and decreases gradually its percentage in every direction.

Zoisite and glaucophane, as minor minerals, have a similar distribution pattern to epidote. Bluish green hornblende has also about the same distribution pattern as above three minerals, but occupies a little wider area.

The maximum tourmaline content of 2.4% is found at the mouth of the Ono river in the southern part of this area. Its percentage decreases gradually to the north, west and east within 10 km from the mouth of the river. No other distribution is known in this bay, with the exception of sporadic existence of one or two grains.

IV. Origin of the Heavy Minerals

The following heads are pointed out from nine distribution maps of heavy minerals.

1) Geology of the hinterland is directly reflected in the primary deposits of kinds of heavy minerals. This case can be seen on the distribution of greenish brown hornblende,

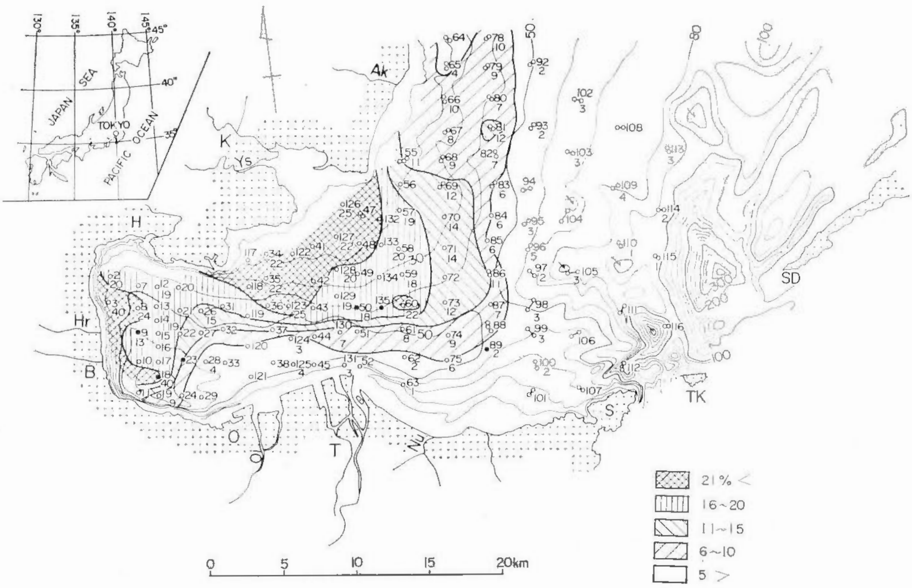

Fig. 9 Map showing distribution of oxyhornblende
For abbreviated river, city and town names, see Figure 2

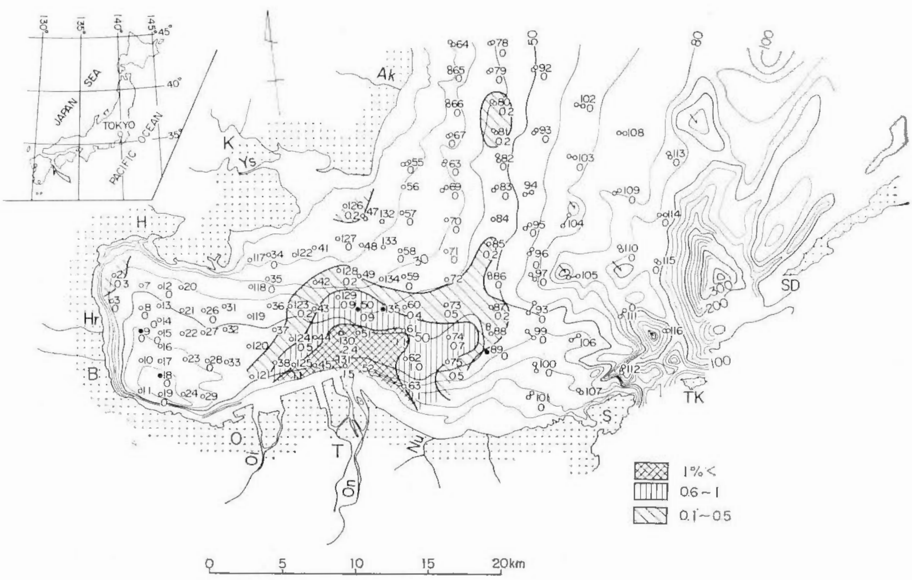

Fig. 10 Map showing distribution of tourmaline
For abbreviated river, city and town names, see Figure 2

oxyhornblende and tourmaline.

2) In addition to the above case, minerals are moved by the tidal currents from the other area to this area. This is the case of hypersthene and augite.

3) Minerals are deposited like snowdrift by the currents near the mouth of the bay. This is the case of epidote, zoisite, glaucophane and bluish green hornblende.

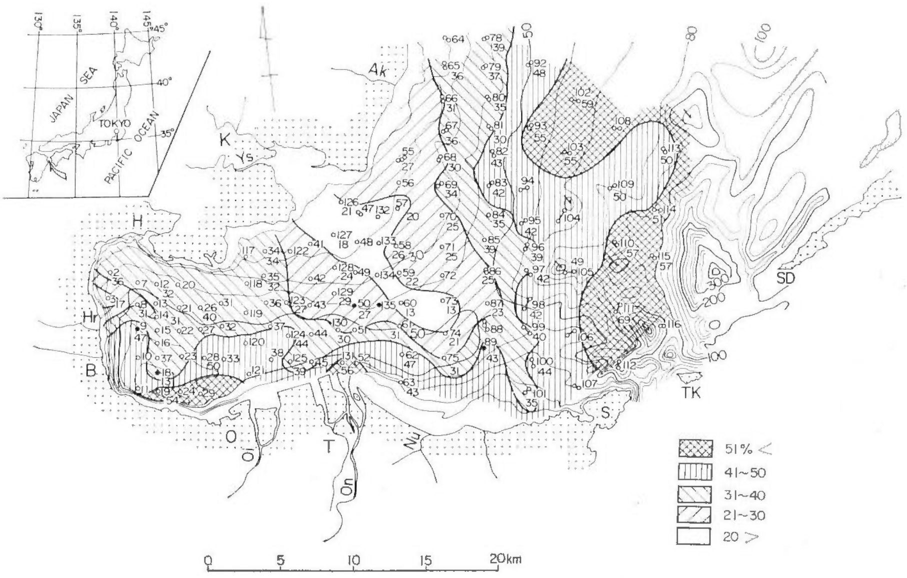

Fig. 12 Map showing distribution of hypersthene
For abbreviated river, city and town names, see Figure 2

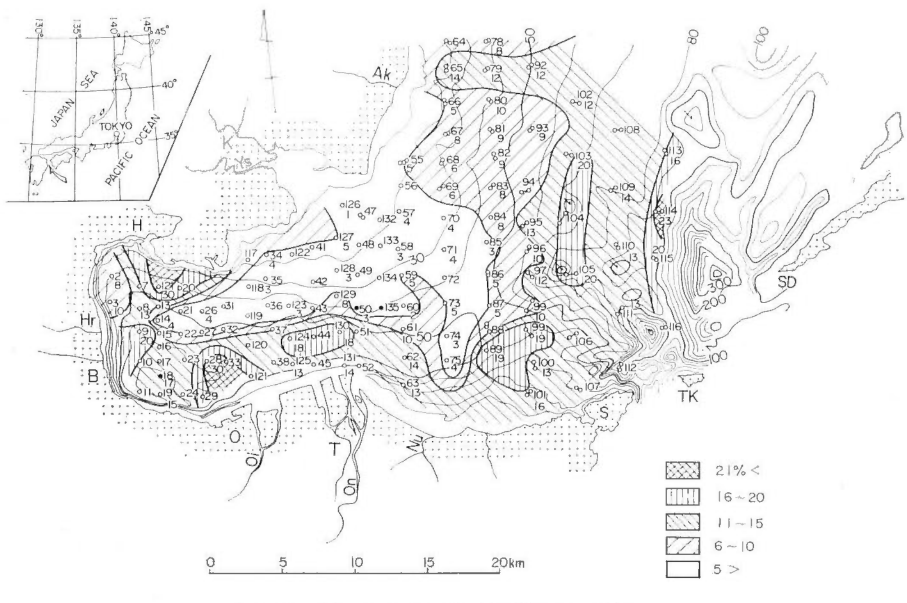

Fig. 13 Map showing distribution of augite
For abbreviated river, city and town names, see Figure 2

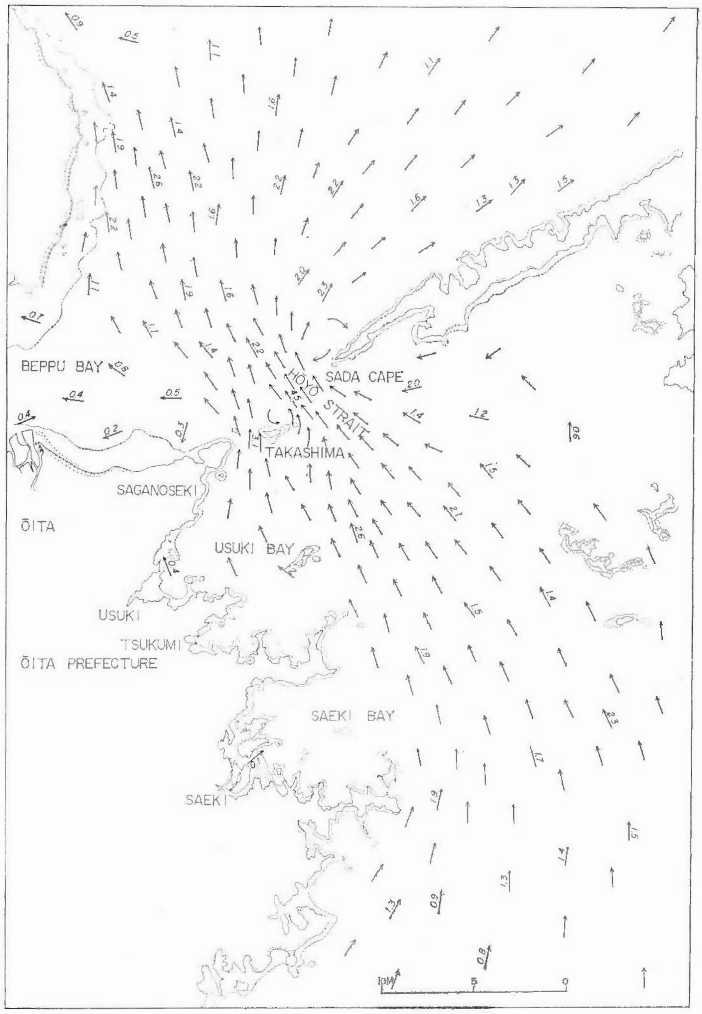

Fig. 14 Chart showing the maximum current speed flowing northward in Bungo Channel and Approaches (Maritime Safety Agency, Tokyo, Japan, 1967)

Now the writer discusses the origin of the heavy minerals in each case.

Greenish brown hornblende: High concentration of this mineral is observed in the area east of Kitsuki city (Fig. 7). The hinterland of this marine area, Kunisaki Peninsula, is composed mostly of the Yabakei formation which is stratified tuff-breccias of augite and hornblende andesite. It is obvious that the mineral are transported from Kunisaki Peninsula to the bay by the Aki river, and the Yasaka river.

Oxyhornblende: This mineral is highly concentrated in the area from the south of Kitsuki city to the northeast of Beppu city (Fig. 9). This mineral must be derived from the San-in volcanic rocks erupted during Quaternary age, and now distributes from the western part to the northern part of Beppu city.

Tourmaline: This mineral is concentrated in the northern part of Tsurusaki city (Fig.10) where is near the mouth of the Ono river. In the upstream region, about 60km from the mouth of the Ono river, there develops granite which is known for including a large

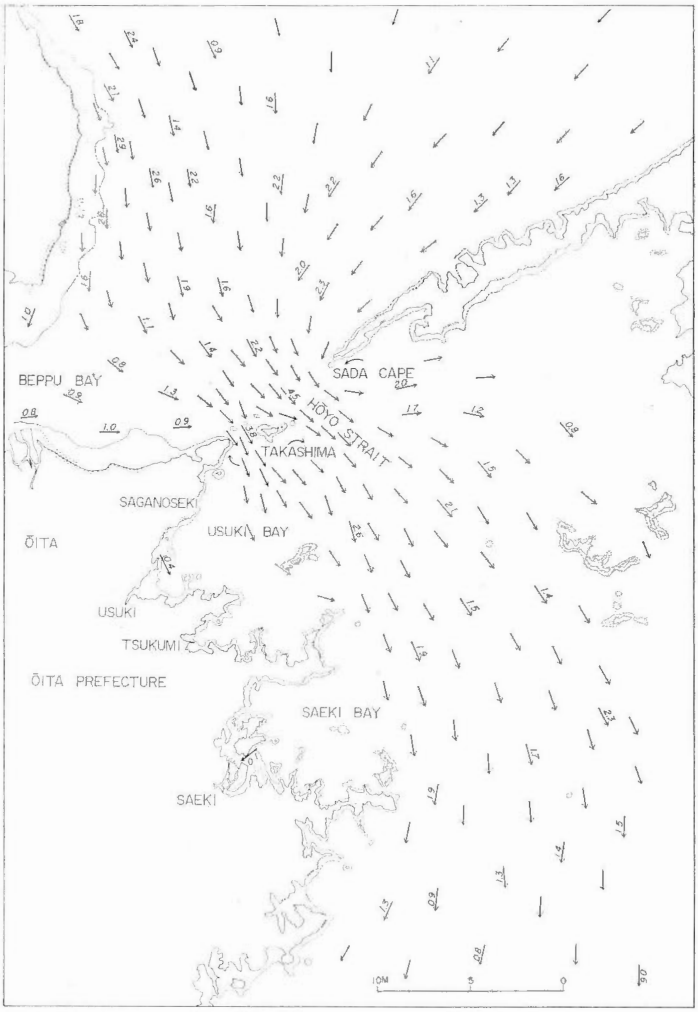

Fig. 15 Chart showing the maximum current speed flowing southward in Bungo Channel and Approaches (Maritime Safety Agency, Tokyo, Japan, 1967)

amount of tourmaline. This granite, intruded in Tertiary age, is called "Younger granitic rocks of Outer Zone of Southwest Japan." This suggests that tourmaline is transported by the river. Tourmaline in the surveyed area is crushed and small in size, telling being transported from a long distance (Fig. 11).

Hypersthene and augite: These minerals are highly concentrated in the surveyed area from east to south and are in direct proportion to each other. According to the charts of tidal currents in Bungo Strait and Approaches, the fastest tidal current is measured at the Hōyo Strait that lies between Cape Sada in Shikoku and Saganoseki Peninsula in Kyushu. The speed of northward flow at its maximum time is 3.1–4.5 knots, and its speed for south is 3.8–4.5 knots (Figs.14, 15). I don't think that there might be the Recent sediments on the bottom, because the currents sweep the exposed bottom-surfaces. The concentrated part of hypersthene and augite lies to the north of the above-stated strait and still rapid current flows with 2 knots at its utmost speed. The sizes of two minerals are generally large,

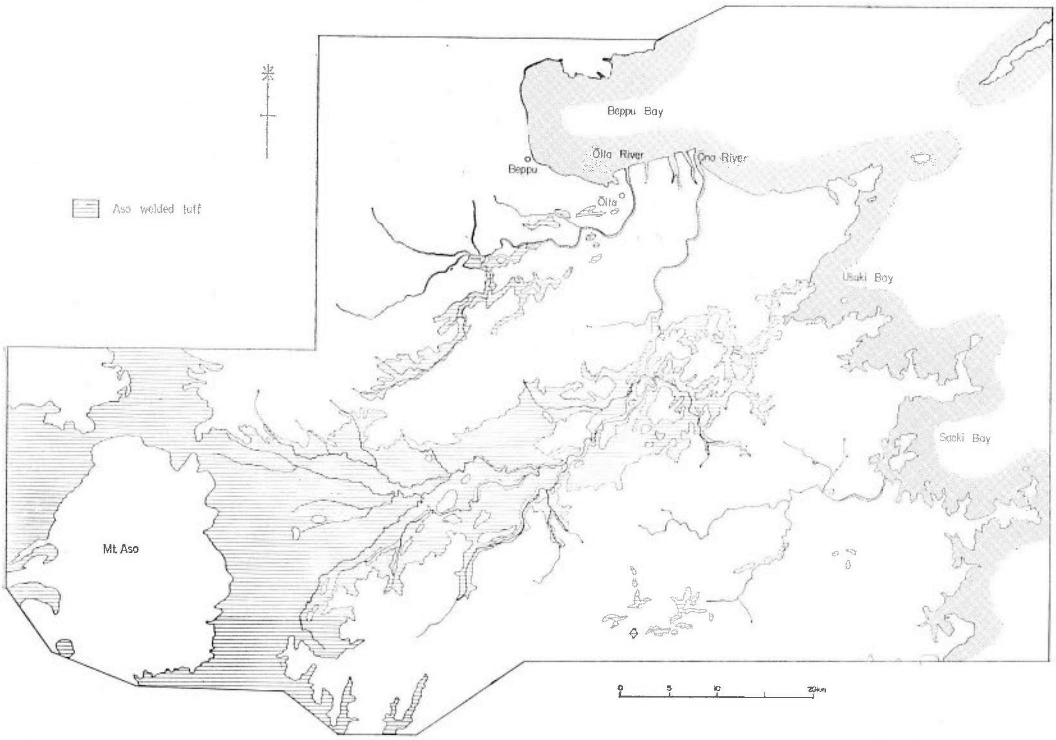

Fig. 16 Map showing distribution of Aso welded tuff

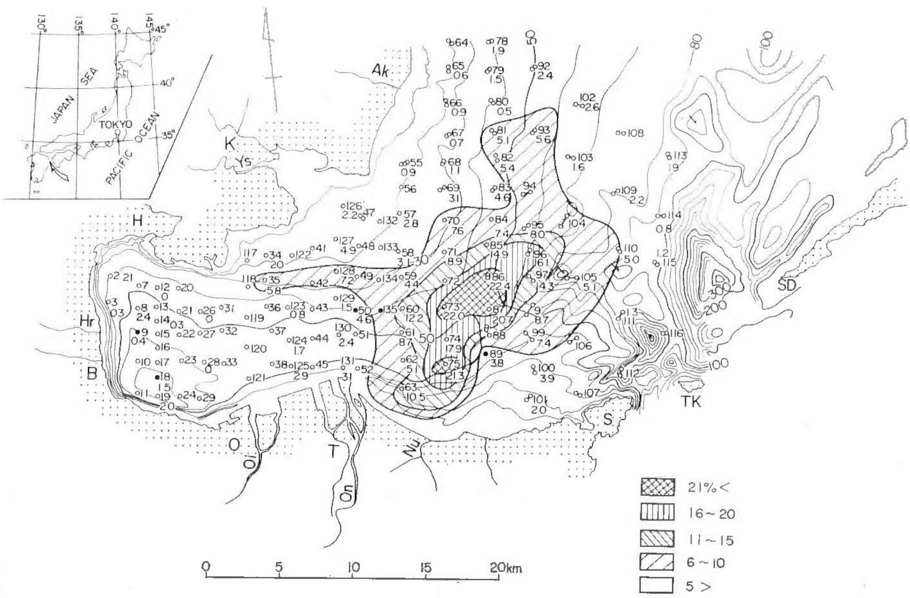

Fig. 17 Map showing distribution of epidote
For abbreviated river, city and town names, see Figure 2

mostly about 0.5mm and rarely 1mm in diameter. The volcanic rocks that contain abundant hypersthene and augite are considered to be the Aso augite andesitic welded tuff which widely distributes to the south of Oita city. The high-concentrated part of those two minerals in the bay must be transported by the Ono river and the Oita river from the Aso welded tuff area (Fig. 16). Aso welded tuff also exposes in the sea-bottom of Usuki Bay,

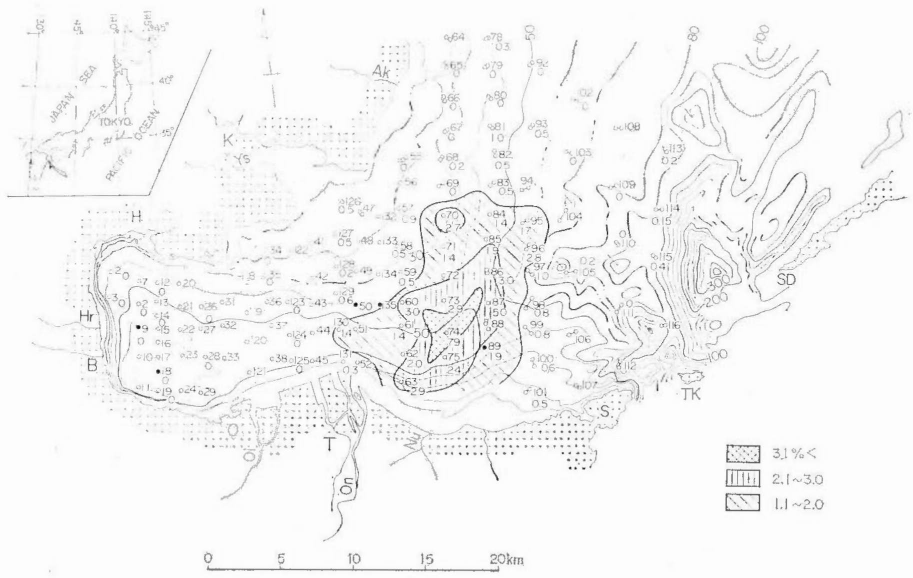

Fig. 18 Map showing distributions of zoisite
For abbreviated river, city and town names, see Figure 2

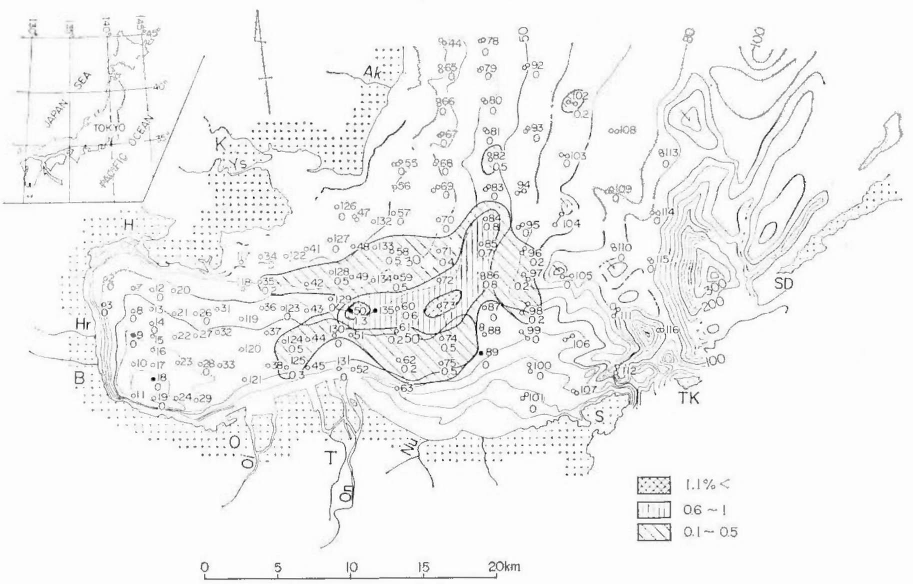

Fig. 19 Map showing distribution of glaucophane
For abbreviated river, city and town names, see Figure 2

south of Bungo Strait on the outside of the surveyed area. The volcanic materials, which are considered as Aso welded tuff, were dredged at some stations in Bungo Strait during the subsequent survey carried out in November to December, 1972. It is very reasonable that this tuff also crops out in Usuki Bay according to the distribution map of Aso welded tuff. The other high-concentrated part of hypersthene and augite, east of the surveyed area,

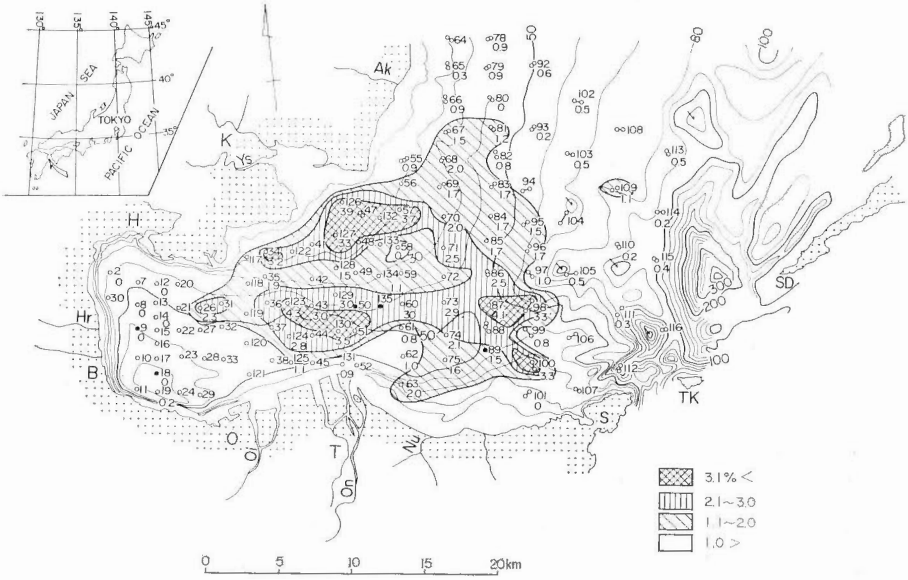

Fig. 20 Map showing distribution of bluish green hornblende
For abbreviated river, city and town names, see Figure 2

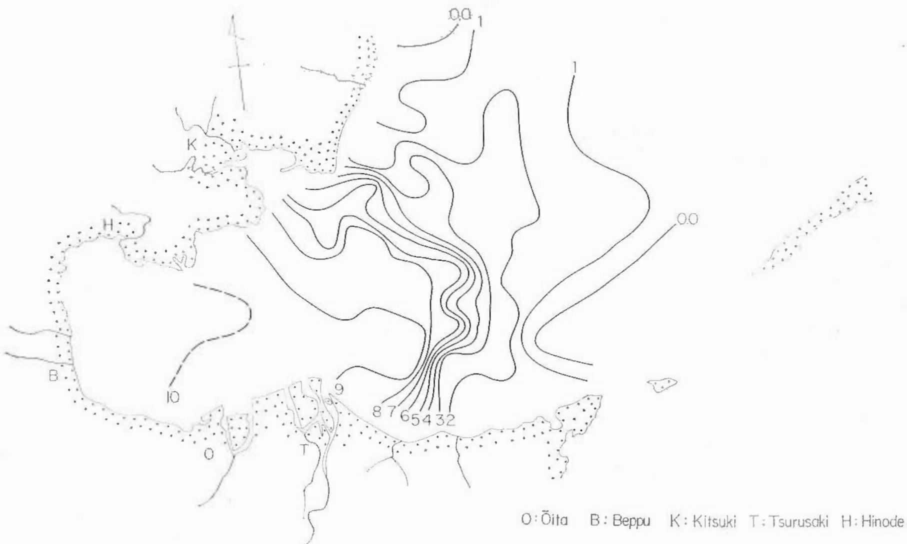

Fig. 21 Median diameter contour map of Beppu Bay (Marine Geology Section, Geological Survey of Japan, 1973).

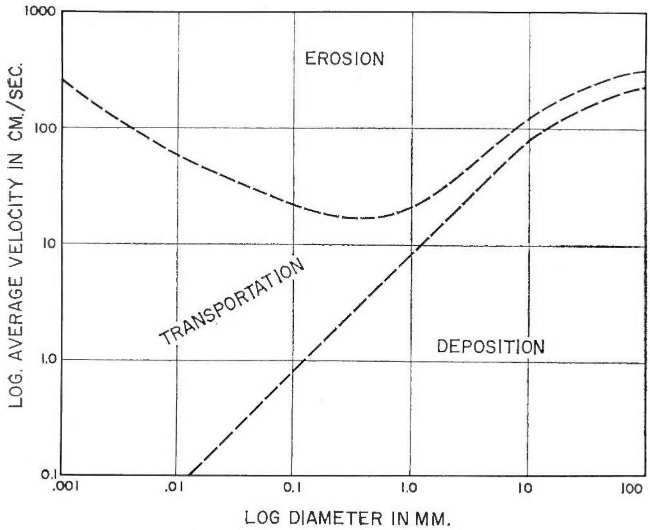

Fig. 22 Hjulstrom's Diagram

may be derived from the southern area by the rapid current flow.

Epidote, zoisite, glaucophane and bluish green hornblende: A high concentration of epidote, a few zoisite and glaucophane are found, in common, in a limited area, about the center or a little east of the surveyed area (Figs. 17, 18, 19). Bluish green hornblende has the same pattern but shows a wider distribution than the above three minerals(Fig. 20). On land, these minerals are contained mostly in Paleozoic to Mesozoic systems comprising metamorphic rocks and basic to ultrabasic volcanic rocks. These rocks are exposed to the east of Oita city and in Shikoku islands having a general trend of east-west. As shown in the map, distribution of these minerals on the sea bottom has a shape of snowdrift. After these four minerals reached to the sea, they might be transported by strong tidal currents to the mouth of Beppu Bay, where the current is not so strong enough to carry the material, then they deposit on the sea-bottom. As it is seen in the median diameter contour map (Fig. 21), the high-concentrated part of epidote, zoisite and glaucophane is almost in coincidence with the dense part of median diameter contour. The current speed at the mouth of Beppu Bay varies from 0.2 to 1 knot at places even in the utmost time. This place is situated just along the border area between the strong oceanic current and embaymental current of Beppu Bay. This is one of the data for supporting the above explanation.

According to the Hjulstrom's Diagram (Fig. 22), sand-sized grains of epidote, zoisite, glaucophane and bluish green hornblende are not removed by the current speed of 1 knot prevailing in the area, after deposition. On the other hand, hypersthene and augite grains are again shifted by the current speed of 2 knots which is common on the outside of the bay. However, the above-mentioned current speed is surface, so we should measure the bottom current speed for the better interpretation

V. Weight Percentage Distribution of Heavy Minerals

I discuss here on the weight percentage of heavy minerals to the total analysed sample excluding mud. A high value, more than 41%, of the weight percentage of heavy minerals is seen in the east to northeast area, decreasing its value toward the west. In Beppu Bay, it is less than 10% except in the west-southern part (Fig. 23).

The weight percentage of magnetite to the total analysed sample is more than 21% in the east to the northeast part, diminishing its value toward the west. In Beppu Bay, it is less than one percent except the southwest corner (Fig. 24). It is in direct proportion to the weight percentage of heavy minerals.

In short, the weight percentage of heavy minerals is large in the east where the velocity

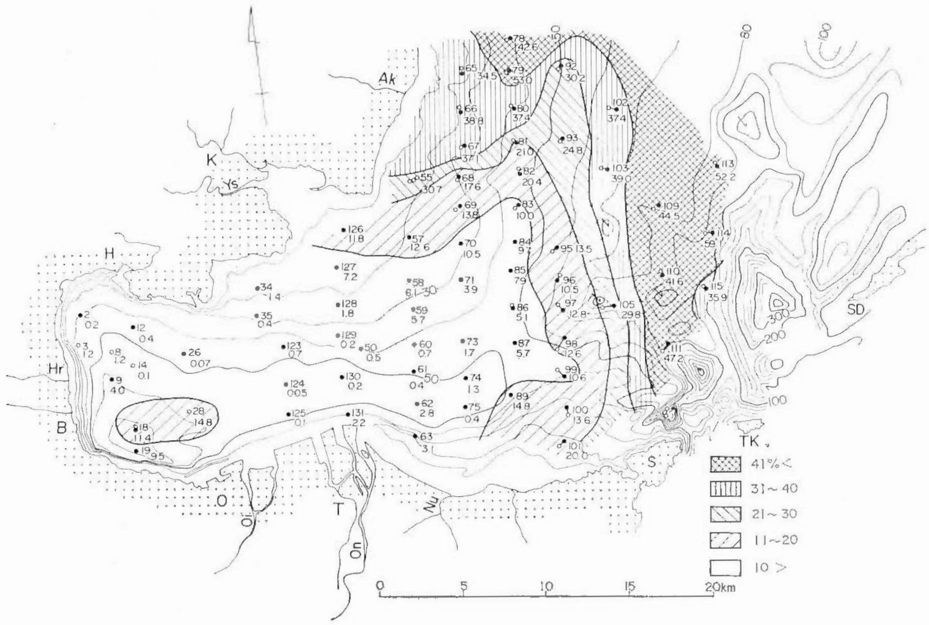

Fig. 23 Map showing distribution of weight percentage of heavy residue

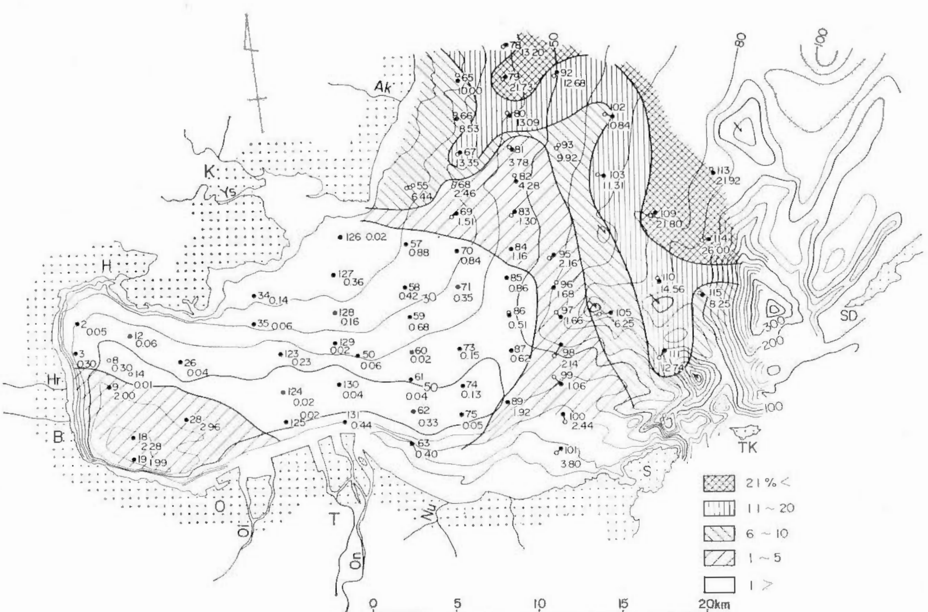

Fig. 24 Map showing distribution of weight percentage of magnetite in the total heavy minerals.

of current is very strong, and decreases its percentage toward the west as the current velocity becomes weak. It is due to the sorting effect of ocean currents that the weight percentage of heavy minerals shows such areal differences. Ocean current does not work so much in Beppu Bay and bottom sediments there consist of finer materials such as silt and clay. On the other hand, the size of heavy minerals becomes larger and they concentrate in the east to the northeast part of the surveyed area.

Highly concentrated magnetite is known along the eastern offshore part of Kunisaki Peninsula north of the surveyed area. The northeast part of the surveyed area lies in the southern chip of the above-mentioned area, so the magnetite is derived from the Yabakei formation and deposited by the effect of wind and wave actions.

VI. Summary

The writer referred to the depositional mechanism of Recent heavy minerals of Beppu Bay. Greenish brown hornblende, oxyhornblende and tourmaline are transported to the sea by the rivers and are deposited at the mouth of the rivers where only weak current prevails.

Hypersthene and augite are deposited in the bay both by the transportation of the rivers and by that of the strong ocean currents which bring these minerals from the southern offshore area.

Epidote, zoisite, glaucophane and bluish green hornblende are brought to the sea by the rivers or directly from the hinterland, and are removed by rapid tidal currents and are deposited like snowdrift at the mouth of the bay where the tidal currents become slow.

The writer also stated in this report heavy minerals in the marine sediments in connection with their source rocks in the hinterland.

It is needed to study in more detail, the heavy minerals in the rocks on land, and besides condition of weathering and erosion, process of transportation by rivers, and effects of waves and currents with velocity of bottom current.

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III. 九州・別府湾における底質中の重鉱物組成

鈴 木 泰 輔

要　旨

中部九州の北東方，別府湾における海底堆積物について重鉱物分析を行なった。重鉱物は角閃石類と輝石類が量的に多く，次いで緑れん石が普通にみられる。少数鉱物としてかんらん石，ジルコン，電気石，ざくろ石，ゆうれん石，斜ゆうれん石，モナズ石，チタナイト，金紅石，鋭錐石および雲母類などが認められる。

各鉱物の産出頻度は，かなり片寄った傾向を示す。この要因としては各重鉱物の原岩となっている後背地の地質，地理的条件および調査海域における海流状況などがあげられる。

緑褐色の角閃石，酸化角閃石および電気石は三角州のような堆積を示している。

紫蘇輝石と普通輝石は三角州のような堆積を示すものと潮流によって他海域から移動して堆積したと思われるものとがある。

緑れん石，ゆうれん石，らんせん石および青緑色角閃石は周辺の陸域から海域にもたらされ，潮流によって分布区域が選別されたものと推定される。

分析した重鉱物のうち，9種類について起源を推定した。

この研究によって，重鉱物の側からみた現世堆積物の初生的な堆積機構が若干判明した。

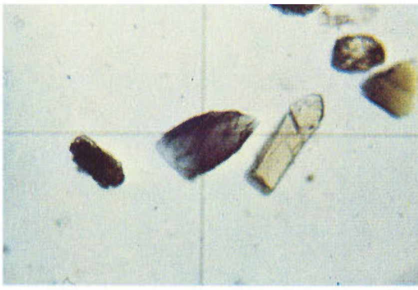

Fig. 1

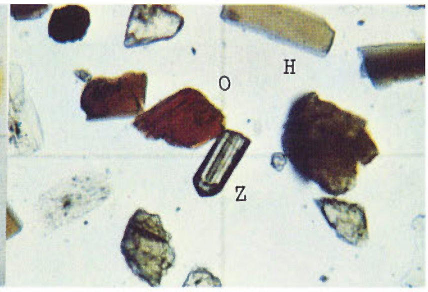

Fig. 2

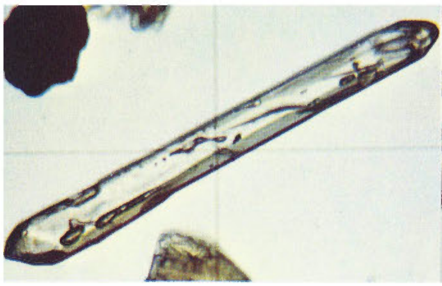

Fig. 3

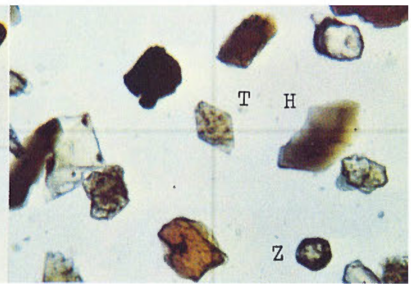

Fig. 4

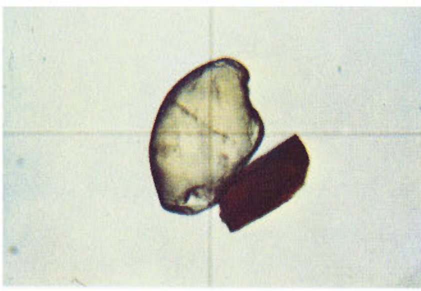

Fig. 5

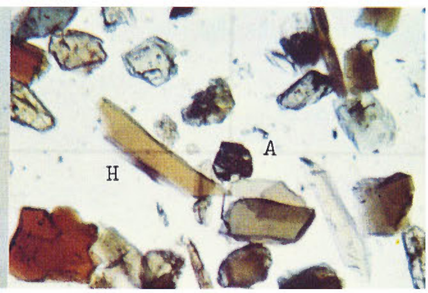

Fig. 6

Fig. 1 Glaucophane Sample No. 73 0.14 mm×0.08 mm

Fig. 2 H : Brown hornblende 0.05 mm×0.16 mm
O : Oxyhornblende 0.12 mm×0.08 mm
Z : Zircon 0.05 mm×0.11 mm
Sample No. 73

Fig. 3 Zircon (long prismatic shape) Sample No. 102 0.67 mm×0.06 mm

Fig. 4 T : Tourmaline 0.08 mm×0.05 mm
H : Brown hornblende 0.14 mm×0.08 mm
Z : Zircon (short prismatic shape) 0.05 mm×0.05 mm
Sample No. 60

Fig. 5 Monazite Sample No. 26 0.24 mm×0.14 mm

Fig. 6 A : Anatase 0.05 mm×0.05 mm
H : Brown hornblende
Sample No. 50

地質調査所報告は1報文について報告1冊を原則とし，その分類の便宜のために，次のようにアルファベットによる略号をつける。

A．地質およびその基礎科学に関するもの
- a．地　質
- b．岩石・鉱物
- c．古生物
- d．火山・温泉
- e．地球物理
- f．地球化学

B．応用地質に関するもの
- a．鉱　床
- b．石　炭
- c．石油・天然ガス
- d．地下水
- e．農林地質・土木地質
- f．物理探鉱・化学探鉱および試錐

C．そ の 他

D．事業報告

As a general rule, each issue of the Report, Geological Survey of Japan will have one number, and for convenience's sake, the following classification according to the field of interest will be indicated on each Report.

A. Geological & allied sciences
- a. Geology
- b. Petrology and Mineralogy
- c. Paleontology
- d. Volcanology and Hot spring
- e. Geophysics
- f. Geochemistry

B. Applied geology
- a. Ore deposits
- b. Coal
- c. Petroleum and Natural gas
- d. Underground water
- e. Agricultural geology and Engineering geology
- f. Physical prospecting, Chemical prospecting & Boring

C. Miscellaneous

D. Annual Report of Progress

地 質 調 査 所 報 告

第250号-1

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異なった三つの環境下における現世海底堆積物中の重鉱物組成

鈴 木 泰 輔

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異なった3環境下における海底堆積物，すなわち，1) 九州西方海域の大陸棚堆積物，2) マリアナ諸島周辺の深海底堆積物，3) 別府湾内海底堆積物などの重鉱物分析を行ない，初生的な堆積機構を研究した。各海域における重鉱物種，組成などを検討して，その分布と後背地との関連を記述した。

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